WBC2022 is made possible thanks to the support of our sponsors:

**Platinum Sponsor**

[Major Transport Infrastructure Authority](#)  
[Victoria's Big Build](#)

**Gold Sponsor**

[City of Melbourne](#)

**Silver Sponsors**

[L.U. Simon Builders](#)  
[Glodon](#)  
[VBA Victorian Building Authority](#)
<table>
<thead>
<tr>
<th>No.</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>103.</td>
<td>An investigation into the relationship between diversity, leadership and innovation in the South African Construction industry</td>
<td>3</td>
</tr>
<tr>
<td>110.</td>
<td>Technology implementation status and perceived benefits: A study of New Zealand construction organisations</td>
<td>4</td>
</tr>
<tr>
<td>111.</td>
<td>Combined effects of fibre geometry and aggregate size on the workability and mechanical properties of steel fibre reinforced concrete</td>
<td>5</td>
</tr>
<tr>
<td>158.</td>
<td>Alignment of construction procurement strategies for the effective implementation of BIM in the UAE</td>
<td>6</td>
</tr>
<tr>
<td>160.</td>
<td>The impact of changing the project organization structure on project performance</td>
<td>7</td>
</tr>
<tr>
<td>164.</td>
<td>Use of BIM and visual data collected by UAS and 360° camera for construction progress monitoring</td>
<td>8</td>
</tr>
<tr>
<td>172.</td>
<td>Automated 360° photographic data capture for building construction projects: analysis of a prototype</td>
<td>9</td>
</tr>
<tr>
<td>195.</td>
<td>Deep learning-based text detection on architectural floor plan images</td>
<td>10</td>
</tr>
<tr>
<td>226.</td>
<td>Blockchain-based framework for a smart supply chain management in construction</td>
<td>11</td>
</tr>
<tr>
<td>243.</td>
<td>Towards improved dissemination of results from strategic innovation programmes: the case of ‘smart built environment’</td>
<td>12</td>
</tr>
<tr>
<td>248.</td>
<td>Algorithmically generated construction 3d printing facades</td>
<td>13</td>
</tr>
<tr>
<td>260.</td>
<td>A servitization profile of the Construction 4.0</td>
<td>14</td>
</tr>
<tr>
<td>273.</td>
<td>A conceptual framework for including “safety in design” in engineering training and design practice</td>
<td>15</td>
</tr>
<tr>
<td>295.</td>
<td>The uptake of exoskeletons and how they will become stabilized: a social construction of technology approach</td>
<td>16</td>
</tr>
<tr>
<td>339.</td>
<td>Innovation profile of services offered by Brazilian construction startups</td>
<td>17</td>
</tr>
<tr>
<td>418.</td>
<td>Teaching of emerging technology in construction education</td>
<td>18</td>
</tr>
<tr>
<td>571.</td>
<td>An investigation into how BIM exploitation leads to BIM benefits in construction organisations</td>
<td>19</td>
</tr>
<tr>
<td>586.</td>
<td>Exploring the thermal conditions in construction sites through IoT based methodologies</td>
<td>20</td>
</tr>
<tr>
<td>654.</td>
<td>Influence of innovation on construction firms’ clients in northern Nigeria</td>
<td>21</td>
</tr>
<tr>
<td>684.</td>
<td>Regenerative-based green supply chain management model for the construction industry</td>
<td>22</td>
</tr>
<tr>
<td>691.</td>
<td>Case study: an Australian construction innovation incubator using the agile approach</td>
<td>23</td>
</tr>
<tr>
<td>732.</td>
<td>A construction hackathon: one answer to the industry's innovation malaise</td>
<td>24</td>
</tr>
<tr>
<td>743.</td>
<td>Roadmap to artificial intelligence usage in the construction industry of developing countries: systematic literature review</td>
<td>25</td>
</tr>
</tbody>
</table>
ADVANCEMENTS IN UTILIZING EXPERTISE AND AUTOMATION TO INCREASE PROJECT PERFORMANCE

126. Automated regulatory compliance towards quality assurance in healthcare building projects ........................................................................................................27

174. Utilisation of technology in construction material logistics processes for efficiency .........................................................................................................28

233. Impact of construction coating products and warranty services on customer satisfaction .................................................................29

237. Workforce demographics in the southeast United States: general contractors vs. specialty contractors/trade partners ..................................................................................30

242. Profit factors in real estate projects: a comparison of academic studies and expert opinions ...............................................................................31

250. Implementing and sustaining the best value approach in an organization ................................................................................................................32

269. Data augmentation for deep learning-based detection of pump anomalous conditions ........................................................................33

347. Utilisation of remote monitoring systems to improve management of multiple projects in construction ........................................................................34

497. The application of the best value approach in purchasing card services ................................................................................................................35

498. The application of the best value approach in janitorial services ..........................................................................................................................36

522. A data-driven approach for monitoring performance of equipment in construction earthwork using IoT and cloud computing ........................................................................37

574. Enhancing productivity in construction with co-existence of different definitions ................................................................................38

595. Digital lean management system in residential construction projects. Application in Santiago, Chile ...................................................................................39

673. BIM applied to budgeting and quantification for design building companies in Brazil .....................................................................................40
ARCHITECTURAL, SPATIAL & INFRASTRUCTURE PLANNING, AND THE FOURTH INDUSTRIAL REVOLUTION

55. BIM and the future of architecture teaching ................................................................. 41
56. Digitalisation of the building permit process - a case study ....................................... 42
171. A survey of environmental performance enhancement strategies and building data capturing techniques in the Nigerian context .................................................. 43
213. Stakeholders’ perception in early stages of a social housing retrofit living lab ........ 44
214. Social housing retrofit living lab: methodological approach .................................... 45
229. Visual Management (VM) supporting collaborative practices in infrastructure engineering design ............................................................................................................. 46
280. The disparity in greenspace quality between low and high SES settings: a case study in Victoria ................................................................................................................. 47
304. Preferences for medium density housing in Aotearoa New Zealand ......................... 48
306. Construction ergonomics in robotics and human-robot teams in the AEC domain: a review .................................................................................................................. 49
327. Sources of challenges for sustainability in the building design – The relationship between designers and clients ......................................................................................... 50
341. Innovating liveable and affordable higher density housing through design and planning: the case of Bennett Street, WA ............................................................... 51
483. Ground-level documentation of heat stress exposure and response strategies in informal settlements in Tshwane, South Africa ......................................................... 52
491. Synergies between BIM and whole life cost ................................................................. 53
502. Identifying indicators of success from end-of-deployment reports ............................ 54
517. Transportation infrastructure as catalyst: evolving urban structure in the in-between space of railway stations ....................................................................................... 55
543. An architectural design process for housing in South Africa .................................... 56
546. A comparative study of layout typologies for wayfinding in healthcare facilities in northwest Nigeria ........................................................................................................ 57
547. Exploring spatial flexibility strategies in the design of public residential buildings in Kaduna state ............................................................................................................. 58
585. A review of research on strategies and methods for the revitalization of urban historic districts ................................................................................................................ 59
650. Measuring agricultural loss and the impact of differing dwelling types: a case study in Melbourne ................................................................................................. 60
678. Statistical cost modelling for preliminary stage cost estimation of infrastructure projects ..................................................................................................................... 61
725. Multi-quantified based urban renovation strategies in TOD development, a case in Heifei, China .......................................................................................................... 62
<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>64</td>
<td>100. Building’s digital twin model shown as first-person and third-person views</td>
</tr>
<tr>
<td>65</td>
<td>104. Reality capture for historic BIM (HBIM) development of the Old Polk County Courthouse in Bartow, Florida, USA</td>
</tr>
<tr>
<td>66</td>
<td>271. Review of driving forces for digital twin adoption in the construction industry</td>
</tr>
<tr>
<td>67</td>
<td>314. Exploring a digital twin framework for lean management of constraints in construction: a literature review</td>
</tr>
<tr>
<td>68</td>
<td>348. SIMULTAN data model for Python development</td>
</tr>
<tr>
<td>69</td>
<td>420. Sensor-based pavement layer change detection using Long Short-Term Memory (LSTM)</td>
</tr>
<tr>
<td>70</td>
<td>479. Creation of situational awareness using Internet-of-things (IoT) applications for onsite scaffolding project management</td>
</tr>
<tr>
<td>71</td>
<td>674. Automatic classification and coding of prefabricated components using IFC and random forest algorithm</td>
</tr>
<tr>
<td>72</td>
<td>726. 3D informatization of component forms and construction methods of existing wooden houses</td>
</tr>
<tr>
<td>73</td>
<td>729. Multiple system integration in local government asset management – a New Zealand case study</td>
</tr>
<tr>
<td>74</td>
<td>758. Information exchange and interoperability of heterogeneous building automation systems and BIM applications</td>
</tr>
<tr>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>14. Forensic delay analysis as evidence of transaction costs in construction projects</td>
<td>77</td>
</tr>
<tr>
<td>15. Factual disagreements in construction delay disputes: identification, evaluation and testing of the justifications for difference in opinion</td>
<td>78</td>
</tr>
<tr>
<td>31. The perception of commercial construction companies on using technology to review contracts in New Zealand</td>
<td>79</td>
</tr>
<tr>
<td>41. Seeking equitable resolution for COVID-19 associated delay claims– who should recover the loss and expenses?</td>
<td>80</td>
</tr>
<tr>
<td>84. Using forensic reports to manage the probability of lawsuits being filed in relation to pitched roofs: the case of Madrid</td>
<td>81</td>
</tr>
<tr>
<td>163. Building Information Modelling (BIM): insights from collaboration and legal perspectives</td>
<td>82</td>
</tr>
<tr>
<td>228. To be or not to be: why do transaction partners in construction industry avoid formulating agreements into contract documents?</td>
<td>83</td>
</tr>
<tr>
<td>283. Application of smart contract in infrastructure procurement: a systematic literature review</td>
<td>84</td>
</tr>
<tr>
<td>319. An investigation of difficulties in information management for delay and disruption claims</td>
<td>85</td>
</tr>
<tr>
<td>349. Incorporating emerging technologies in the forensic analysis of construction project delays</td>
<td>86</td>
</tr>
<tr>
<td>626. A review of cybersecurity challenges for digital construction</td>
<td>87</td>
</tr>
<tr>
<td>646. Bridging psychological distance of negotiation failure in construction dispute negotiation</td>
<td>88</td>
</tr>
</tbody>
</table>
CONTENTS

CHALLENGES AND OPPORTUNITIES TO THE USE OF DATA IN CONSTRUCTION .................................................................89

96. Analysis of heat-related health outcomes of indoor overheating in residential buildings using connected thermostat data .......................................................................................................................90

148. Real-time employee monitoring technologies in the construction sector – effects, readiness and theoretical perspectives: the case of New Zealand ........................................................................................................91

162. Building a data-driven future for construction team? Capabilities matter .................................................................................92

190. Design and analysis of the real-time progress tracking system: practical case study .................................................................93

311. Using smartwatches to understand the relationship between construction workers’ travelled distance and time spent on direct work .......................................................................................94

333. Building-related data structuring with focus on building damages .................................................................................................95

345. Standardized data integration in the AEC domains – What does it take to succeed? .................................................................96

377. Research on the plane intelligent design of homestays based on deep learning ...........................................................................97

424. Guidelines for managing customer complaints in the real-estate market .................................................................................................98

438. Investigating the applications and implementation of UAV technologies for small or medium contractors ...........................................................................................................................................99

452. Building our future and the future of building: challenges from an organizational-cultural viewpoint ........................................................................................................................................100

472. Comparing two AI methods for predicting the future trend of New Zealand building projects: Decision Tree and Artificial Neural Network .............................................................................101

524. Building cost database for South Africa – key data trends and implications ..................................................................................102
<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repertory grid methodology to research tacit knowledge in construction</td>
<td>104</td>
</tr>
<tr>
<td>Managing the risks associated with remote learning project implementation</td>
<td>105</td>
</tr>
<tr>
<td>Implementation of integrated BIM-VR into construction management curriculum: lessons learned and development of a decision support system</td>
<td>106</td>
</tr>
<tr>
<td>A review of methods to specify information requirements in digital construction projects</td>
<td>107</td>
</tr>
<tr>
<td>A review of smartphone-based methods for pavement roughness index estimation</td>
<td>108</td>
</tr>
<tr>
<td>Analyzing the impact of simulation fidelity on VR-enabled hazard detection on construction sites – A case study on crane lift operation</td>
<td>109</td>
</tr>
<tr>
<td>Data augmentation approach in detecting roof pathologies with UASs images</td>
<td>110</td>
</tr>
<tr>
<td>A common configurator framework for distributed design, collaboration and verification across the full AEC supply chain</td>
<td>111</td>
</tr>
<tr>
<td>How can blockchain benefit to the payment system in smart construction contracts: a brief review</td>
<td>112</td>
</tr>
<tr>
<td>Unmanned aerial vehicles (UAV) for safety in construction industry: a systematic literature review</td>
<td>113</td>
</tr>
<tr>
<td>A bibliometric review of research on crowdsourcing in smart cities</td>
<td>114</td>
</tr>
<tr>
<td>B-SMART: A reference architecture for autonomic smart buildings</td>
<td>115</td>
</tr>
<tr>
<td>Long video-based action segmentation for earthmoving excavators using improved Temporal Convolutional Network models</td>
<td>116</td>
</tr>
<tr>
<td>IFC-based linking of the risk management process using a building data model</td>
<td>117</td>
</tr>
<tr>
<td>Impact assessment model for low cost (shoestring) digitization in small construction organisations</td>
<td>118</td>
</tr>
<tr>
<td>Digital Twin: A conceptualization of the task-technology fit for individual users in the building maintenance sector</td>
<td>119</td>
</tr>
<tr>
<td>Multi-requirements ontology engineering for automated processing of document-based building codes to linked building data properties</td>
<td>120</td>
</tr>
<tr>
<td>Automatic BIM model auditing for quantity take-off using knowledge graph techniques</td>
<td>121</td>
</tr>
<tr>
<td>Enabling building digital twin: ontology-based information management framework for multi-source data integration</td>
<td>122</td>
</tr>
<tr>
<td>Exploring quality issues in building information models via structural design reviews</td>
<td>123</td>
</tr>
<tr>
<td>A cost model for additive manufacturing in construction</td>
<td>124</td>
</tr>
<tr>
<td>A BIM-based model to study wayfinding signage using virtual reality</td>
<td>125</td>
</tr>
<tr>
<td>Digital Twin based built environment asset management services development</td>
<td>126</td>
</tr>
<tr>
<td>Structural shop drawings at the Sydney Opera House: An instructive model of information flow?</td>
<td>127</td>
</tr>
<tr>
<td>Research proposal on architectural copper-based antimicrobial solutions in high traffic spaces</td>
<td>128</td>
</tr>
<tr>
<td>Page</td>
<td>Title</td>
</tr>
<tr>
<td>------</td>
<td>----------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>720</td>
<td>Establishing a collaboration model for BIM training program in technical and vocational education and training (TVET): a Vietnam case study</td>
</tr>
<tr>
<td>722</td>
<td>Improving posture recognition among construction workers through data augmentation with generative adversarial network</td>
</tr>
<tr>
<td>723</td>
<td>Enhancing the resilience of low-income housing using emerging digital technologies</td>
</tr>
<tr>
<td>728</td>
<td>Evaluating the challenges of data management in COBie datasheet and mitigation measures</td>
</tr>
<tr>
<td>733</td>
<td>Integration of blockchain with emerging technologies in AEC industry: merits and challenges</td>
</tr>
<tr>
<td>739</td>
<td>From building to city level dynamic digital twin: a review from data management perspective</td>
</tr>
<tr>
<td>740</td>
<td>Building information modelling implementation in the design stage of chinese prefabrication construction</td>
</tr>
<tr>
<td>742</td>
<td>Challenges in developing a holistic Whole Building Life Cycle Assessment (WBLCA) software tool: developers’ goals</td>
</tr>
<tr>
<td>752</td>
<td>A survey on BIM information management: the approach of producers and consumers of model information in Brazil</td>
</tr>
<tr>
<td>753</td>
<td>Development of the reward function to support model-free reinforcement learning for a heat recovery chiller system optimization</td>
</tr>
<tr>
<td>754</td>
<td>Lessons learned from implementation of Key Technological Developments to improve occupational safety and health processes in a complex UK-based construction project</td>
</tr>
<tr>
<td>756</td>
<td>Digital measurement of construction performance: data-to-dashboard strategy</td>
</tr>
<tr>
<td>759</td>
<td>AI-driven safety checks for ladders used on construction sites</td>
</tr>
<tr>
<td>761</td>
<td>Success factors to large-scale adoption of wearable technology for musculoskeletal disorders (MSDs) prevention: a case study</td>
</tr>
<tr>
<td>762</td>
<td>Privacy and security in the use of wearable internet of things for construction safety and health monitoring</td>
</tr>
<tr>
<td>763</td>
<td>Neural semantic parsing of building regulations for compliance checking</td>
</tr>
<tr>
<td>770</td>
<td>BIM adoption and maturity anno 2021: a large scale empirical study on the current state of affairs</td>
</tr>
<tr>
<td>772</td>
<td>Health, well-being and comfort in smart buildings innovation: state-of-play and opportunities</td>
</tr>
<tr>
<td>CIRCULAR BUILT ENVIRONMENTS</td>
<td>Page</td>
</tr>
<tr>
<td>----------------------------</td>
<td>------</td>
</tr>
<tr>
<td>68. Mapping sustainability indicators for circular built environments in the Global South</td>
<td>148</td>
</tr>
<tr>
<td>95. What does low-carbon living look like in Europe in various types of built environment?</td>
<td>149</td>
</tr>
<tr>
<td>116. Precursor considerations for new circular economy business models</td>
<td>150</td>
</tr>
<tr>
<td>143. A case study of construction and demolition waste management process flow in mega infrastructure projects in Australia</td>
<td>151</td>
</tr>
<tr>
<td>193. Vibe and Tribe - adaptive reuse of buildings delivering aesthetic experience and social inclusion</td>
<td>152</td>
</tr>
<tr>
<td>276. Decarbonisation of the urban built environment through vegetation-based carbon sequestration</td>
<td>153</td>
</tr>
<tr>
<td>278. Comparison of green building rating systems from LCA perspective</td>
<td>154</td>
</tr>
<tr>
<td>281. Circular economy trends - potential role of emerging technologies</td>
<td>155</td>
</tr>
<tr>
<td>312. Resource indicator-oriented building information modeling for the management of infrastructure materials</td>
<td>156</td>
</tr>
<tr>
<td>342. Improvement of environmental sustainability and Circular Economy through construction waste management for material reuse</td>
<td>157</td>
</tr>
<tr>
<td>407. A critical review of the circular economy within the construction industry</td>
<td>158</td>
</tr>
<tr>
<td>515. Design for circularity: the case of the building construction industry</td>
<td>159</td>
</tr>
<tr>
<td>534. Circular economy in Africa’s built environment: a conceptual bibliometric analysis</td>
<td>160</td>
</tr>
<tr>
<td>628. Green building practitioners’ understanding of the concept of sustainability: a South African perspective</td>
<td>161</td>
</tr>
<tr>
<td>647. Testing the principles of design for disassembly through design-led research</td>
<td>162</td>
</tr>
</tbody>
</table>
DURABILITY & CLIMATE CHANGE: IMPLICATIONS FOR BUILDING DESIGN & CONSTRUCTION PRACTICE

38. Zero carbon refurbishment for existing buildings: A literature review .......................................................... 164
49. Climate actions versus design conditions: the impact on the maintainability of architectural concrete façades .................................................................................................................. 165
133. Bio-concretes and reduction of GHG emissions: what does the scientific literature say? ........................................ 166
205. Advances in service life prediction and thermal energy performance of timber buildings ........................................ 167
219. Building facade failures due to rainwater entry in Turkey .................................................................................. 168
220. Resilience of Canadian residential brick veneer wall construction to climate change ......................................... 169
231. Projected changes of moisture load in a hardboard siding-clad wood-frame wall assembly ..................................... 170
356. A holistic framework for determining the trade-off between embodied and operational carbon emissions of high-rise residential buildings ........................................................................ 171
623. Application of Partial Least Squares regression to assess the hygrothermal performance of wood frame walls in Canada under historical and future climates ................................................. 172
625. Long-term durability of ETICS: comparing the impact of natural exposure and artificial aging .......................... 173
657. Climate-adaptive housing for the elderly: A preliminary study in New Zealand ...................................................... 174
660. Impact of climate change on the degradation of rendered façades: Expectations for a dry and hot summer temperate climate ........................................................................................................ 175
764. Durability of high reflective materials designed for building envelopes ............................................................... 176
21. Investigating into the causes and prevention of mental illness among construction workers: Analysis of case studies

45. The more local, the better: Green jobs and climate justice in the U.S. urban built fabric

109. Scholarship of teaching and learning for construction management education amidst the fourth industrial revolution: recommendations from a scientometric analysis

169. Competence of Indonesia workforce in facing liberalization

369. Learning on the job through collaborative learning: analysing the appropriation of BIM knowledge in micro-enterprise architectural design companies

417. Development of an introductory course in design phase management for constructors

423. SafeCl: A BIM- based system to visualize safety standards to reduce falls from heights

425. Comparison of data skills perceived by the undergraduates and graduates in quantity surveying programme of Malaysia

478. Gender diversity in the UK construction industry

556. Evaluating the need for recovery from work for site-based construction practitioners in Australia

658. Evaluating the effectiveness of BIM-based virtual reality for coordinating the design disciplines in a building renovation project

727. How personality affects construction workers' vigilance to repeatedly exposed struck-by hazards in road work zones

766. Weather and suicide of construction workers in Australia
<table>
<thead>
<tr>
<th>Contents</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>60. Allocation in life cycle assessment of recycled aggregate and CO2 concrete</td>
<td>192</td>
</tr>
<tr>
<td>62. Impacts of policies on the price of recycled concrete</td>
<td>193</td>
</tr>
<tr>
<td>89. A semi-automated BIM-LCA integration model for the economic and environmental assessment over a building’s life cycle</td>
<td>194</td>
</tr>
<tr>
<td>264. The barriers of lean construction application in Australian construction industry: literature review</td>
<td>195</td>
</tr>
<tr>
<td>301. Life-cycle impacts from environmental friendly bricks: the case of Nu-Rock bricks and blocks</td>
<td>196</td>
</tr>
<tr>
<td>643. Influence of BIM-enabled digital transformation on service innovation performance</td>
<td>197</td>
</tr>
<tr>
<td>649. Automated assembly of reciprocal frame structures using robotics</td>
<td>198</td>
</tr>
<tr>
<td>656. An investigation of the drying shrinkage of CO2 concrete</td>
<td>199</td>
</tr>
<tr>
<td>663. An IFC approach for BIPV technical pre-design consideration</td>
<td>201</td>
</tr>
<tr>
<td>665. Unlocking human factors for more resilient and sustainable built environments: human centric solutions</td>
<td>202</td>
</tr>
<tr>
<td>667. Reusing prefabricated concrete panels: a sustainability approach</td>
<td>203</td>
</tr>
<tr>
<td>669. Real-time stress-based topology optimization using neural network</td>
<td>204</td>
</tr>
<tr>
<td>675. Personal protective equipment compliance monitoring enhanced by worker re-identification across multiple cameras</td>
<td>205</td>
</tr>
<tr>
<td>677. A scientometric-content analysis of integration of BIM and IoT</td>
<td>206</td>
</tr>
<tr>
<td>680. An indicator framework for assessing the readiness of hospital in the smart healthcare transformation</td>
<td>207</td>
</tr>
<tr>
<td>681. Effect of engineering training on teamwork skills in a multi-user virtual reality platform</td>
<td>208</td>
</tr>
<tr>
<td>683. Analysis and identification of building construction accident risk in china basing exclusively database</td>
<td>209</td>
</tr>
<tr>
<td>685. A novel environmental impact assessment ontology using a graph-based database</td>
<td>210</td>
</tr>
<tr>
<td>686. An exploratory configurational analysis of collaborative innovation in megaprojects</td>
<td>211</td>
</tr>
<tr>
<td>689. A tailored artificial intelligence model for predicting heat strain of construction workers</td>
<td>212</td>
</tr>
<tr>
<td>692. A review on modelling for life cycle energy estimation of buildings</td>
<td>213</td>
</tr>
<tr>
<td>694. A socio-technical system framework for modular construction of cognitive building</td>
<td>214</td>
</tr>
<tr>
<td>702. Application of terrestrial laser scanning in dimensions measurement of indoor door opening</td>
<td>216</td>
</tr>
<tr>
<td>703. Experimental study of condensation characteristics and operation strategies of induction radiant air-conditioning system</td>
<td>217</td>
</tr>
</tbody>
</table>
CONTENTS

704. BIM-based collaborative design for prefabrication using blockchain technology ........................................ 218
705. A method of making DEM by data fusion of multi-device point cloud ..................................................... 219
707. Defect analysis for condition assessment using IFC ...................................................................................... 220
709. An overview of treatments on recycled concrete aggregate ......................................................................... 221
710. Automated classification of piping components from 3D LiDAR point clouds using deep learning and squeeze-excite mechanism ........................................................................................................... 222
712. Review on improvement of solid wastes incorporated cement-based material using 3D printing technology ........................................................................................................................................... 223
713. Review of computational optimisation applications in cementitious material ........................................... 224
714. Research on 3D laser scanning and BIM for accuracy detection of fabricated concrete wall .......................................................... 225
715. A framework of optimal procurement decision-making of prefabricated component based on BIM component library ............................................................................................................................ 226
716. An analysis on the existing BIM delivery standard system in China ............................................................. 227
741. Smart governance of urban ecological environment driven by digital twin technology: a case study on the ecological restoration and management in S island of Chongqing ........................................ 228
746. Research on risk evaluation of logistics park construction project by FMEA based on hesitation environment ........................................................................................................................................... 229
748. Automatic generative design and optimization of hospital building layouts in consideration of public health emergency ...................................................................................................................................... 230
755. Method on pose estimation of excavators based on onboard depth camera .................................................. 231
765. 4D real-time mapping for thermal inspection and energy auditing in GPS-denied environment .................. 232
767. Construction and application of intelligent platform for engineering project management ......................... 233
773. Lightweight shotcrete containing surface pre-treated coal gangue .............................................................. 234
774. Mechanical analysis of self-compacting concrete mixed with active fibers and stone chips .................... 235
775. Properties of cement stabilized soil with Construction Waste and Polypropylene Fiber .......................... 236
776. 3D building model reconstruction from drone images based on feature lines ........................................ 237
<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyzing the COVID-19 challenge in the context of a smart city considering the sustainable development goals: case study in New York City</td>
<td>239</td>
</tr>
<tr>
<td>Interactions between industry 4.0 digital technologies and COVID-19 construction safety measures</td>
<td>240</td>
</tr>
<tr>
<td>Rethinking the influence of the Intelligent Building Systems (IBSs) on productivity, health and well-being for enhancing the quality of life during mandatory Working From Home (WFH): lessons learned from the COVID-19 pandemic</td>
<td>241</td>
</tr>
<tr>
<td>Establishing indicators for reducing the transmission of airborne viruses in buildings</td>
<td>242</td>
</tr>
<tr>
<td>New Zealand responses to the COVID-19 pandemic and the effects of its governance on the construction industry</td>
<td>243</td>
</tr>
<tr>
<td>Social distance monitoring of site workers for COVID-19 using context-guided data augmentation, deep learning, and homography transformation</td>
<td>244</td>
</tr>
<tr>
<td>A survey on the effects of the Covid-19 pandemic at construction sites</td>
<td>245</td>
</tr>
<tr>
<td>Management of infection prevention and control in the development of new hospital buildings – effective stakeholder engagement during design and construction</td>
<td>246</td>
</tr>
<tr>
<td>The changing role of BIM-facilitated facilities management in the post-COVID era: A systematic literature review</td>
<td>247</td>
</tr>
<tr>
<td>The influences of facilities management on mental health of underground development users during the pandemic in Hong Kong</td>
<td>248</td>
</tr>
<tr>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Effects of air change rate and moisture load related to moisture index and the expected moisture performance of a wall assembly</td>
<td>257</td>
</tr>
<tr>
<td>Influence of the urban heat island effect on interstitial condensation in residential buildings with a temperate oceanic climate in winter: Case of Puerto Montt, Chile</td>
<td>258</td>
</tr>
<tr>
<td>Space4Free: A feasibility study on the conversion of historic 100+ year old brick basements (type ‘Gründerzeit’) to flats in downtown Vienna</td>
<td>259</td>
</tr>
<tr>
<td>Hygrothermal simulation and risk evaluation - A literature review and assessment of the applicability of the Lattice Boltzmann Method to derive the influence of convection on moisture behaviour in building components</td>
<td>260</td>
</tr>
<tr>
<td>Page</td>
<td>Title</td>
</tr>
<tr>
<td>------</td>
<td>-------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>261</td>
<td>59. SWOT analysis of offsite manufacturers of prefabricated building components in Singapore</td>
</tr>
<tr>
<td>262</td>
<td>197. The influence of organisational safety climate factors on offsite manufacturing safety</td>
</tr>
<tr>
<td></td>
<td>performance</td>
</tr>
<tr>
<td>263</td>
<td>259. Transaction cost of offsite construction (OSC): A New Zealand study</td>
</tr>
<tr>
<td>264</td>
<td>266. Waste generation comparison of modular and conventional construction projects</td>
</tr>
<tr>
<td>265</td>
<td>293. Development of a framework for quality assurance of off-site manufactured building</td>
</tr>
<tr>
<td></td>
<td>components: A case study of the New Zealand housing sector</td>
</tr>
<tr>
<td>266</td>
<td>331. Mapping activities and inputs of modular construction with steel 3D modules in Brazil</td>
</tr>
<tr>
<td>267</td>
<td>332. A dialectical system framework for adopting modular integrated construction</td>
</tr>
<tr>
<td>268</td>
<td>388. A BIM-enabled Decision Support System to support large-scale energy retrofitting processes</td>
</tr>
<tr>
<td></td>
<td>and off-site solutions for envelope insulation</td>
</tr>
<tr>
<td>269</td>
<td>411. Quantifying safety performance in off-site construction</td>
</tr>
<tr>
<td>270</td>
<td>430. Offsite construction: reflection is simply not good enough – we need a new Prism!</td>
</tr>
<tr>
<td>271</td>
<td>458. The use of prefabrication in building</td>
</tr>
<tr>
<td>272</td>
<td>481. The status quo of prefabricated housing: an investigation into New Zealand construction</td>
</tr>
<tr>
<td></td>
<td>sector</td>
</tr>
<tr>
<td>273</td>
<td>495. Implementation of a novel data-driven approach to optimise UK offsite housing delivery</td>
</tr>
<tr>
<td>274</td>
<td>496. Applied generative design implementation to support UK offsite housing demand</td>
</tr>
<tr>
<td>275</td>
<td>602. Life cycle sustainability assessment for modular construction – a proposed conceptual</td>
</tr>
<tr>
<td></td>
<td>framework</td>
</tr>
<tr>
<td>276</td>
<td>690. Overcoming barriers to wider adoption of off-site construction</td>
</tr>
<tr>
<td>277</td>
<td>731. Exploring the off-site construction and building information modelling integration challenges</td>
</tr>
<tr>
<td></td>
<td>in New Zealand</td>
</tr>
<tr>
<td>278</td>
<td>769. Premanufactured value as a metric for assessing the use of modern methods of construction:</td>
</tr>
<tr>
<td></td>
<td>Critical insights from UK industry experts</td>
</tr>
<tr>
<td>279</td>
<td></td>
</tr>
</tbody>
</table>
OPEN BUILDING: THE KEY TO A REGENERATIVE HOUSING STOCK ........................................... 280

53. Housing as critical social and economic infrastructure: A decision-making framework, ....... 281

127. Research on housing complex rehabilitation evaluation criteria focusing on the global environment and sustainability -comparative analysis of environmental assessment indexes in the world- ........................................................................................................ 282

129. Research on the regeneration procedure for reutilizing vacant housing stock in Japan ........................................................................................................ 283

132. Research on the renewal process of housing complex - From the case of Japanese public rental housing complex - ........................................................................ 284

139. A comparison study on the long-life housing development histories and plans of collective housing based on the open building theory in China and Japan ................................................................. 285

146. Network design. Using a platform approach and network cooperation in housing design, formation & revitalization of living environment – participation, complexity approach ........................................................................ 286

200. Application of open building theory in the regeneration of old residential buildings ....... 287

230. Regeneration design study based on long-lasting building strategy of typical Chinese work-live unit in Guangzhou, China ................................................................................................. 288

262. Research on the assistance of MySQL database platform to the renewal design of the interior space of urban existing housing ................................................................................................. 289

381. Generation of interior phenomenal quality from refurbishment of commercial spaces in residential areas ................................................................................................................. 290

465. Human Rights, Disability, and Construction: How responsive are building regulations to changing community attitudes towards housing for people with a disability? ........................................... 291

467. Study on effective long-term space optimization design regarding existing campus buildings in China ................................................................................................................................. 292

477. A study on the process of design changes that deviate from “standard specifications” in housing production of Japanese house builders - focusing on communication in design meetings ......................................................................................... 293

531. Regeneration Mode on Skeleton System of Existing Housing in China Based on Open Building Theory ................................................................................................................................. 294

747. A survey of apartment shophouses’ conditions for future housing adaptability revitalization in Phnom Penh ............................................................................................................................. 295
ORGANISATION AND MANAGEMENT OF CONSTRUCTION: NEW CHALLENGES AND OPPORTUNITIES

9. Classification of rework root causes in the design stage of projects for contract assessment .................................................. 297
34. Strategic partnering motives of clients, contractors, and subcontractors in the Dutch retrofit market .......................................................... 298
36. Improving safety compliance of construction workers: a theory of trait activation perspective ......................................................... 299
43. The planning of construction incentivisation .......................................................................................................................... 300
52. Benefits of performance measurement for construction project organizations; a Norwegian case study ........................................................................... 301
87. The value of dialogue in alliances ........................................................................................................................................ 302
90. Restructuring of Nigerian construction industry through lean production approach ......................................................................... 303
108. Success factors in mega infrastructure projects (MIPs): developing nation’s perspectives .................................................................... 304
135. The built environment contribution to the South African economy amid Covid-19: a case of the eastern cape province ........................................................................................................... 305
149. A comparison study between guideline for pure CM Method in local governments of Japan and pure CM contracts in other countries ...................................................... 306
183. Visualization of blockchain-based smart contracts for delivery, acceptance, and payment process using BIM ........................................................... 307
186. Stakeholder engagement and collaboration in overcoming the constraints to delivering low carbon buildings in high-rise high-density cities: Insights from a social network analysis .................................................................................. 308
196. The relationship between mindfulness and safety performance of building repair and maintenance: an empirical study in Australia ........................................................................... 309
315. Building without digital skills ........................................................................................................................................ 310
354. Trends in residential building materials in the state of Victoria .......................................................................................................................... 311
446. Examining the agile project management practices in the Malaysian construction industry ........................................................................ 312
464. Business sustenance strategies in the competitive construction industry: Emerging contractor’s perspective ........................................................................... 313
484. The institutional framework of construction safety management: A case study of Sri Lanka ........................................................................ 314
490. Modern way of performing construction management responsibilities ............................................................................................ 315
535. Factors predisposing public tertiary education building projects to risks in a developing economy ............................................................................................................................................. 316
583. Barriers to construction and demolition waste management in Australia: a review ........................................................................... 317
641. Non-financial management practices to enhance construction labor productivity: A study on worker motivation .......................................................................................................................... 318
648. Bid packaging decisions for construction project organizations ......................................................................................................................... 319
<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>320</td>
<td>Analysis of sustainable procurement in supplying recycled content: a case study in Western Australia</td>
</tr>
<tr>
<td>321</td>
<td>An exploratory study on communication complexity in mega construction projects</td>
</tr>
<tr>
<td>322</td>
<td>Construction industry classification systems: Defining the construction sector in New Zealand</td>
</tr>
</tbody>
</table>
8. Criticality analysis of financial risks of public-private partnership projects in a Sub-Saharan African country, ................................................................. 325

40. Social housing provision in rural areas: lessons learned from a historic analysis of council house building in a small town in rural England, .......................... 326

118. Potential for PPP in the next wave of smart infrastructure: in smart villages and rural infrastructure, .................................................................................. 327

130. A scientometric review of public-private partnership in critical infrastructure resilience, ................................................................. 328

235. Effect of transparency on development phase of public-private partnership: analysis of highway projects, ................................................................. 329

355. Crisis driven literature in PPPs: a network analysis, ....................................................... 330

359. Towards a sustainable framework for road infrastructure management and maintenance scheme in south East Nigeria, .................................................... 331

416. Persistent inefficiencies in the delivery of low-income housing in South Africa: is governance the missing ingredient? – A review of literature, .......................... 332

513. Making BOT Great Again: Revisiting the BOT standard concessions and exploring the expectations, ................................................................. 333

544. Public-private partnerships for transit-oriented development: a case study on the potential of Hobart, Australia, .............................................................................. 334
78. True cost of construction material wastage: a case study ........................................... 336
128. Exploring demolition pathways: routes toward circular construction .......................... 337
212. BIM use for construction waste management: a case study ....................................... 338
385. The use of building information modelling tools for effective waste management: a systematic review .............................................................................................................................................. 340
455. Environmental attitudes and recycling behaviour of architects in New Zealand ........... 341
466. From waste heat to domestic hot water; a sustainable and financially viable solution? .... 342
629. Knowledge, attitude, and practice of Construction Waste Prevention among construction professionals ............................................................................................................................................................................. 343
637. The impact of new international waste policies on the Australian construction and demolition waste stream ............................................................................................................................................................................. 344
645. The impact of regulations on construction and demolition waste market creation and stimulation: Australian stakeholder perceptions ............................................................................................................................................................................. 345
17. Barriers to the implementation of green buildings in Palestine
24. The social and environmental impact of building integrated photovoltaics technology
65. ABEM-based simulation of building egression safety for the elderly under different circumstances: enlightenments of healthy residential buildings for the elderly
70. Accelerating the green energy transition for sustainable buildings and cities: estimating benefits of community power purchase agreements
85. Automate construction schedules at the pre-construction stage – a case study
92. Forecasting green building growth in different regions of China
93. The contribution of smart buildings to low carbon built environment
97. Social sustainability indicators for road infrastructure projects: a systematic literature review
98. Climate benefits of wooden construction in urban context
107. Sustainability indicators in building construction projects through the lens of project delivery elements
113. Indoor environmental factors affecting the productivity of workers engaged in research in office buildings
121. Explaining the changes in the greenhouse gas emissions of New York City buildings
123. Integrating the sustainable development goals into green and sustainable neighborhood rating tools
124. Integrating the sustainable development goals into green and sustainable building rating tools
134. Smart retrofitting of buildings: a bibliometric study
156. Urban biodiversity and carbon sinks – do they overlap? Case study of Helsinki Metropolitan Area, Finland
161. Energy-as-a-Service: a new business model for the built environment?
178. Towards a theoretical understanding of BIM innovation success in facilities management: a comparison of actor-network theory and diffusion of innovation theory
188. Digital transformation of the UK construction industry
189. Quality improvement strategies for principal contractors
204. ISO standards or global indices: who decides if a city is smart?
268. Code checking using BIM for digital building permit: a case study in a Brazilian municipality
277. Optimal UAV image overlap for photogrammetric 3D reconstruction of bridges
320. Trends in residential sustainability measures in the state of Victoria
330. Cities as factories - sector coupling in smart cities
352. Reducing embodied carbon emissions of concrete modules in high-rise buildings through structural design optimisation
353. Internet of Things (IoT)-integrated embodied carbon assessment and monitoring of
prefabricated buildings ................................................................................................................................. 373
370. An occupant-centric approach in BIM environments to improve comfort and renovation planning ......................................................................................................................... 374
375. Prioritising urban green spaces using accessibility and quality as criteria ........................................ 375
403. Evaluating the impact of building material selection on the life cycle carbon emissions of South African affordable housing ................................................................................................... 376
453. An artificial neural network analysis of rework in sustainable buildings ........................................... 377
475. A review of sustainable technologies for energy efficient upgrade of existing buildings and structures ........................................................................................................................................ 378
482. Impact of technology developments on multicriteria performances of BIPV in non-domestic buildings ........................................................................................................................................ 379
604. Systematic review of critical success factors for developing an Afro-centric neighbourhood sustainability assessment framework ........................................................................................................ 380
616. Digitalization of climate adaptation planning: the potential of simulation software tools for landscape design ........................................................................................................................................ 381
652. The development of BIM-MyCREST process model for concept design of green buildings ............... 382
693. Extracting electricity patterns from high-dimensional data: a comparison of K-Means and DBSCAN algorithms ......................................................................................................................................... 384
696. Building typology prediction in smart cities ......................................................................................... 385
699. Defect digital twinning: A technical framework to integrate robotics, AI and BIM for facility management and renovation ........................................................................................................... 386
701. Opportunities for using blockchain in distributed solar energy projects ........................................... 387
730. Shoreline recognition using machine learning techniques ................................................................. 388
749. Design of façade and envelope for a high residential building using energy-efficient materials: A case in Istanbul, Turkey .........................................................
CONTENTS

SUSTAINABLE FACILITY MANAGEMENT AND MAINTENANCE ................................................................. 390

54. User-centric student housing performance evaluation approach: a case study in the Netherlands ................................................................. 391

115. Conceptualizing the identification of critical success factors for heritage building maintenance management ................................................................. 392

125. Retro-commissioning for buildings: problems and the way forward ................................................................. 393

142. Sustainable accounting standard for increasing sustainable refurbishment projects ................................................................. 394

203. Research and Evidence-based standards: Research and standards in combined efforts for a sustainable transformation of the built environment ................................................................. 395

238. A security-minded approach to BIM-maturity: A multidisciplinary review ................................................................. 396

401. An investigation of the impact of green methods and technologies on the environmental sustainability of supportive educational buildings, case study of UCT ................................................................. 397

402. The impact of industry 4.0 technologies on the environmental sustainability of commercial property by reducing the energy consumption ................................................................. 398

406. Investigating the safety and security of the open campus using community-based facilities management and technological innovation principles: University of Cape Town ................................................................. 399

422. The significance of occupants satisfaction on the maintenance planning process ................................................................. 400

605. Interfacing between FM and project phases through digital processes and collaborative practices ................................................................. 401

607. Facilities management and disaster risk reduction: the TURNkey project ................................................................. 402

609. How Sustainable Facilities Management can add value to organisations and the environment ................................................................. 403

610. Get smart: the importance of urban FM to smart cities and their citizens ................................................................. 404

611. Block by block: the current and potential impact of the blockchain on facilities management and green leasing ................................................................. 405

614. Influence of building design on the satisfaction of office building occupants ................................................................. 406

617. Lean and visual managements contribution to sustainable facilities management ................................................................. 407

624. Discussion of digital transition impact in Facility Management of buildings ................................................................. 408

635. It's not only hygienic: identifying problems in thai community hospital outpatient clinic during the first COVID-19 outbreak ................................................................. 409

695. Integrating UAV and BIM for automated visual building inspection: a systematic review and conceptual framework ................................................................. 410
27. Evaluating how management safety empowerment influences health and safety compliance on construction sites .......................................................... 412

28. An offsite construction scoping study for occupational health and safety ........................................................................................................ 413

37. A conceptual framework for integrated Designers Risk Assessments - a case study of an Insulated concrete formwork framed project ........................................................................................................ 414

64. Improving the built environment for manual wheelchair users: A review ........................................................................................................ 415

79. Exploring leadership and construction workers mental wellbeing ............................................................................................................... 416

141. Developing an AI-powered smart insole system to reduce the possibility of back-pain among older workers: lessons from the Norwegian construction industry ........................................................................................................ 417

152. Exploring government responses to residential fire threats from cladding and bushfires ................................................................................................. 418

179. Developing client leadership to drive BIM adoption for WHS management ............................................................................................................... 419

202. Prediction on construction industry safety management performance based on AHP and grey system ......................................................................................................................................................... 420

326. Investigating green gentrification in the Silo District, Cape Town ...................................................................................................................... 421

329. Stressors in the multicultural construction working environment ................................................................................................................................. 422

390. Health and Safety practices relative to nanomaterial usage in the South African construction industry ........................................................................................................ 423

394. The impact of various safety leadership styles on construction safety climate: A case of South India ......................................................................................................................................................... 424

398. An investigation on the effects of psychological contract (PC) towards site safety in the South Indian construction industry ........................................................................................................ 425

532. Computer vision-based human-machine collision warning system on construction site ................................................................................................................................. 426

548. Work-family conflict – An examination of within-domain and boundary-spanning demands and resources ......................................................................................................................................................... 427

598. A comparative study of occupational safety and health (OS&H) regulations in United States, United Kingdom, Australia, South Africa, and Oman ........................................................................................................ 428

634. How the construction industry can improve the health and well-being of their workers in a post COVID-19 era ......................................................................................................................................................... 429

638. Why are early career professionals leaving the construction industry? It's all about the culture ......................................................................................................................................................... 430

655. Mental workload and physical energy impact on construction worker task demand: a survey study of the carpentry trade ......................................................................................................................................................... 431

724. Beyond compliance in the construction sector: mapping the modern slavery statements through content analysis ......................................................................................................................................................... 432

757. The status of emergency alert systems for construction project sites ................................................................................................................................. 433

771. Impact of job quality on construction worker’s health and well-being in a developing country context ......................................................................................................................................................... 434
<table>
<thead>
<tr>
<th>Number</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>A taxonomy of evacuation infrastructure for urban areas; an assessment of resilience towards natural hazards</td>
<td>436</td>
</tr>
<tr>
<td>12</td>
<td>Women’s empowerment in post conflict housing reconstruction in Palestine</td>
<td>437</td>
</tr>
<tr>
<td>50</td>
<td>Combining BIM and VR for future earthquake damage assessment training tools</td>
<td>438</td>
</tr>
<tr>
<td>106</td>
<td>Creating liveable and accessible social and affordable higher density housing: the case of Green Square, Brisbane</td>
<td>439</td>
</tr>
<tr>
<td>138</td>
<td>The intra-Covid renaissance: envisioning resilient urban neighbour-‘wood’</td>
<td>440</td>
</tr>
<tr>
<td>145</td>
<td>Sustainability of post-disaster temporary houses: a review of principles and assessment methods</td>
<td>441</td>
</tr>
<tr>
<td>177</td>
<td>Prototyping an immersive virtual reality training system for urban-scale evacuation using 360-degree panoramas</td>
<td>442</td>
</tr>
<tr>
<td>180</td>
<td>Flood risk management in New Zealand: a case study of the Northland urban community</td>
<td>443</td>
</tr>
<tr>
<td>223</td>
<td>Urban resilience actions in the built environment: an analysis of the city of Salvador – Bahia - Brazil3</td>
<td>444</td>
</tr>
<tr>
<td>246</td>
<td>Shelter needs of informal settlements: implications for inclusive shelter guides</td>
<td>445</td>
</tr>
<tr>
<td>459</td>
<td>Assessment of occupant adaptive heating behavior in office buildings - a pilot field study</td>
<td>446</td>
</tr>
<tr>
<td>507</td>
<td>A national response for internal displacement in Australia</td>
<td>447</td>
</tr>
<tr>
<td>527</td>
<td>Unravelling the challenges for long-term planning post-disaster resettlement in Cagayan de Oro, Philippines</td>
<td>448</td>
</tr>
<tr>
<td>536</td>
<td>Assessing emergency animal safe sites for evacuation</td>
<td>449</td>
</tr>
<tr>
<td>537</td>
<td>Beyond early self-evacuation from bushfire: factors influencing non-evacuation of at-risk communities</td>
<td>450</td>
</tr>
<tr>
<td>570</td>
<td>Evaluating the spatial variation of heat wave intensity to enhance urban resilience</td>
<td>451</td>
</tr>
<tr>
<td>577</td>
<td>Study of building vulnerabilities to forest fires in Portugal</td>
<td>452</td>
</tr>
<tr>
<td>578</td>
<td>Resilience of industrial buildings to wildland-urban interface fires</td>
<td>453</td>
</tr>
</tbody>
</table>
Without a diverse leadership and workforce, in the South African construction industry innovation is hindered and slowed, resulting in a weakened ability to respond to a fast paced and technologically driven market and economical changes, which has a direct impact on organisational growth. Little is known about the role of leadership in managing the relationship between diversity and innovation in the South African construction industry. The construction industry has not been responsive to market changes and therefore slow to innovate. This rapidly evolving contextual landscape requires a more diverse workforce in order to address these challenges. This paper presents the findings from a study that investigated and analysed the role of leadership in managing the relationship between diversity factors and innovation in the construction industry. Specifically, it investigated how leadership influences, drives, and manages the relationship between diversity and innovation for improved organisational performance and providing inclusive innovative solutions in the South African construction industry. In this context leadership is described as the ability to select, equip, train, and influence one or more followers who have diverse gifts, abilities, and skills and focuses the followers to the organisation’s mission and objectives. Diversity factors are described as age, ethnicity, cultural background, gender, race and capabilities. Innovation is described as the implementation of ideas that have come together to create new solutions to problems or improvements to existing systems, processes, products, or attempted solutions.
New and emerging technologies such as digital technologies and new construction techniques have altered the way buildings are designed and constructed. However, to what extent they are practically implemented in the construction sector remains unknown. By employing a qualitative interview approach, this study attempts to examine the current status and perceived benefits of technology implementation in the New Zealand construction industry. The results manifest high adoption rates of technologies for basic design, group collaboration, and data visualisation, acquisition and management. Benefits of improvements in work efficiency, productivity, quality, and health and safety are highly appreciated by the interviewees as being primary. The findings of this study contribute to an improved understanding of the practical needs, trends and motivations for technology adoption among construction organisations in New Zealand. Such knowledge and understanding can inform the decision making of government agencies and industry body organisations in facilitating technology adoption, allocating resources for effective technological transformation in the sector.
Reinforcing concrete with thin short discrete steel fibres seems to be an efficient process in obtaining a multi-directional reinforcement to modify and improve the properties of concrete, especially its ductility. Therefore, it is imperative to understand the preference and selection of materials to make appropriate mixes for efficient result of steel fibre reinforced concrete. This study investigates the effects of length and aspect ratio of steel fibres when mixed with maximum course aggregate on the workability and subsequently, on the mechanical properties of the material. Variables selected for the study were fibre lengths of 50 mm and 60 mm, aspect ratio of 45, 50 and 60, fibre dosages of 25 kg/m³, 40 kg/m³, 50 kg/m³ and 60 kg/m³ and maximum aggregate sizes of 10 mm and 20 mm. Slump test was performed on fresh concrete while compressive strength was measured using 100 mm cubes and flexural performance assessed through 150 mm x 150 mm x 600 mm prism. The experimental results confirm that the combination of geometry and maximum aggregate size in the mix has an important influence on the workability of fresh steel fibre reinforced concrete. Consequently, the obtained results confirm that there is relationship between the mechanical properties of hardened concrete and the workability of fresh concrete. The concrete with poor workability reveal inadequate orientation and distribution of fibres, leading to poor actions of fibres within the mix and hence, affecting the mechanical properties of tested concrete materials.
The effective diffusion of Building Information Modelling (BIM) presents strong potential to evolve the productivity and performance of the construction industry. Implementing BIM effectively requires significant changes in the construction business practices to improve communication, collaboration and sharing information among team members in design, construction and operating phases.

The aim of this paper is to investigate the required reformation of current procurement methods in the UAE to enable the effective diffusion of BIM. The paper will present a conceptual framework which illustrates the needed changes in procurement methods being change in the relationship among participants, change in the contractual agreements, sharing the risks and rewards among stakeholders, early involvement of stakeholders, and involvement of new participants.

The paper will report the findings of the analysis of four case studies of companies with vast experience in projects that adopted BIM and how it has impacted the procurement approaches adopted. The research findings have articulated that in order to implement BIM process effectively, it is critical for the UAE construction industry to adopt more collaborative relationships and share the risks and rewards among the participants. The findings show that the most important requisite change is for the key players at design stage to collaborate to create an effective BIM model that will save time and cost. Furthermore, contracts should oblige the participants to adopt BIM, identify the level of development in each stage and determine the responsibilities and intellectual property rights of each stakeholder.
Instigating changes to project organization structure during the project execution could disrupt many project processes and influence project performance. The purpose of this study is to investigate a particular problem occurred in completed construction projects in UAE market. The problem appeared as a result of unnecessary changes and due to slow or inadequate response to change by senior managers in contractor’s project organization structure. These changes had negative impact on the project management roles and responsibilities, additional cost and time impact. Furthermore, there were negative consequences on the performance of the project’s team and their effort to create new ideas as well as their innovation inside the construction project that they are involved. The qualitative methodology is used in this study through investigating five case studies for construction projects that completed in UAE market along with extensive literature review that focused on the different sides of the problem as well as an interview with ten members of contractor’s project management and senior managers to examine the impact of the problem on project performance and team effectiveness.

The main findings indicate that having clear and defined roles and responsibilities have positive impact on project performance and team effectiveness. Moreover, senior management have a vital role in managing the project organization structure and ensuring that any changes to the structure are dealt with effectively. This would enable the project to progress according to plan, reduce project activity reworks and address any weakening communication and cohesiveness between project team members.
Despite progress monitoring is an essential practice for achieving the success of construction, traditional monitoring methods based on manual information gathered through visual inspections are error-prone, depending on the experience of those who carry them out. Furthermore, most studies of progress monitoring using digital technologies focus on activities carried out outdoors, limiting the application of these methods in residential construction sites, which have several indoor activities. This study proposes a method for outdoor and indoor visual monitoring of construction progress using Building Information Modeling (BIM), 360° camera, and photogrammetry aided by an Unmanned Aerial System (UAS). For this purpose, exploratory case studies were carried out. The first exploratory study aimed to understand data collection and processing operationalization using the proposed technologies. Then, these technologies were used and evaluated to monitor progress in a second exploratory case study, enabling the development of a proposed method for using visual data collected by UAS and 360° camera integrated to BIM for progress monitoring. The status of the external area of the construction site was represented by point clouds generated through images collected by UAS. For monitoring inside the buildings, a 360° camera attached to the safety helmet was used. The results include evaluating the use of a 360° camera to monitor the internal progress of works, presenting its strengths, limitations, and use recommendations. In addition, the results also include the proposal of a method for visual progress monitoring of indoor and outdoor activities using BIM, UAS, and 360° cameras.
Effectively carrying out the digital documentation of a construction project site makes it possible to capture important events, allows for the measurement of progress, and creates an archive of data that can be called upon if issues arise in the future. It is best if the documentation can occur at regularly scheduled intervals to eliminate the possibility of missing important project details. Anecdotally, it has been found that practitioners are not good at keeping up with this important task – it is often viewed as a chore for a junior-level employee to undertake when there are no other important tasks to accomplish. This attitude toward project documentation is problematic for the success and the effectiveness of the process. An alternative is necessary. Robotic automation is often viewed as a good replacement for tedious activities that require a degree of accuracy in repetitiveness. Experimentation was conducted by scoring the drone’s ability to complete a 10-point trial run across three different terrain types. This study focused on how terrain affects the drone’s accuracy and validates the findings by way of incorporating industry feedback about the prototype being proposed in this paper. The study reveals the viability of this solution while documenting potential shortcomings when using ground-based drones on a construction project site. Lastly, the research considered the economics and complexity of the drone’s implementation by practitioners who may be less experienced with coding and prefer to focus their efforts on construction-oriented tasks.
Architectural drawings are an important source of information for many construction-related tasks, as they contain geometric and semantic information about building parts. However, the manual extraction of room stamps and the insertion of such gleaned information into CAFM systems is quite laborious and, thus, its automation is anticipated. In this paper, a method is proposed to detect and to classify obscure or illegible text elements on legacy 2D architectural drawings of possibly poor quality. In contrast to existing approaches, a deep learning model is specifically trained for the task at hand rather than making use of transfer learning approaches. The resulting text snippets can be further processed with natural language processing (NLP) tools to be fed into a CAFM system automatically. Other conceivable applications include the extraction of drawing header information, material type or any additional text given on the drawing, to facilitate the enrichment of digital twins of existing structures with semantic data. To provide training data, two floor plan datasets are annotated in a consistent manner. The influence of different data augmentation techniques and the generalization ability of the trained models is investigated systematically. With regard to performance and efficiency, the presented method is compared to alternative tools for the task at hand and shows superior performance over state-of-the-art open source tools.

**Keywords:** Architectural Floor Plans, Deep Learning, Computer Vision, Information Extraction, Text Detection
The flow of information in construction supply chain stands out for being inefficient and lacking in automation. Some authors have identified the potential of blockchain technology to solve problems related to the lack of transparency, automation, productivity, and efficiency. This study builds a novel blockchain-based information management framework for a typical supply chain of the construction industry. Using design science research as methodological research strategy, this study presents and analyses a blockchain framework and its development processes. The framework performance was evaluated through its potential to generate organizational knowledge and its impact on the current management context. The challenges of the proposed system are the integration of Hyperledger systems, the development of channels and the layout of the supply chain within the blockchain, as well as the addition and control of members within the network. The main contribution of this study is the proposition of a SaaS (Software as a Service) concept platform with great potential to meet the needs and particularities of the Construction sector.
Towards improved dissemination of results from strategic innovation programmes: the case of ‘smart built environment’

Mattias Jacobsson
School of Engineering, Jönköping University, Jönköping, Sweden
Umeå School of Business, Economics and Statistics, Umeå University, Umeå, Sweden

Henrik Linderoth
School of Engineering, Jönköping University, Jönköping, Sweden

Government sponsored Research, Development, and Innovation (RDI) initiatives have lately become a common way to foster industry transformation. We report on a so-called Strategic Innovation Programme (SIP) in the Swedish built environment sector which constitute such an initiative. More precisely, we investigate the process of disseminating results from the initiative, and the inherent challenges thereof. The purpose is to increase the understanding of how to enable sector-wide dissemination of results from SIPs. The studied programme is backed by three state research agencies and corresponds to an investment of a total of 60 million euros (600 million SEK) over 12 years. The programme builds on a collaboration-oriented model where actors in the sector jointly identify, plan, and undertake RDI-efforts, with an overarching goal to find “… solutions to global social challenges and increase Sweden’s competitiveness”. Based on a combination of document analysis, semi-structured interviews, and focus group interviews, the challenges of reaching beyond involved actors with RDI-results are analysed and discussed. The article show how dissemination of RDI-results is dependent on two essential preconditions (ambition and capacity), and how clarity of target group(s) in combination with the alignment between RDI-logic and the target group’s frame of reference, inhibits or enables dissemination of results. The article ends with a discussion on an inherent paradox identified in the quest of simultaneously trying to maximize successful dissemination of results and support sector-wide transformation.
For over a decade there has been an urgent need to improve productivity within the New Zealand architecture and construction (AC) industry. A need that has largely been met with ongoing conservatism, scepticism and reluctance to innovate. Investment in the research and development (R&D) of new construction technologies, techniques and processes has frequently been cited as the most capable and realistic solution. Overseas, construction 3D printing (C3DP) has been at the forefront of R&D as a faster, cheaper and more sustainable construction technique over traditional methods. However, we are currently entering the fourth industrial revolution (industry 4.0) and the majority of existing construction 3D printing case studies do not adhere to holistic industry 4.0 principles. While they do make use of a few industry 4.0 technologies (3D printing and autonomous robotics), the underpinning processes and principles used in architecture and construction (AC) design procurement remains in the third industrial revolution. The research investigated how C3DP could be approached through the “digital first” lens of a holistic industry 4.0 framework and develop a contemporary design workflow for generating unique and functionally viable architectural facades. The research consisted of a CAD workflow created within Grasshopper and Rhinoceros 7 where a range of different façade designs can be generated, customised, visualised and re-customised at any point before being sent through a 3D printing process. It exhibited how a workflow could be used to achieve different architectural aesthetics quickly and efficiently that can be instantly translated into a manufacturable 3D printed product.
The incorporation of technologies associated to Construction 4.0 is an alternative to innovate conventional services in construction. Nonetheless, little is known about the components of services associated to Construction 4.0 that could be incorporated into conventional services in construction, in a process called servitization. Therefore, the purpose of this paper is to present a servitization profile of Construction 4.0. To this end, a bibliographic and documental review was performed, gathering data from 262 components of services, or subservices, associated to 15 technologies in websites from 148 companies that offer 38 services associated to Construction 4.0. Results include the characterization of a servitization profile of Construction 4.0 subservices in eight levels. The first level of servitization is composed by non-digital servitization (33.2%); the second is the data collection (24.4%); the third is the non-autonomous data processing and analysis (7.6%); the fourth is modeling and simulation (9.9%); the fifth is the autonomous data processing, analysis and monitoring (11.8%); the sixth is the results presentation (10.7%); the seventh is the autonomous construction (1.5%); and, finally, the eigth is the command (0.8%). In other words, seven levels of servitization are digital, and one is non-digital, where all the autonomous subservices are at digital servitization levels. This means that automatic data gathered from a sensor depends on the installation of this device by a fundamental intervention of human expertise. Consequently, a combination of digital and non-digital servitizations is needed to enable Construction 4.0 attributes, that could be incorporated into conventional services in construction.
273. A conceptual framework for including “safety in design” in engineering training and design practice

Weifang Shi  
University of Auckland, Auckland, New Zealand  
Zhongyuan University of Technology, Zhengzhou, China

Alice Chang-Richard  
University of Auckland, Auckland, New Zealand

Brian Guo  
University of Canterbury, Canterbury, New Zealand

Despite great efforts taken to reduce hazards on the construction site, statistics across the globe suggested that construction-related fatalities remain high. While prevention through design gains momentum to eliminate latent health & safety hazards at the upfront design stage, designers often lack experience in recognising hazards that take place later on during the construction or operational stage.

To fill this gap, based on previous studies, this paper develops a conceptual framework aimed at better-communicating safety in design (SiD) to designers in order to raise their awareness of SiD and build their capability when considering appropriate design features. The conceptual framework embrace visualization, knowledge sharing, highly engagement and embedded-in questionnaire technologies. This research is part of a doctoral study, and it is hoped to lay a conceptual foundation for ongoing research that aimed to enable designers to embrace SiD in their training and practice in the future.
The research focuses upon understanding the uptake of exoskeletons (EXO) and how they will progressively be subject to reinterpretation. EXO are a mechanism to assist the weight-bearing capacity of an operative. EXO could have a wide-ranging influence on the construction sector’s on-site production methods; health & safety, operative fatigue/injury, procurement, regulations, guidance, codes, standards, productivity and sub-contracting. Construction firms are currently trialling EXO in several locations globally. It is proposed that questions remain unanswered regarding uptake, especially how EXO will reach stabilization through closure mechanisms, potentially seen to be ‘operated’ (plant), ‘used’ (operatives’ tool) or ‘worn’ (PPE). It is argued that uptake and stabilization are intertwined. The theoretical lens of the Social Construction of Technology (SCOT) is mobilized to understand this intertwined uptake and stabilization, thus privileging the iterative relationship between social groups, the technological frame and interpretive flexibility. The SCOT lens potentially offers understanding how EXO will become stabilized as uptake occurs over time. For example, if stabilized as plant EXO would be subject to specific regulations and operator licenses; as an operative’s tool responsibilities would shift, as PPE EXO become mandatory with the responsibility on main contractors. Each of these possible interpretations and others yet to be voiced may result in institutional practices and organizational processes manifesting to accommodate stabilization. A scoping study is presented, outlining initial interests around EXO to understand potential relevant social groups. The scoping study is critiqued in order to better understand how to approach the subject of EXO uptake in the sector.
Construction startups offer to optimize services in construction through innovation, by raising the levels of productivity and quality through new technologies or their application. In Brazil these companies are known as Construtechs or Proptechs, but publications provide details on the type of innovations they offer in their services. In order to fill this gap, this paper provides an innovation profile of services offered by Brazilian construction startups. To this end, a document and bibliographic review was conducted, where data was gathered initially based on a list published by a Brazilian venture capital company in 2020. This was then expanded by extracting information from the websites of 257 firms on the list, limiting the scope to companies belonging to the categories of “Design and Viability” and “Construction”. From the information available on 222 Construtechs, results shows that most of the companies offer organization and management services (79 companies, 36%), through digital platforms that improve the flow of information (166 companies, 75%) and innovate the way services are performed in the client companies, that is, the process (161 companies, 73%). In addition, it was identified that Brazilian Construtechs mostly offer services at the basic technological level and that only 33 companies (15%) are related to Construction 4.0. This paper provides a profile of Brazilian Construtechs and their service innovation opportunities, mainly associated with Construction 4.0.
As technology becomes ubiquitous in the architecture, engineering and construction (AEC) industry, there is a need to evaluate how construction education is incorporating technology in the undergraduate curriculum. We are especially interested in emerging technologies that facilitate the integration of AEC disciplines, because recent trends, such as Building Information Modeling (BIM), offsite construction, and collaborative delivery methods point to a more integrated approach to the design and building process. In the first phase of the study, a scoping review of literature was used to identify publications related to eight emerging construction-related technology types. The second phase was focused on how these emerging technologies were taught in construction education. Our findings indicate 58 papers focused on education and emerging technology. Of those, the overwhelming majority discussed technology as pedagogical aid to improve visualization (mainly virtual reality), while only 10 focused on instruction about the technology. Some technology types (data analytics, blockchain and offsite construction) did not have any education specific publications identified by the researchers. Emerging themes from the data also suggest drones are frequently integrated into surveying courses, teaching of robotics is frequently aligned with programming and computational thinking, and BIM is frequently mentioned with other technology types. A majority of the papers mention not one, but several technology types, indicating an integrated view of emerging construction technology. We conclude the review by suggesting the need for more publications related to teaching of new technology, so that instructors can share best practices in integrating them into the construction curriculum.
Building Information Modelling (BIM) has recently attracted substantial attention in the construction industry concurrent with the rise of digital urbanisation and its increased use of digital technology. Organisations in the construction industry have now started paying more attention not only to adopt BIM but also to ‘exploit’ BIM. Adoption of BIM can make an industry set itself as an example to others. However, exploitation refers to something beyond adoption which seeks more validity and reliability on its outcomes - the real benefits. BIM has the potential to offer a range of benefits. The benefits of BIM are connecting project teams, workflows and data across the entire project lifecycle from the design stage to the construction and operations stages. BIM allows its users to realise better ways of working and receive better outcomes while increasing productivity, efficiency, and sustainability. Although BIM benefits have been on the discussion for a while, it has never been rightly attributed to BIM exploitation. Therefore, this paper aims to see how ‘BIM exploitation’ offers the promised benefits of BIM at an organisation level. The research employs quantitative means to collect and analyse data from construction professionals in the UK. The questionnaire surveys confirm the trends and relationships between variables in the inquiry and helps creating a robust conclusion on how BIM exploitation leads to BIM benefits.
586. Exploring the thermal conditions in construction sites through IoT based methodologies

Ruwini Edirisinghe
RMIT University, Melbourne, Australia

Myla Andamon
RMIT University, Melbourne, Australia

Ali Ghanem
RMIT University, Melbourne, Australia

Despite improvements in reducing the rate of injuries to construction workers, the construction industry remained a high-risk industry in terms of safety record. Working conditions in construction sites frequently pose heat hazards and presents uncontrolled heat risks. Technological solutions that generate early warnings have the potential to improve health and safety. However, little research has been done in the construction industry.

The Smart Safety Vest system is proposed as a ‘internet of things’ solution to the heat stress problem in construction. This electronic textile-based system monitors the physiological parameters of workers, communicates the data to the cloud, visualises the data and generates alerts of anomalies in real time. The system development has followed series of technology readiness levels and construction site testing.

This paper reports on the early preliminary data analysis from the study on the validity and usability of the system in real construction sites. Real-time environmental data through portable weather stations and physiological data through Safety vest were collected. Specifically, this paper presents the evaluation of the thermal conditions of four residential construction project sites. The environmental data collected in four residential construction project sites are quantitatively analysed which set the context for the further reporting of analysis of the smart vest data from construction workers. The initial results obtained during extremely hot summer conditions are used to derive recommendations. It presents the viability of an integral part of the real-time monitored future pervasive construction site.
Innovation of a firm is considered the firm’s ability to develop a new or improved product and processes or equipment for the creation and production of new product. While clients are essential to the realisation and success of innovation in construction firms. However, there is deprived understanding of the impacts of innovation on construction micro, small and medium enterprises’ (CMSMEs) clients. This paper, hence, exploratively determine the impacts of innovation on construction clients. To achieve this the research employed qualitative research method to exploratively determine the effects of innovation on construction micro, small and medium enterprises’ (CMSMEs) clients. While recorded semi-structured interview with opened ended questions were utilized to gather information from 43 innovative CMSMEs through judgemental and snowballing examining procedure. Information gathered were, open and axial coded, examined and interpreted. The outcome from the study reveal that innovation predominantly impacts on client/customer satisfaction, client/customer retention and client/customer relations. In addition, the findings also indicate minor occurrences of innovation impacting clients’/customers’ value for creativity, clients’/customers’ value for money and after sales services to clients’/customers. This outcome implies that innovation could be postulated as a driver of client satisfaction of a firm resulting in improved client retention and ultimately, the success of the firm. The search improves body of knowledge in respect of the basic effects of innovations on construction firm clients.
Green Supply Chain Management (GSCM) is considered to be the most effective management tool, aiming to integrate environmental sustainability thinking into the built environment. This is in relation to its ability to substantially reduce greenhouse emissions, energy consumption, pollution, waste, and other drivers of negative environmental change across the entire construction supply chain. Despite the implementation of GSCM practices as a means to reduce negative environmental footprints, climate change continues to occur with a steady rise in greenhouse gas emissions per year that are associated with the built environment. Hence, there is a need for a more proactive regenerative approach that focuses not only on reducing negative environmental footprints but also aims to create net positive impacts on the environment. This study aims to address this issue by first identifying the dominant forms of construction GSCM practices and their performance limitations through a Systematic Literature Review (SLR). The result revealed that regenerative factors were lacking in current GSCM practices. To further explore the nature of expanding current GSCM practices, a regenerative-based GSCM model was developed that demonstrates the relationship between regenerative principles and GSCM practices. This research addresses the gaps in current GSCM practices and directs future policy and research in regenerative-based GSCM. In addition, findings from this research could serve as a strategic response to climate change in terms of both mitigation and adaptation responses. Future research will focus on assessing and validating the developed regenerative-based GSCM model.
691. Case study: an Australian construction innovation incubator using the agile approach

Matt Stevens
Western Sydney University, Parramatta NSW, Australia

Ali Al-Ashwal
Western Sydney University, Parramatta NSW, Australia

Kasun Gunasekara
Western Sydney University, Parramatta NSW, Australia

This paper explores and examines the Innovation Incubator approach using the Agile Method as an approach to develop an innovative safety app, which was the winning concept of ‘Constructathon 2019’, Australia’s first construction hackathon. The construction industry ranks in the bottom half of all sectors in innovation. It is critical to seek ways to increase the quantity and quality. One approach is the use of business incubators for promising ideas. This study identifies key tools, information sources and phases in developing this construction software application. The incubator team featured interviewed dozens of construction field and office personnel, deriving their insights, wants and needs. The interviewees represented both subcontractors and main contractors, providing a view of the industry’s safety process and information technology gaps. The incubator was a construction-focused one using a modest Agile Methodology to tailor the solution to construction’s unique characteristics. Few construction centric innovation incubator experiences have been explored within the Agile framework in literature. Innovation incubators facilitate and direct creative thinking towards an identified problem. This paper shares and analyses a software development journey of a team immersed in an Australian construction innovation incubator.
The first construction-centric hackathon in Australia, titled Constructathon, was held in 2019, and this case study explores many of its critical philosophies, practices, and outcomes. The two-day process reflected successful hackathon practices learnt in previous attempts in other sectors. The competition was agenda-driven with valuable support such as thinking exercises, subject matter experts, and work assignments for the group. The researchers were members of the winning team. This research discusses the structural barriers of the construction industry’s innovation. These obstacles are not immovable, but an innovation-minded company should be aware of them when launching a potentially expensive innovation program. Construction-centric hackathons are one solution to overcome innovation these barriers. This paper shares the group’s experience of creating and developing a construction safety service product, including beneficial and non-beneficial practices. The Constructathon idea has significant potential to produce well-developed built environment innovation ideas. This case study contributes to academia by exploring the theoretical underpinnings of hackathons and a case study of a successful team. Lastly, the paper provided suggestions for improving future construction-oriented innovation competitions.
Digital technology, such as Artificial Intelligence (AI) has led to work change across all sectors globally. The construction industry has also experienced significant workflow improvement. AI integration in the built environment can leverage the building’s planning, design, construction, and operation to promote collaboration and integration between the parties in the construction projects environment. AI is the theory and development of computer systems that normally require human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages. Governments and relevant stakeholders need a AI roadmap to know the adoption models, as they are important for policy to drive the adoption in the construction and built environment. However, despite strategic implementation plans recently developed worldwide, there has been no review or analysis of the current discourse on AI roadmaps in the built environment. Hence, the objective of this paper is to systematically look at the strategic analysis elements in the AI roadmap. The study undertook a systematic literature review of AI literature in the construction industry. The study looked at journal articles published between 2012 and 2022 in Web of Science. A total of 27 studies selected through a robust protocol are analysed through content analysis. Thematic research areas and inherent gaps are identified, including Government, Industry and Professional Bodies, Organisation, Education and Training, Vendors and Clients and Information Management. The authors propose a comprehensive framework based on the SLR findings to advance AI research.
ADVANCEMENTS IN UTILIZING EXPERTISE AND AUTOMATION TO INCREASE PROJECT PERFORMANCE
Healthcare building projects are severely constrained by their associated regulatory frameworks. In this context, regulatory requirements define a basic outline upon which design is developed, as well as aid designers towards compliance to minimum healthcare standards. Whereas the use of automation has been explored by existing research focusing mostly on compliance checking (i.e., quality control), there has been limited developments within this domain related to quality assurance in design processes. This paper aims to highlight what are key needed improvements to enable the use of automation to promote quality assurance based on regulatory compliance in healthcare building projects. For this purpose, we have analysed an ongoing revision of a British healthcare design guidance document (HBN 11-01) according to a requirements’ taxonomy, as well as identified key areas of improvement based on a series of interviews conducted within the healthcare design backdrop. Our main findings relate to identifying that despite the guidance character of regulatory documents in the UK, they are rarely used for this purpose during design development, revealing the focus on quality control from a practical perspective. In this context, the regulatory framework could be repositioned as a catalyst towards automated design quality assurance as long as (i) the regulatory documents are developed and revised to fit automated design processes’ needs; and (ii) there are compatible software developments to streamline design processes through automation.
174. Utilisation of technology in construction material logistics processes for efficiency

Alumbugu, Polycarp Olaku  
Department of Quantity Surveying, Federal University of Technology, Minna, Nigeria  
Department of Construction Management, School of the Built Environment, 
Faculty of Engineering, the Built Environment and Information Technology, 
Nelson Mandela University, Port Elizabeth, South Africa

Winston W M Shakantu  
Department of Construction Management, School of the Built Environment, 
Faculty of Engineering, the Built Environment and Information Technology, 
Nelson Mandela University, Port Elizabeth, South Africa

Tsado Abel John  
Department of Quantity Surveying, Federal University of Technology, Minna, Nigeria

Adeniran Wasiu Ola-awo  
Department of Quantity Surveying, Federal University of Technology, Minna, Nigeria

The adoption of technology for logistics operations is critical for improving the total effectiveness and efficiency of a logistics system. However, the current technology used for construction materials logistics processes in the Nigerian construction industry are relatively unknown and inadequately investigated. The aim of this study was to determine the level of technology used in logistics processes by construction material manufacturers in North-Central Nigeria, with a view to improve operational efficiency thereby reducing cost. This article adopted a case study research design method in which quantitative data were collected and analysed. The target population was the North-Central geo-political zone of Nigeria. A total of 32 construction material manufacturers were purposively selected from the zone. The observation and measurement approaches were adopted for data collection for logistics processes. A total of 72 customers’ orders were observed and recorded to be representative of deliveries from the sampled (n = 32) manufacturers’ warehouses to other terminals. The descriptive method of data analysis was employed using percentage and results presented in a form of bar charts. The study established low level of utilisation of technology such as, AutoID, order picking, communication, information technology, e-business, and technology in vehicles in logistics processes by the manufactures. This leads to inefficiencies in terms of speed, accuracy and reliability. It concludes by providing the construction material manufacturers with areas that requires technology to optimise material logistics operations. A recommendation is made for further study to explore why technology is not adopted by these companies, despite its advantage.

Keywords: Construction material, Technology, Logistics processes, Efficiency and Projects
The growing importance of facility management has given rise to a new set of opportunities and challenges in the construction industry. Facility managers use performance measurement to predict the success of any project. The prediction of project success is imperative to maintain the trust and relationship of the facility managers with their clients and building occupants. Customer satisfaction scores have emerged as an important tool to measure performance and ensure repeat business. Multiple studies have identified the factors to improve customer satisfaction. One of the key roles of a facility manager is to ensure quality installation and operational performance. Quality of installation and operation performance are dependent on the product type and the nature of warranty services. The product type explored in this study involves different coating systems utilized by facility managers for exterior coating. Warranty services are measured using two parameters of warranty type and warranty duration. Specifically, this study evaluates the impact and correlation of warranty duration on customer satisfaction for different product type (acrylic and non-acrylic) and different warranty types (material and labor, joint and several, and material). The findings suggest a moderately positive correlation between warranty duration and customer satisfaction for all coating products combined and only for acrylic coating types. Material warranty was observed to have a positive correlation between warranty duration and customer satisfaction. In addition, non-acrylic products were observed to have 25% higher levels of customer satisfaction in comparison with acrylic products.
The United States Department of Labor reported that forty-four percent (44%) of the current US employed population will be above 65 by 2028, making workforce studies a key driver in leading construction business models. Multiple studies indicate a similar trend for the US construction industry. More than half of the construction companies expect to grow in the next year while also facing an unprecedented workforce shortage challenge. Local and regional factors play a significant role in workforce demographics in the diverse construction industry. This study conducted an in-depth investigation in the southeast region of the US on the current state of workforce demographics for field and office personnel. The study compares the general contractors (GCs) with specialty contractors/trade partners (Spl. Cs) from the commercial and residential sectors. The companies (representing over 5,000 employees) in the southeast region of the US were surveyed to measure the perception of workforce shortage and age distribution to evaluate the rate of retirement, gender distribution, and COVID-19 impact on the workforce. The data collected was also assessed to evaluate field and office personnel differences. The study findings were further validated by subject matter experts (SME’s) from the industry. The study findings indicated that thirty-eight percent (38%) of the surveyed GC workforce are expected to retire in the next twenty (20) years compared to twenty-seven percent (27%) of the specialty contractors. The study will benefit the companies to gauge the urgency of strategies to attract and retain future talent.
Primary goal of private real estate investment projects (REIPs) is to make profit. Therefore, REIP profitability is a critical performance indicator, which needs to be studied extensively. This study identifies and compares the determinants of profit in REIPs in the academic literature and the industry. In the first step, 191 profitability factors are identified and categorized by an in-depth review of the literature over the period of 2000-2019 in the selected databases and journals on construction and real estate, finance and economics. In the second step, a final set of 66 factors from the literature are constructed based on the frequency analysis and using the normative refinement technique. In the last step, face to face interviews are conducted with 15 senior managers working in the Turkish real estate and construction sector to validate the factors identified with the comprehensive literature review. As a result, 96 REIPs profit factors were obtained from the industry. The comparative analysis of the literature review and expert opinions shows that beside the prevalent similarities, experts focus more on design related factors, records and experiences of the past projects, value engineering, testing and commissioning and the work environment. The benefits of this study are twofold: (i) helping professionals to understand the factors required to control profitability in REIPs, (ii) providing an extensive list of profitability factors for future researchers.

Keywords: construction, performance, profit, real estate investment projects (REIPs), success
In recent years, construction companies have had million-dollar losses due to poor project management performance on projects. The Best Value Approach (BVA) is one of the only documented systems to show an increase in the performance of project management. It has been used on over 2000 projects with a 98% customers satisfaction to cut costs, decrease time, reduce effort, and improve quality on projects. The BVA system is the most licensed technology at Arizona State University with 65 licenses. The issue with the BVA is that professionals have struggled to implement and sustain the system in their own organizations. Research was conducted at SKEMA Business School as part of a Doctor of Business Administration (DBA) to resolve the sustainability issue. The research included a complete literature review of the BVA and 32 other buyer/supplier systems along with a practitioner’s survey (107 participants) and 10 test projects from a large organization that has been utilizing the BVA for over three years. The result of the study is 11 unique BVA characteristics, 6 identified issues by practitioners, and 15 modifications to improve the sustainability of the BVA. The research provides a foundational framework for how organizations can implement and sustain the BVA that has been tested and used with a large organization.
269. Data augmentation for deep learning-based detection of pump anomalous conditions

Seyed Mostafa Hallaji
Monash University, Melbourne, Australia

Yihai Fang
Monash University, Melbourne, Australia

Brandon K Winfrey
Monash University, Melbourne, Australia

Adopting effective asset maintenance approaches is critical to enhancing the longevity and cost-effectiveness of assets in civil infrastructure. Pumps are a crucial asset in many civil infrastructures such as the wastewater treatment plants. Current maintenance strategies fail to identify and respond to pump anomalies effectively. Data-driven predictive maintenance (PdM) is an emerging asset maintenance method that diagnoses asset conditions proactively. The current PdM of pumping assets still requires extensive expert knowledge for finding robust feature extraction methods before applying machine learning methods. This is a significant barrier to the automation and robustness of the PdM of pumps. Deep learning-based algorithms offer the potential to address these issues by capturing shifts in various features in monitoring data and performing incremental learning of features without human interventions. To train an analytical model for accurate condition assessment, these methods require a great deal of training data, which is not often available due to time and cost limitations. This research aims to address the scarcity of training data by proposing a novel data augmentation method. The proposed approach consists of a signal-to-image data conversion method and multiple image augmentation methods. The LeNet-5 architecture was employed to produce the CNN model, and its performance, including training and validation accuracy, was evaluated using a public data set. It was shown that the proposed augmentation method significantly enhances the validation accuracy and model generalisability.
The construction industry adopted a multi-project strategy to use a shared pool of resources to maximize project delivery productivity for obvious economic reasons. Multiple project managers have since been constrained to devise and employ damages mechanisms to avoid the challenges of this strategy using the traditional methods that cause high financial losses, delays in project completion and general poor project performance.

This paper aims to pinpoint the challenges faced in managing multiple projects in the construction industry and how remote monitoring systems can alleviate the difficulties faced by multi-project managers. The remote monitoring method utilized automated tools and programmes, enabling project managers to monitor projects in real-time remotely.

A literature review was conducted to identify the critical challenges affecting project managers and performance in multiple projects. Further, a case study was explored based on two sub-cases to compare traditional onsite monitoring and remote monitoring systems on project efficiency, resource optimization, and project outcome.

Findings from the study revealed that remote monitored multiple construction projects had better project performance on its goals and objectives compared to traditional monitored systems.
In 2018, the State of Arkansas faced a problem with renewing their purchasing card services. They had difficulty attracting competitors to their incumbent service provider. They needed an approach to increase competition and value. The purchasing director had been exposed to the Best Value Approach (BVA). The BVA simplified the purchasing process, shortened the delivery time, minimized bias decision making as well as attracted major vendors due to the simple requirements, minimized effort and gave credit for vendor expertise. The State tested the BVA on their purchasing card service. This paper captures the implementation of the BVA in the test case. The paper covers the entire test case. The test case shows the purchasing capabilities of the BVA. It also shows the reaction of competing vendors to a process that was not specified by the client. It also shows that the BVA can be used for commodities and services outside of the construction industry. The BVA is a supply chain solution and the paper proposes that the construction industry may have a supply chain problem.
A problem facing the construction industry is how to reduce cost and increase value. The construction industry has been plagued by non-performance and legal problems. To rectify the problem, the industry has attempted to increase the level of trust and collaboration. Different approaches including private public partnerships (PPP), alliance contracting, integrated project delivery (IPD), design-build (DB), construction management (CM) and Construction Management @Risk (CMAR) have been designed and implemented. The industry through the Project Management Body of Knowledge (PMBOK) has attempted to increase the level of trust, collaboration and participation of stakeholders to increase construction project performance. The Performance Based Research Group (PBSRG) proposed that increasing the level of trust, collaboration, the number of stakeholder participation and increased communications [meetings, information being passed, emails and technical details] will increase risk and lower performance. The City of Longmont had a requirement for janitorial services. Their budget was lower than their current janitorial expenses. The City agreed to utilize the BVA to attempt to cut cost, increase the level of service. This paper covers the implementation of the BVA test. It analyzes the ability of the BVA to identify and utilize expertise to lower cost, increase performance and minimize the need to utilize trust, collaboration and the passing of information.
522. A data-driven approach for monitoring performance of equipment in construction earthwork using IoT and cloud computing

Elham Mahamedi
Northumbria University, Newcastle upon Tyne, United Kingdom

Mohamad Kassem
Northumbria University, Newcastle upon Tyne, United Kingdom

Kay Rogage
Northumbria University, Newcastle upon Tyne, United Kingdom

Construction earthworks are equipment extensive and represent a significant proportion of the total cost of infrastructure projects. Monitoring the performance of earthwork equipment in a traditional manner is laborious, time consuming, costly and error prone. Advances in computing and digital technologies can provide new opportunities to develop and automate data-driven approaches for monitoring the performance of earthwork equipment, enabling efficiencies in both the use of equipment resources and their monitoring processes. This research aims to develop and demonstrate a data-driven approach for monitoring the performance of construction equipment such as trucks and excavators in typical earthmoving projects. The approach is enabled using IoT-based sensing devices and cloud computing technologies. Smartphone sensors such as GPS, gyroscope and accelerometer are used to generate data related to location and motion of equipment on the construction site. A ‘data pipeline’ is created to manage the IoT-generated data to the cloud storage enabling to handle large data sets from multiple equipment using Google Cloud Platform (GCP). Adopting deep learning and data analytics methods, the performance of the equipment is measured through performance indicators (e.g., utilisation ratio). Finally, the GCP visualisation dashboard is used to illustrate the analysed data in an intuitive format. The proposed data-driven approach was implemented in three pilot studies to demonstrate its practicality and effectiveness. The result showed that this approach can provide project managers with near real-time information about the equipment performance and enable them to make data-informed decisions in a timely manner.
Productivity has long been considered highly important in Singapore. In 2015, a national strategy considering skills, innovation and productivity as the basis for sustaining economic growth involving all sectors, was replaced with one seeking to move the economy from a “value-adding” to a “value-creating” one. In Singapore, construction productivity is mainly measured by: value added per person employed; and m2 of floor area completed per manday. By the economic measure, construction usually has the lowest annual growth rate among sectors, but the physical measure shows consistent improvement. This discrepancy has led to debate on the appropriate measure. The construction productivity programme in Singapore has included: promoting mechanisation, standardisation and prefabrication; training; procurement arrangements; regulatory requirements; and application of information and communication technology. Part of the findings of a study commissioned by two trade associations is presented. The aim was to derive findings which would help construction companies to improve productivity, and government to devise better policies and programmes. The study is based on interviews and focus group discussions with senior practitioners in Singapore. The questions included: level of construction productivity; how it is measured; firms’ policies on productivity; obstacles to, and enablers of, productivity measurement and improvement; the productivity development programme; and how productivity could be improved. The study found that construction firms could systematically develop their productivity-enhancing capabilities. It proposed indicators for firms to measure productivity, and use the results to set targets, and monitor their work.
This study explores new approaches regarding management of residential construction project delivery, computational systems present an innovative technology for the implementation of effective improvement strategies. These kinds of digital methods are able to manage data obtained from construction projects and data obtained from the knowledge base of professional experts (expert survey). The performance management of residential construction projects under the lean philosophy requires cooperative efforts, where the opinion of professional experts is absolutely paramount to examine multidisciplinary knowledge. Thus, new procedures and protocols based on digital methods can help decision makers to prioritise activities and avoid performance activities, which did not add any value to the project, and they can be minimised or completely eliminated. The aim of this study is to develop a new approach regarding a digital management system, which uses a fuzzy inference system for managing performance in residential construction project delivery in the metropolitan area of Santiago, Chile. A theorised application of the model reveals that the sample (50 construction projects) was classified into three main performance condition levels in terms of high, medium or low performance effects considering lean principles. This kind of results can be helpful to stakeholders and decision makers to take better decisions in the exact moment, which it should be taken.

Keywords: Digital tools, Lean construction, smart technologies, fuzzy logic, Chile
Among the activities of budgeting, quantification is the most manual one, slow and subjected to errors. Errors of quantification may compromise not only the budgeting but also the planning and control of the enterprise. The applications BIM most used by design and building companies (DBC) in Brazil do not provide, in the way in which they are many times used, the quantities needed and enough for budgeting. This paper has as its goal to show the limitations mentioned and propose use alternatives using BIM, aiming to overcome them, increasing the degree of quantification automation in the reality of DBC companies in Brazil. For that, a general conceptualization of budgeting and quantification was made. A case study illustrating usual BIM for design, quantifying the limitations pointed, and the improvements obtained with proposal to overcome them. Results of the work may contribute to widen the knowledge and continuation of researches on the subject.
ARCHITECTURAL, SPATIAL & INFRASTRUCTURE PLANNING, AND THE FOURTH INDUSTRIAL REVOLUTION
Innovations offered by digital technologies to architecture, civil engineering and construction can significantly alter professional practices. Among the alternatives, BIM (Building Information Modeling) can accelerate the design management through a process based on the interoperability, leading architects, and engineers to work collaboratively. Since 2007, there was a huge increase on research related to BIM possibilities. However, the rapid pace of research has not been accompanied by the necessary changes in the curriculum of architecture and civil engineering undergraduate courses. In Brazil, Decree No. 9,983 of 2019 established the basis for BIM’s National Strategy, starting initiatives to leverage actions to promote gains in productivity and competitiveness in the civil construction sector. So, it is urgent to analyze the impacts of BIM on professional practices in order to modernize undergraduate courses. In this sense, this paper presents the results of a research that considered the list of BIM Domain Model Uses as an alternative to establish a pathway for including BIM in architecture teaching process. A case study has been carried out analyzing an architecture undergraduate course at a Brazilian Faculty. Preliminary result allows to identify the main alternatives for including BIM in architecture teaching practices particularly considering the adoption of a collaborative teaching process. However, the mindsets and attitudes need to change in order to fully take advantage of BIM potentialities in architecture teaching.
Building permitting plays a significant role in a building’s life cycle because without a building permit a legal construction fails. However, digitalization in building permit authorities is rare in global context and issuing a building permit is still mostly a manual and time-consuming process. Moreover, a gentle instrument that authorities do not feel overwhelmed with is missing so far. Hence, a BIM-oriented and process-based web application prototype was developed in preliminary research. This research aims at validating and testing the BIM-oriented and process-based web application prototype by analysing the building permit processes in relation to digitalization and promotion of BIM usage by means of a specific case study. For this purpose, an empirical study using qualitative expert interviews in a building permit authority in South Tyrol (Italy) is conducted. The results shed light on the level of acceptance and plausibility of the web application prototype, as well as the ability of the prototype to assist building permit authorities within their review process.
The need to improve the environmental performance of Nigeria’s office buildings is due to new expectations, and the current challenges including energy shortage, increasing population, changing user’s needs, and climate change. While several Nigerian cities have been expanding, existing buildings constitute a significant portion of the building stock. Improving the performance of existing buildings including their environmental behaviour could be more cost-effective than reconstruction. The use of simulation packages to assess alternative retrofitting enhancement scenarios is a straightforward approach. However, in Nigeria it is often challenging to get appropriate information to facilitate this type of evaluation; many buildings were not built to the original specifications, and when available, records are often in a poor state due to the deterioration. Previous studies that aimed at enhancing buildings performance have not stated how the building information has been acquired. This paper, part of a larger study on data capturing techniques and enhancement strategies, investigates current practices and future possibilities of improvement measures and data capturing of existing buildings. Over 130 building professionals in Benin City participated in the study, which used a combination of web-based and hard copy questionnaires. The inter-relationship between energy efficiency, the environment, and building design is known by the participants. However, this knowledge, with high potential for meaningful retrofit to mitigate energy inefficiencies is not fully integrated into office buildings. The collected thoughts on the current practices are necessary for the development of a more economical and reliable methodology for data capturing and evaluation.
213. Stakeholders’ perception in early stages of a social housing retrofit living lab

**Joao Soliman-Junior**  
Innovative Design Lab, School of Art, Design and Architecture,  
University of Huddersfield, Huddersfield, United Kingdom

**Samira Awwal**  
Innovative Design Lab, School of Art, Design and Architecture,  
University of Huddersfield, Huddersfield, United Kingdom

**Morolake Ayo-Adejuyigbe**  
Innovative Design Lab, School of Art, Design and Architecture,  
University of Huddersfield, Huddersfield, United Kingdom

**Patricia Tzortzopoulos**  
Innovative Design Lab, School of Art, Design and Architecture,  
University of Huddersfield, Huddersfield, United Kingdom

**Mike Kagioglou**  
School of Engineering, Design and Built Environment, Western Sydney University, Penrith, Australia

Living Labs (LLs) are social and dynamic environments that allow the development of innovative solutions through intense collaboration and co-creation. LLs have been used to address complex problems across different domains. In the social housing (SH) context, retrofit initiatives usually consist of top-down approaches, with residents often playing a secondary role in such projects. The use of LLs in SH projects can improve retrofit outcomes through the development of adequate and fit for purpose solutions, co-created with all relevant stakeholders. Whereas existing research on LLs reports successful developments in several areas, research findings are often fragmented. They lack an in-depth discussion on the benefits and limitations of these initiatives, as well as how different stakeholders engage in the LL process. This paper aims to discuss stakeholders’ perceptions in the early stages of a SH retrofit LL in the UK. It reports preliminary findings of an ongoing LL located in West Yorkshire, focused on the retrofit of 8 dwellings aiming to improve their energy efficiency. For this purpose, we conducted a series of semi-structured interviews with different stakeholders involved in this LL (e.g. residents, retrofit coordinator, architects, among others). Research findings highlight the difficulties associated with the LL initiation, partially due to communication problems and lack of alignment, but also because of intrinsic behavioural, institutional and technical issues related to construction projects. Results suggest that collaboration is needed in LLs not only to co-create solutions but also to develop the LL itself.
Social Housing Retrofit offers positive social, financial and health improvements for low-income populations. However, the stakeholders in such projects might have conflicting needs and interests, thus hampering the retrofitting process. Living labs can play a vital role in supporting mediation amongst stakeholders and thus help alleviate such challenges. Living Labs (LLs) are user-centred initiatives for the development of innovative solutions in real-life contexts through a collaborative process. User involvement is vital in the LLs’ innovation process. This paper describes the setup of a Social Housing Retrofit LL from a methodological perspective. Existing literature reporting LLs often lack clarity on its description of the LLs underlying methodological approach. The main contribution of the paper is to depict living lab as a method based on the social housing retrofit context. The proposed solution i.e., the LL methodological approach, is described at a detailed level, including its main activities and expected outcomes. The approach can bring together residents and other stakeholders, leveraging knowledge sharing, collaboration, and co-creation through their involvement in the retrofit process. The solution is evaluated in contrast to existing literature, and it should be implemented in the future throughout the development of an ongoing research project U-VITAL.
Managing the design of complex engineering systems requires an organisational structure and an information system to support collaboration among all stakeholders. Technological developments in information management have the potential to facilitate interactions across organisational and physical boundaries, even more during the Covid-19 pandemic, in which remote work has been encouraged. Visual Management (VM) is an information management strategy, as well as a means for communication between individuals, supporting collaborative work. However, there is a lack of effective understanding of how digital VM can support infrastructure engineering design. The adoption of digital collaborative VM in the context addressed is new, under rapid evolution, and there is limited understanding of how the users embrace VM while interacting with it. The aim of the paper is to explore the adoption of VM, focusing on digital whiteboards, to support collaborative practices in design processes, considering the human-technology interactions and the users’ cognitive processes. The ongoing investigation is carried out in collaboration with an infrastructure design and consultancy company, and follows the action research approach. The VM effectiveness was investigated by analysing the whiteboards applicability to diverse functions and comparing digital and manual implementations. Initial findings include understanding digital whiteboards as a means for collaboration among individuals with different perceptions to establish a common point of view, as it allows the information to be transferred across time and space, identifies abnormalities, and supports problem-solving. By creating a common ground, it has the potential to support complex and emergent interactions in the collaborative space.
The disparity in greenspace quality between low and high SES settings: a case study in Victoria

Ali Ghanem  
RMIT University, Melbourne, Australia

Ruwini Edirisinghe  
RMIT University, Melbourne, Australia

The presence of greenspace, its profound impact and association on physical and mental health, biodiversity, and aesthetical pleasure has been delineated abundantly. Contrarily, there is a concerning disparity in the accessibility and proximity between affluent and disadvantaged areas in urbanised jurisdictions. Previous studies have prioritised distribution and proximity attributes when assessing the inequitable greenspace. However, the assessment towards the quality of greenspaces and its correlation to low and high SES settings remains deficient. This paper endeavours to fill this gap through a case study in Melbourne, Australia using a quantitative method to derive findings and a policy analysis to generate recommendations. The disparity in quality of urban greenspaces between the varying social classes were assessed to understand the extent of inequality. Socioeconomic data from deprivation indexes were used to systematically define the low and high SES settings. The analysis followed a Geographical Information System observation of greenspaces according to a scoring criterion contingent on safety/security, environmental elements, accessibility, maintenance/cleanliness, facilities/amenities, and aesthetic facets. Means and standard deviations were then synthesised to produce a Cohen effect score highlighting disparities in each facet between the two SES groups. Findings affirmed a disparity between high and low SES settings, with effect sizes resulting a ‘medium’ difference. Results contribute to existing strands of literature surrounding inequitable greenspace paradigms. Ultimately, findings serve invaluable evidence to planners and policy makers on redirecting the emphasis in the existing ‘Plan Melbourne’ policy, and any foreseeable policies and strategies to facilitate intervention in those underprivileged settings.
Medium density housing (MDH) typologies are not widely used in Aotearoa New Zealand compared with other countries. With current pressures to build housing in the places people want to live, interest in these forms of housing has surged. Government regulators and housing agencies, as well as many private developers, understand that MDH can help use land and infrastructures more efficiently and create liveable neighbourhoods. However, there are still strong preferences amongst housing consumers for standalone dwellings. In an increasingly diverse society, little seems to have changed in the forms on MDH provided to the market by housing providers. The study reported in this paper interrogates the needs and preferences of people who have experience of living in MDH as well as those who may be considering it. Interview respondents were selected around four demographic dimensions; gender, ethnicity, whether they are property owners or renters and their prior experience of living in MDH. The interviewees were invited to provide their preferences around eight different MDH characteristics, first in unconstrained conditions and then again when constrained to a budget. The findings shed light on the most important MDH characteristics across the diverse respondent group as well as areas where they differ. The findings will be of interest to other housing researchers and housing providers.
306. Construction ergonomics in robotics and human-robot teams in the AEC domain: a review

Adetayo Onososen
University of Johannesburg, Johannesburg, South Africa

Innocent Musonda
University of Johannesburg, Johannesburg, South Africa

Over the last decade, potential and prospects for using Robotics for various construction activities have increased, particularly for dangerous work areas such as roof construction, construction in hazardous environments, and improving productivity while shielding construction workers from strenuous work and accidents. As there have been concerns about human factors in collaborating robotics with humans on construction worksites, ergonomics in human-robot teams’ research is critical to enhancing the advantages and adoption of collaborative robots in improving the productivity of construction workers and the competitiveness of construction organisations. Furthermore, as research on human-robot collaboration is a developing area, the dearth of research studies necessitates the urgent need to understand the current situation in the area insightful for developing theory and guiding subsequent design in robotics and adoption for the AEC domain. This study reviews the emerging trends in human-robot teams and ergonomics in robotics, focusing on addressing the grey areas in constructing human-robot teams bodies of knowledge. A systematic review of publications from similar industries with extensive studies on human-robot teams and factors applicable to the built environment were identified. The study summarises articles that have emerged over the last decade and highlights the emerging nature of robotics collaboration, ergonomic problems and the interplay between robotics design and construction robotics ergonomics. Its outcome is beneficial to AEC research and practice in building knowledge in construction human-robot collaboration, guiding practice and design in robotics by focusing on critical ergonomic issues.

Keywords: Collaborative robots, Construction Ergonomics, Human-Robot Collaboration, Cobots, Human-Robot Teams, Robotics
Sustainability demands have changed the building design nature gaining complexity due to the increased diversity of requirements, activities, agents and tools. Building Information Modeling (BIM) has a potential to contribute to sustainability enabling the building integrated design, performance simulations, life cycle assessment and information use throughout the building life cycle. The aim of this paper is to investigate the sources of challenges in the relation between architectural and engineering (AE) design firms and clients (developers or private individuals) for promoting sustainability in the building design. Also, it is investigated if BIM has been implemented by the firms and how it relates to management and sustainability. The adopted research method is qualitative and participatory based on focus group. Two groups were interviewed: eight AE design firms and six developers and/or construction companies. Analysing the research findings, the sources of challenges that could be pointed is the lack of definition and communication about the stakeholders’ sustainability approach; the lack of a more detailed design scope and required qualifications by the clients, but also the lack of business management and firm’s performance evaluation processes by designers; the traditional project delivery systems, traditional work relationships, tools and processes that do not support the collaboration needs. In addition, AE design firm’ organization affects the client relationship and design quality including the consideration of sustainability issues in the design solutions. The sources are found in the AE design firm’s processes of strategy planning, business and marketing, design, people and knowledge management.
Innovating liveable and affordable higher density housing through design and planning: the case of Bennett Street, WA

Francesco Mancini
Curtin University, Perth, Australia
SBEnrc, Perth, Australia

Tanja Glusac
Curtin University, Perth, Australia
SBEnrc, Perth, Australia

Francesca Perugia
Curtin University, Perth, Australia

Chris Smith
Foundation Housing, Perth, Australia

Innovating liveability and affordability through medium and higher density housing and precinct developments is critical in ensuring the sustainable quality of living while maximising returns on investment for all the stakeholders involved, including buyers and developers. In this context, the liveability framework focused on housing as an integrative good (Rosenfield 2015), is seen as a critical tool supporting a holistic approach to decision making and investment in housing sustainably enabling the co-creation of value.

This paper discusses the findings of the case study undertaken at 67 Bennett Street, Perth, Western Australia, as part of the SBEnrc research project on developing a liveability framework for social and affordable medium to high-density housing.

The three key areas investigated are:
1. an understanding of government’s role in driving industry structure;
2. built form, urban design, and the creation of social and economic value; and
3. innovative urban forms via liveable design outcomes responding to the whole of life community needs.

Twelve interviews with key stakeholders from the housing industry and government were conducted in 2021, to inform the definition of a liveability framework for social and affordable medium to high-density housing against five key components:
1. Liveability – place-based and community-focused,
2. Accessibility – person-centred and community-focused,
3. Value equation – cost-benefit,
4. Regulatory and policy environment and
5. Adoption and overcoming barriers.

An analysis of the precinct, including the planning scheme and building type, was then performed against the components of the liveability framework to holistically assess the intervention as an integrated set of decisions.
483. Ground-level documentation of heat stress exposure and response strategies in informal settlements in Tshwane, South Africa

Jan Hugo,
University of Pretoria, Pretoria, South Africa

Paul Sonnendecker
University of Pretoria, Pretoria, South Africa

The adverse impacts of climate change coupled with the rapid informal urbanization in the Southern African region are leading to the increased vulnerability of an already sensitive population group. Resultantly these urban regions are noted as highly vulnerable to urban heat island effects and heatwaves due to exogenous and endogenous factors. While the dynamic interplay between the built environment, climate, and response strategies are known, this paper aims to highlight the lived experience of informal settlement residents. It, therefore, presents work from the Public health and Architecture nexus project undertaken in an informal settlement, Melusi in Tshwane South Africa. It is a multi-disciplinary project focusing on improving the local resilience to current and future climate change associated heat stress. Following a mixed method approach, a semi-structured observational analysis of the spatial layout and material articulation of selected dwellings along with the continuous monitoring of their indoor environments were undertaken. The paper presents the preliminary results in terms of the dwelling characteristics, as spatial and material tactics, and heat stress exposure documented in these informal structures. Currently, there are little empirical data on the heat stress residents living in informal settlements in Southern Africa are experiencing. This article provides the first preliminary findings and argues for alternative response strategies.
Life Cycle Costing (LCC) is a cost estimating approach to project and asset planning and delivery that considers all the direct and indirect costs incurred over the life cycle of an asset. This approach can evolve to consider Whole Life Cost (WLC) that introduces externalities and benefits into the calculations of the life cycle cost of an asset. This approach has the potential to demonstrate the financial impacts, both positive and negative, of a project on its environment, in other words to show its complete value. Despite its potential, the approach is still perceived as complex due to the fact that, among other things, access to data can be difficult and there is no standardized methodology to support the approach.

Building Information Modeling (BIM) presents an opportunity to address these issues. These approaches are complementary. Their synergies are based on decision making, project understanding and life cycle thinking. BIM provides LCC/WLC with better data management, improved calculation accuracy and visualization of project impacts. In return, LCC/WLC improves project understanding, decision making and reinforces life cycle thinking. The paper aims to study the potential synergies between BIM and LCC/WLC using a systematic literature review. From the identification of these synergies, a theoretical framework for the association of the two approaches is proposed for a better understanding of the opportunities that this combination can offer for future studies.
Better’ is not currently measured with any great authenticity in the ‘Build Back Better’ (BBB) framework. This gap significantly limits the effectiveness of humanitarian aided post-disaster recovery. As natural disasters increase in both frequency and severity the number of displaced people continues to rise. This has caused recovery following an unexpected event to be at the forefront of international aid. Yet identifying the indicators (or the components of an indicator) to effectively measure success beyond output-based deliverables remains elusive. This is evident in several well-known cases where a gap between the intent and the outcome has resulted in a negative impact.

This paper focuses specifically on the BBB framework to advance the currently prescribed industry standard and improving existing practices. By identifying indicators of success, a more effective and sustainable approach to aid assistance can be expected, reducing negative outcomes and positively impacting the lives of millions of the most vulnerable.

This can be accomplished by conducting a thematic analysis on 40 end-of-deployment reports that have been provided for this study by a leading INGO. In these documents the delegates comment on the progress of their deployment in their own words. These reports cover Europe, Middle East, Africa, Asia and the Pacific engaging with United Nations, National Disaster Management Offices (NDMO) and governmental offices. These reports all consider BBB as a primary directive and therefore offer key insights and themes from practitioners.
Struggling to cope with the pandemic, people are seeking for a more convenient and short-distance community lifestyle. The fourth industrial revolution has also given rise to more convenient transportation and information-based lifestyles. Around railway stations, the traditional circular planning method based on 5-10-15 min walking distance forms the centralized urban structure. When focus on the in-between space of multiple stations, sometimes there is still a vacuum of space that difficult to access by walking. Taking material transportation infrastructure (railway and connecting traffic modes such as buses and bicycles) as catalyst, this study explores the networked coordination of immaterial infrastructure (space, function, place, urban structure, etc.). The station area is redefined by different speeds of various connecting traffic modes, which improves the radiation and integration capacity of stations. Meanwhile, the multiplying of multiple isochrones is applied as another criteria for accessibility and land value, guiding the evolution of multi-centralized urban structure. It contributes to a more convenient community lifestyle as an urban design pandemic response. Furthermore, a definition method and quantitative analysis of 3D Station Realm is proposed relying on Urban Network Analysis (UNA), with practical exploration of Feixi Road Station urban design taken as an example based on the idea.
543. An architectural design process for housing in South Africa

Francine van Tonder
Tshwane University of Technology, Pretoria, South Africa

The government provided low-cost housing since 1994 in South Africa have been efficient in number of units, but have proven ineffective to address the housing problem. It is a premise of this paper that this is in part due to the limited architectural design process employed for the unit design, resulting in low-cost housing unable to address the housing problem. For this paper, an architectural design process for a ‘matchbox’ housing unit is presented. With a proposed redesign criterion, listed under two categories namely ‘existing design generators’ and ‘emerging design generators’. The research findings indicate that there are possible alternatives to the ‘matchbox’ house, and that these alternatives can be achieved while remaining within the cost and size of the units currently provided. Furthermore, the research findings indicate that a neighbourhood of these redesigned units could potentially host a higher population density as well as a greater diversity in use and social inclusion. The ‘matchbox’ house has been redesigned many times over the years. This paper is significant as it presents the finding of a redesigned ‘matchbox’ house, guided by an architectural design process not yet published. Thereby, this paper contributes to the body of existing academic research available on low-cost housing in South Africa.
Wayfinding difficulties are an established problem in health care facilities, which are complex built-up environments with occupants are often under stress. Wayfinding as a cognitive process has an established linked with building circulation. Building circulation/layout typologies are cognitive architectural descriptions of building circulation and how people interpret a buildings’ layout. Research into the wayfinding performance of the different circulation typologies remains limited in developing countries like Nigeria. This study seeks to provide a user centred insight to designing functional building layouts for wayfinding. An analysis of layout typologies using a framework for assessing wayfinding systems (subjective) was conducted in comparison with a visual analysis of the buildings’ wayfinding design (objective). Chosen circulation typologies for assessment are ‘Grid’ and ‘Linear’, the most prominent typologies in the Northwest Nigeria, the study location. Results reveal higher wayfinding performance for the linear typology in both analyses. Results also revealed disparity between the objective and subjective analyses and a high deficiency in navigational aids and coded signage systems with a heavy reliance on social interaction. This combined with the low literacy level of the study location results in a dependency on elements of building layout; entrances/exits, lines of sight, and elements of social practices; social interaction for wayfinding, posing a potential threat due to the Covid19 pandemic and increasing the need for improved functional layout design for wayfinding in health care facilities. Further research is needed to investigate the spatial properties of other layout typologies for the optimization of wayfinding.
The design of public housing is based on the crude assumption of the user’s specifications. This results in the initiation of user based transformations at a very early stage of occupancy to cater for the user’s needs. Users instigate changes to different components of the houses to suit their needs which in turn increases their satisfaction levels and directly increases the occupancy and life span of the houses. To ascertain this, a case study was done at the Malali Federal Housing Estate in Kaduna state which was constructed in 1976 for the Festival for Arts and Culture (FESTAC) hosted in 1977. Questionnaires were administered to 26 units of 2-bedroom semi-detached houses which covered demographics, housing components and space satisfaction levels. Results showed that the users catered for their needs by addition of other spaces like toilets and bedrooms with 81% and 73% respectively. This was achieved using different methods like expansion (58%) of the whole building or conversion (50%) of other spaces to the desired function or modifying (50%) the building components due to trending technological advancements. Most houses underwent either of the processes or all. Thereby, this paper suggests that the implementation of space flexibility strategies at the design and construction stage of public residential building to allow the users different choices before occupation and the ability to easily adjust the houses to their needs through the occupancy. This increases their satisfaction levels, the performance and life-span of the houses.
China has a long history of urban construction and many historic districts. However, with the advancement of large-scale urbanization, these historic districts have suffered varying degrees of destruction. In recent years, the government has gradually attached great importance to protecting and revitalizing historic districts. However, the current protection and revitalization of urban historic districts mainly focus on the morphological integrity of districts and the originality of buildings. Therefore, we need to examine the whole problem from a relatively macroscopic and relatively micro perspective for this proposition. From a macro point of view, there is a lack of planning and analysis of urban development planning on the revitalization direction and positioning of historic districts; From a micro perspective, there is a lack of analysis of the impact of human behavior activities on the vitality of historic districts. Therefore, this research proposes that the vitality revitalization of historic districts should start from three aspects: urban development planning, human behavior activities, and the primary conditions of the districts. Furthermore, it also puts forward the strategies and methods of vitality revitalization of historic districts by reviewing and sorting out representative research at home and abroad. The research provides systematic strategies and methodological summaries for the vitality revitalization of historic districts and provides theoretical support for the revitalization design of historic districts.
Agricultural land loss is a serious issue that Australia faces along with many other countries. A myriad of research studies discussed the repercussions and reasons for such land loss including urban sprawl as the main factor. However, there is a knowledge gap in understanding the impact of dwelling type on farming land reduction. Also, there is an application gap particularly in local context. The objective of this paper is to fill these research and practice gaps through a case study using mixed methodology approach. Quantitative analysis of housing types, their growth and agricultural land area taken up by those different housing types over an 18 years’ period was conducted. Thematic analysis of policies, strategies, schemes, and codes relevant to the case study enabled a better understanding of practice gaps. The findings revealed a significant loss of agricultural land. Separate housing was found to be the main culprit due to its larger number and area size, thus exhibiting the lack of effective guidelines in place to prevent their overdevelopment. Findings enabled to identify opportunities for better practice through government interventions and potential industry alterations. These approaches could contribute to reduce or end the loss of agricultural ready land within areas observing a population growth.
Having reliable and accurate cost estimates is essential for construction projects. It is even more critical for infrastructure projects considering they consume more time, cost, and public constraints. Therefore, developing a better cost model is required for infrastructure projects. An extensive literature review was carried out to identify various statistical modelling techniques and models developed using those techniques. The literature identified seven statistical modelling techniques. They are; regression analysis, Monte-Carlo simulation, support vector machine, case-based reasoning, reference class forecasting, artificial neural networks, and, fuzzy logic. These techniques were used in various cost models developed for construction projects. According to the analysis of the results, neural networks and support vector machine-based models show better performance in their cost estimation models. However, it is concluded that combining several techniques into a hybrid model, for example, neuro-fuzzy hybrid, can significantly increase the results. Therefore, the reliability and the accuracy of the current estimation process can be improved through these techniques. Finally, the identified techniques with better performances can be used to develop a cost estimation model for the preliminary stage as these techniques perform well even though the availability of information is less. The results of this research are limited to the identified seven techniques and the literature used in the review.
725. Multi-quantified based urban renovation strategies in TOD development, a case in Heifei, China

Yuan Zhu
Southeast University, Nanjing, China

Hao Wang
Southeast University, Nanjing, China

With the development of TOD in China, the TOD based urban planning is becoming one of the most important layer during the comprehensive urban design and development. On the one hand, it aims to increase the value of existing urban land effectively by increasing the flow of people, and, on the other, to integrate the scattered and inefficient land for future efficient usage, thus gradually formed the model of TOD oriented urban renewal and development. With the support of multi-dimensional data, this study takes Hefei feixi Station as an example to introduce the project optimization based on the 3D-station realm data analysis, calling for the new cognitive driving force leading to the future pattern of urban blocks, policy support, and urban morphology.
BUILDING DIGITAL TWINS
100. Building’s digital twin model shown as first-person and third-person views

Marja Liinasuo
VTT Technical Research Centre of Finland Ltd, Espoo, Finland

Timo Kuula
VTT Technical Research Centre of Finland Ltd, Espoo, Finland

Vladimir Goriachev
VTT Technical Research Centre of Finland Ltd, Tampere, Finland

Kaj Helin
VTT Technical Research Centre of Finland Ltd, Tampere, Finland

Matthias Aust
Fraunhofer Institute for Industrial Engineering IAO, Stuttgart, Germany

Construction industry is currently facing challenges, which should be met, because construction industry has declined in productivity. One means to amend the situation is related to data. There is a lot data needed in the construction industry. However, not all data is presently available efficiently for construction professionals. Information about the structure and features of the building to be built should be shared so that various professionals can use the so-called digital twin model of the building for his/her purposes. We have created a concept for delivering the building information model (BIM) that can be viewed from the first-person and third-person perspectives. We tested the first-person and third-person views of BIM with high-end eXtended Reality (XR) technology (Microsoft HoloLens 2) and a tablet. Briefly, according to our test results, AR seems to good for first-person immersive view, tablet suits for third-person view and novice users of the AR technology much more support in using the technology than the experienced ones. All test participants found the concept good and the technology with which to use it as promising.
Nestled in the historic district of the small Central Florida town of Bartow, the Old Polk County Courthouse (OPCC) served the citizens of Polk County from 1909 to 1987. Eventually replaced by a high-rise courthouse to accommodate population growth, the OPCC underwent major restorations between 1993 and 1996 and now serves as the Polk County History Center, which houses a historical museum and genealogical library. Due to its historical value within local and regional contexts, it was deemed important to archive the courthouse in a manner that can be utilized from a practical standpoint of preservation, operations, and maintenance and an academic standpoint for research of early 20th century buildings in the southeastern U.S. A research project has been done to use Historic Building Information Modeling (HBIM) technology to digitally preserve and reconstruct the OPCC building. The findings of this project can be implemented to help digitally document and recreate other historic structures. This paper presents the work flow and technologies that were utilized to capture data for developing HBIM models of the OPCC, including conventional field surveys, LiDAR scanning, photogrammetry, and 360-degree photography.
271. Review of driving forces for digital twin adoption in the construction industry

De-Graft Joe Opoku
Centre for Smart Modern Construction (c4SMC), School of Engineering, Design and Built Environment, Western Sydney University, Penrith Campus, Sydney, Australia

Srinath Perera
Centre for Smart Modern Construction (c4SMC), School of Engineering, Design and Built Environment, Western Sydney University, Penrith Campus, Sydney, Australia

Robert Osei-Kyei
Centre for Smart Modern Construction (c4SMC), School of Engineering, Design and Built Environment, Western Sydney University, Penrith Campus, Sydney, Australia

Maria Rashidi
Centre for Infrastructure Engineering (CIE), School of Engineering, Design and Built Environment, Western Sydney University, Penrith Campus, Sydney, Australia

The concept of digital twin (DT) has seen massive utilisation in digitally advanced industries. This has presented an opportunity to integrate the physical world to the digital world. Digitally advanced industries, including the manufacturing and automotive industries, have witnessed improvements in production because of the application of DT. These industries utilise accurate digital models in the form of DT to enhance the predictive maintenance of equipment. Other less digitally advanced industries, including the construction industry, have begun DT adoption. The construction industry has started DT applications in the various lifecycle stages of projects. However, little is known about the driving forces for the adoption of DT in the industry. In this paper, we aim to identify and rank the driving forces to enhance the adoption of DT in the construction industry. After a complete search of several databases, including Scopus, Web of Science and ScienceDirect, 58 academic publications about drivers for DT adoption in the construction industry were identified for the study. The review resulted in identifying 50 drivers, which were ranked accordingly. The findings from the research disclosed the top three drivers for DT adoption in the construction industry: real-time data visualisation, optimised construction process, and enhanced environmental monitoring. The identified driving forces serve as a guide to propel DT adoption in the construction industry. Furthermore, this study contributes to the body of knowledge about the drivers for DT adoption, which is essential for DT promotion in the construction industry.
Construction constraints are conditions or circumstances that impede the standard progress of production tasks in construction projects towards achieving specific production objectives. Construction constraints are highly dynamic and span different domains. Failing to manage constraints on time could result in out of sequence work and suboptimal productivity. As the construction sector embraces digital technologies, an emerging concept, Digital Twin, has been recognised as a potential solution to solve the endemic problems in construction process management. Digital Twin as a virtual model for cyber-physical bi-directional data-driven management and control of the physical counterpart has emerged over the past decade in the manufacturing industry. However, the implementation of Digital Twin in the construction sector is still in its infancy. Hence, there is an opportunity to adopt Digital Twin to enhance the current implementation of constraint management. This paper presents a literature review of constraint management-related studies, aiming to determine the potential constituents of the Digital Twin framework from a dual technological/lean-based perspective. A total of 55 papers published so far were selected using Scopus. The result shows the potential constituents can include: (1) Information technologies, (2) Swarm Intelligence and Genetic Algorithm, (3) Semantic Web, and (4) Lean-based methods. Our study provides valuable insight concerning which technologies could be used to support the development of DT in the construction sector. These findings can serve as a guideline for future researchers in the construction industry to develop their own DT.
Python is an open, general-purpose programming language that is used in many tools, libraries and APIs for Building Performance Simulations (BPS). Advantages of Python in the context of digital twins are the simple and powerful capabilities to generate input files, automate processes, import libraries in many languages and a large number of useful modules.

However, in order to use BPS tools and libraries with real time data, a comprehensive data model is required in which all necessary data such as geometry, system engineering, databases, sensors, or simulation parameters for the different BPS are defined. Python in combination with SIMULTAN as a suitable open BIM data model allows an effective use of these tools and libraries to perform and automate analyses.

This paper presents a Python module that integrates the SIMULTAN model in Python and enables almost seamless integration with minor adaptations to existing tools or modules. The import is achieved using simple text-based templates for the data types and their mapping in the data model. The data model, the definition of the data types and the use of this module is demonstrated by calculating the trend of the CO2 concentration in a zone of a digital twin using real time data.
During construction, pavement projects often suffer from a lack of progress certainty, which leads to cost and time overruns. The pavement construction progress should be monitored in a timely and accurate manner to provide prompt feedback and ensure project success. However, current pavement construction progress monitoring practices (e.g., data collection, processing and analysis) are manual, time-consuming, tedious, inconsistent, subjective and error-prone. The previous research study was limited to only incremental road construction progress measurement. This preliminary study proposes a novel sensor-based method to identify pavement layer changes during construction using a time series algorithm for the approach development of automated as-built measurement of road construction. In this study, data were collected from generating various road construction scenarios in a controlled environment by simulating layer changes using a ground vehicle equipped with a laser ToF (time-of-flight) distance ranging sensor. Subsequently, Long Short Term Memory (LSTM) was utilized on collected data for feature detection as ‘layer up’, ‘layer down’ and ‘layer not changed’ to classify road layer change classification. The experimental result demonstrates 84.91% as a promising overall average accuracy of road layer change classification on the control environment data, confirming the potential implementation suitability to detect pavement layers in real pavement construction projects. However, low-performance measures (e.g., low precision, recall and F1 score) of layer up and layer down suggest further improvement to enhance the robustness of the proposed model. This method can be extended to automate pavement construction progress monitoring by validating the proposed approach in a real case.
Scaffolding is a type of temporary structures on construction sites to provide access to work areas for various trades. Improper management of the scaffolding work can lead to budget overrun and schedule delays. Regardless of the project sizes, scaffolding management requires a clear understanding of the onsite activities and transparent communications among the project teams. This results in the demand of creating situational awareness of onsite work through digital innovations. The emerging Internet-of-things (IoT) applications in the construction industry have provided opportunities for such transition, enabling the scaffolding operations to become data-driven with predictive analytics. In this research, an IoT-based application system has been developed for field scaffolding data acquisition and analytics for a Canadian scaffolding contractor. The IoT system allows the scaffolding contractor to digitize their workflow and utilize collected data for analytical purposes. Similar methodologies can be applied to other similar construction companies to improve efficiency and productivity through digital innovations.
Prefabrication has brought significant advantages to the construction by increasing productivity and reducing safety risks. However, the management of prefabricated components storage and turnover lacks effective integration of information, as relevant information is stored in heterogeneous systems of various stakeholders. Building Information Modelling (BIM) and its underlying data schema, the Industrial Foundation Class (IFC), provide for information collaboration and sharing. In this paper, an automatic classification and coding system for prefabricated building based on BIM technology and random forest is developed to achieve the unique representation of components. The proposed approach starts with the extraction of attributes of components and details the process of attributes extraction using wall components as an example. The random forest model is then employed for IFC building components classification training and testing based on a comparison of different classifiers, which includes the selection of the datasets, the construction of classification and regression tree (CART) and the voting of the component classification results. The experiment results illustrate that the approach is able to automate the uniform and unique coding of each component based on Python, while also reducing the workload of designers. Finally, based on the IFC physical file, an extended implementation process for components encoding information is designed to achieve information integrity for prefabricated components descriptions.
Background

In Japan, wooden buildings and their components are measured and identified with great care at disassembly, repair, and relocation.

That requires a quick but accurate method of measurement by means of digital technology.

Such method has been commonly used, which however was not practically suitable to record and archive the detailed information of hidden internal structure, components, and in-between joints.

Purpose and Methodology

This study aims to develop a method to digitalize the information of internal structure and components, hidden in the existing wooden buildings.

This method is, as we call, “3D informatization,” now widely available thanks to the increasing use of digital technology in the field of building measurement and design.

Specifically, three technical elements will be used in combination: 3D modeling technique in parallel with demolition work, newly developed ID numbering method, and 3D scanning technique using special jigs.

In this study, given an example of a two-storey wooden building, we created a database, in which we can create an archive of the ID-tagged 3D-scanned components as well as internal structure.

Results

This study created a database of as many as 400 3D-scanned components within the time of one month and half for the cost of $3,500.

Thus, it is totally plausible to conclude that this system could be applied to the cases of general building demolition to save budget and time with high efficiency.
Multiple system integration in local government asset management – a New Zealand case study

John Jiang  
University of Auckland, Auckland, New Zealand

Theuns Henning  
University of Auckland, Auckland, New Zealand

Yang Zou  
University of Auckland, Auckland, New Zealand

Local government in New Zealand invests in numerous Asset Management Information Systems (AMIS) in order to support their infrastructure asset operations and decision-making. However, the silo nature of the organisational operations and proprietary constraints of AMIS have created an environment of dispersed information and systems with little or no regard to interoperability or data sharing. Adopting multiple standalone systems creates difficulties for accessing, analysing and maintaining the asset, thus compromising management efficiency and effectiveness. Consequently, there is a great desire to bring the various AMIS systems together using a Multiple System Integration (MSI) approach. This study intends to examine the MSI concept by exploring more open-sourced systems such as GIS, which is widely used in local government’s asset planning and management. In addition, being the key driver behind the technology advancement in the construction industry, BIM has created innovative applications and widened the research domains in areas such as BIM and GIS integration studies. However, the multiple system approach to further integrate the existing AMIS, is missing from both the current industry practices and academic studies. Using a case study of a BIM implementation project carried out by a local government, this research illustrates and validates the integration of BIM/GIS with the lifecycle planning specific AMIS. The novel MSI approach provides a paradigm as a solution to improve the siloed operation manner. The approach will also set the foundation for future studies in local government’s digital transformation and in the field of developing true asset Digital Twins.
The traditional stand-alone building industry is transforming into a digitally intelligent building system. Traditional building automation systems are limited to fulfilling set tasks and have only basic device control capabilities; as technologies evolve, new building automation requires more information integration possibilities (e.g., Building Information Modeling (BIM), Internet of Things (IoT), intelligent computing). In this paper, we provided a review of the different levels of data exchange in the building automation system and the methods of integration of BAS with multiple building phases.

In the first part, we review the data exchange of BAS in three levels according to the IEEE definition of interoperability and evaluate its advantages and challenges; We then analyze the current status of BIM-BAS integration and review the case applications of various integration methods one by one so as to provide a contextual review of data exchange based on the full building lifecycle. The paper is concluded by analyzing the limitations of current research which are systematically summarized. Future research directions are proposed in complex multi-service integration, linking of real-time data, and edge computing.
BUILDING STRONGER LEGAL FOUNDATIONS FOR OUR CONSTRUCTION FUTURE
Construction projects are characterised by supply chains with multiple contracts and significant transaction costs. An example of these costs is to be found in the management of project delays. The operationalisation and measurement of transaction costs, especially in the construction context, has hitherto proved difficult. The work reported here is concerned with defining and measuring the resources required for the management of contractual disputes relating to project delays. Its main argument is that concepts from Transaction cost economics (TCE) theory (bounded rationality, uncertainty, information asymmetry, and opportunistic behaviour) present serious problems for transaction efficiency. This is exemplified in forensic analysis of construction project delays. Data from twelve case studies are analysed, to reveal that up to 90% of time spent on delay analysis was concerned with searching for and validating information which could, ostensibly, be automatically and reliably captured using digital technologies. This research forms part of a wider study that considers the implications of the identified inefficiencies and makes a case for the exploitation of advances in information technology on the more efficient resolution (or even avoidance) of contractual disputes. It concludes that there is a prima facie case for this, and therefore for the reduction in the transaction costs that relate to the management of construction project delays.
Construction delay claims are a leading cause for disputes in the sector. There are two primary aspects to such disagreements: legal and factual. The focus of this paper is the latter. It identifies, evaluates and tests the factors that impact the analysis of evidence concerning construction delays. The research method is two-fold, first involving content analysis of twenty case studies, and then testing those results in a survey questionnaire designed to examine the impact and comprehensiveness of those factors. This method provides a more rigorous assessment than previous studies and therefore a more precise list of variables. It is concluded that the factors can be grouped into two categories: (i) materials and documents and (ii) matters of interpretation. Although both categories are important, the deficiencies in the former are most commonly exploited by the parties and/or analysts to generate conflicting results in terms of extension of time entitlements. Incorrect, incomplete, undisclosed and/or unagreed records and procedures are used to generate ambiguity and create opportunities to perpetuate claims and disagreement. The work presented here provides additional support to the proposition that opportunistic behaviour is at the core of factual delay disputes and further evidence that tailored contractual delay protocols such as delay analysis clauses can be part of a broader solution.
A lack of understanding of project risks and the use of unnecessarily complex contracts have been identified as weaknesses in construction procurement. Contract reviews are often rushed, and risks are not assessed and allowed for appropriately. This process can be improved using digital technology solutions. This research investigated the NZ commercial construction practitioners’ views about adopting computational tools to review construction contracts. A mixed-methods study using a survey questionnaire was undertaken and accompanied by descriptive statistical analysis. The sample consisted of 66 participants from different groups within NZ’s commercial construction industry. The study found a strong positive response towards digital technology adoption, and the overall perception is that there are benefits to using computational tools for contract review. Findings confirmed that these have not been widely adopted for contract review, mainly due to the lack of familiarity with existing solutions. Further research is recommended to investigate how a small portion of the population is currently using computational solutions. The benefits of manual contract reviews may also be explored to enhance software systems for easier adoption.
41. Seeking equitable resolution for COVID-19 associated delay claims—who should recover the loss and expenses?

Peter SP Wong
RMIT University, Melbourne, Australia

Sarah Holdsworth
RMIT University, Melbourne, Australia

In many countries, Standard Forms of Building Contracts do not consider construction-related delays as a qualifying event for any loss or expenses claim caused by a global pandemic and related lockdowns that result in the temporary pausing of economic activity. Recent claims associated with such delays lodged by construction contractors in Melbourne, Australia, a city that experienced the world’s most prolonged COVID lockdown in 2020-21, have resulted in disagreements between parties, given there is no prescribed process or set precedence. Understanding how to resolve mutually beneficial situations for all parties is essential given the long-term effects of COVID-19 on the industry and economy. This paper provides insight into the prevention and resolution of COVID-related loss and expenses disputes. This study explores the experiences of contract administrators during the recent COVID lockdowns in Melbourne, Australia, through sixteen semi-structured interviews. The impact of the lockdowns and their effects on the practices of contract administrators related to project delay claims are explored, including the triggers and resolution of disagreements, measures adopted to mitigate the consequences of the COVID-19 related delays, and potential amendments to contractual provisions to avoid similar future conflicts. The findings illustrate how contracting parties might collaborate to enable an equitable sharing of risks in future contracts.

Keywords: COVID lockdown, claims, equitable risk allocation
84. Using forensic reports to manage the probability of lawsuits being filed in relation to pitched roofs: the case of Madrid

Manuel J. Carretero-Ayuso
Musaat Foundation, Madrid, Spain
University of Alcalá (Department of Architecture), Alcalá de Henares, Spain

Daniel Antón
Nottingham Trent University (School of Architecture, Design and the Built Environment), Nottingham, United Kingdom
University of Seville (Department of Graphic Expression and Building Engineering, ETSIE), Seville, Spain

Enrique J. Fernández-Tapia
University of Alcalá (Department of Architecture), Alcalá de Henares, Spain

Mª Teresa Pinheiro-Alves
University of Évora (Department of Architecture, School of Arts), Évora, Portugal

Roofs are among the construction units in buildings with the highest number of deficiencies and problems. Given their direct and constant exposure to weather (temperature, wind, rain, snow…), even minor issues can lead to important pathology processes if not addressed early on. This research examines unresolved issues of pitched roofs in the capital of Spain which eventually led to the filing of lawsuits. Different types of deficiencies were detected (humidities, condensations, fissures…) and classified according to their recurrence. The thousands of pages of forensic reports presented to the courts were consulted and analysed to determine the probability/risk reoccurrence, based on a number of factors. Among them is the causal origin (according to the properties/characteristics of the materials or to the placement/application conditions) and the respective building typologies (single-family houses or multi-storey buildings). The results that were obtained were calculated through weighted risk matrices of the existing interrelations, before determining the levels of joint severity and the classification categories according to the final operational value.
With the advent of the BIM technology, related guidelines have been formulated by project owners, governments and professional bodies. As an information sharing platform, BIM is applied to various kinds of construction projects for better management and collaboration. Yet, the existing off-the-shelf BIM application software does not fully consider the potential legal liabilities among the collaborating parties. In view of the above, we conducted a review of the relevant literature and legal cases to examine issues including ownership, liability and information reliance, and duty to warn from the perspectives of collaboration and laws. Common procurement initiatives were discussed in relation to BIM application. Drawn from the review and comparison, key legal issues of concern in BIM applications and the way forward for tackling the issues were identified. In conclusion, a collaborative approach under the BIM environment will work better under a project federated committee. Further research on the operation of this committee is recommended in order to make its authorities and liabilities clear.
228. To be or not to be: why do transaction partners in construction industry avoid formulating agreements into contract documents?

Yuting Chen  
London South Bank University, London, United Kingdom

Yanga Wu  
University College London, London, United Kingdom

Sara Hajikazemi  
London South Bank University, London, United Kingdom

Hongjiang Yao  
Tianjin University, Tianjin, China

Obas John Ebohon  
London South Bank University, London, United Kingdom

Designing the construction contracts efficiently and effectively is vital for project success since contracts can not only motivate and regulate behaviors in projects, but also plays a crucial part in managing interfirm relationship. In practice, however, transaction partners in construction industry sometimes avoid formulating all the agreements into contract documents, which is contradictory to common logic. The aim of this research is to prove the existence of such phenomenon and to investigate the reasons for why it happens. Both questionnaire and semi-structured interviews were conducted in construction industry in China for data collection since China provides fertile context to explore the research questions. The questionnaire was used to prove the existence of such phenomenon and the interviews were used to explore the logic behind. The results show that in nearly 50% of the construction projects in China, the phenomenon of the transaction partners deliberately avoid formulating some agreements into contract documents exist. Given explanations as for why this happens include: 1) showing trust towards the other partner, 2) reducing risks in transaction, 3) increasing the possibility of further collaboration in the future, 4) bypassing the contract check in their own legal departments, and 5) preventing other competitor companies in the market from stealing technology through the contract documents. A comprehensive understanding for designing contract documents is generated in this research, which will not only help project managers for project success but also provides insights into drafting contract terms.
The application of Smart Contract (SC) is disrupting industries, offering a legal tool to reshape contractual relationships. Due to its unique potential for automatic execution of predefined processes, transparency, and immutability within a Blockchain environment, active attention has been directed toward the subject matter. Thus, causing a steady growth in the number of related literature by researchers and practitioners within the AEC domain. However, applying SC in the construction industry context is still in its infancy, especially from the infrastructure procurement perspective. By adopting a mixed-method of bibliometric analysis and systematic literature review, this research reviews the longitudinal and current developments of SC applications regarding keyword burst, journals distributions, chronological trend, and contributions networks between authors, institutions, and countries. Based on the evaluation of filtered publications, this research also identifies and articulates the SC and procurement processes separately and how to integrate SC in procurement contract design. Furthermore, an integrated conceptual framework is proposed to highlight the future procurement needs for better SC adoption in infrastructure procurement. The systematical analysis is intended to narrow the gap between insufficient SC knowledge domain and mature infrastructure procurement practices and provide a substantial guide to facilitate project collaboration and delivery, thereby securing a solid business value growth.
319. An investigation of difficulties in information management for delay and disruption claims

Babar Ali
The University of Melbourne, Melbourne, Australia

Ajibade Aibinu
The University of Melbourne, Melbourne, Australia

Vidal Paton-Cole
The University of Melbourne, Melbourne, Australia

Information is of vital importance for delay and disruption claims in construction projects. Without the required and complete information, it becomes challenging to produce supporting evidences and facts for the damages incurred due to various delay and disruption events. However, there are several difficulties when it comes to managing the information needed for these claims, which create complexities in the substantiation and resolution of these claims. Therefore, this research explores difficulties that causes hinderance to the availability of information required for delay and disruption claims. To do this, concept of information management and its processes is adopted for delay and disruption claims. Based on systematic review of literature on delay and disruption claims using well-recognized databases (SCOPUS and Web of Sciences) and following PRISMA guidelines, 26 different difficulties are identified in the collection, storage, retrieval and usage of information required for delay and disruption claims. Recommendations are given to overcome these difficulties including the use of available modern digital technologies. This will pave way to obtain complete and accurate contemporaneous information on delays and disruptions in construction projects. Moreover, effective information management of delay and disruption claims will also help in avoiding and resolving disputes on these claims among contracting parties.
Considering the significant role of the construction industry in the global economy, its continuous adoption of new technological advances is both desirable and inevitable. These advances include Building Information Modelling (BIM) and Artificial Intelligence (AI)/Machine Learning (ML). However, not all sections of the industry currently embrace these developments. Forensic Delay Analysis (FDA) is an activity of specialists in extracting and presenting evidence contractual claims disputes that relate to project delays. Such delays are frequent and expensive, but the FDA process has benefitted little from these new technologies. The paper reports the initial work of a collaborative PhD project funded under the Intensive Industrial Innovation Programme of the European Regional Development Fund. The project explores the integration of BIM and AI/ML technologies within the FDA process. The potential of emerging technologies in different parts of the FDA process is first considered, followed by a systematic literature review (SLR) of published work that might support, refute, or exemplify such contributions. The findings show that BIM and AI/ML offer promising solutions to the current challenges of FDA and opportunities for enhancing the effectiveness of dispute resolution, but further work is needed to test the proposed improvements on real-world project workflows and to collect expert feedback to assess their effectiveness.
Digitisation of construction processes is one of the significant disrupters changing the landscape of the modern construction industry. The construction industry's future is increasingly dependent on generating and processing vast amounts of data to enable informed and timely decisions. The emerging digital technologies could yield tangible benefits like accurate and timely reporting, complete process control, predictive and prescriptive solutions, and the explosion of valuable data. However, the hype around utilising innovative and futuristic technologies in the construction industry often overlooks the data security and privacy concerns related to their adoption and use in a project-based environment. Consequently, there is a need to identify the security challenges of implementing emerging technologies to ensure their safe and secure use and improve construction practitioners’ awareness of cybersecurity threats. The paper reviews significant cyberattack issues that need to be considered while implementing emerging digital technologies in the construction industry. Major cyberattacks in the construction sector include industrial espionage, digital theft and even destruction of critical digital resources causing enormous financial loss. It also outlines prospective countermeasures to mitigate such attacks and offers recommendations for proper management of cybersecurity issues to facilitate the adoption of these technologies. The recommended countermeasures include standards, frameworks and guidelines to develop a robust cybersecurity architecture; organisational focus on data security; process innovations; proper data access and control in a project environment; threat modelling; and cybersecurity training.
Negotiators are not always rational. Prior studies have found that negotiators tend to be overconfident about their ability to win and underestimate the possibility of negotiation failure. This biased judgment may lead to irrational evaluation and miss the chance to settle. It is argued that negotiators handle a negotiation respective to their perception of the risk of failing. The meaning of failure therefore may have a pivotal influence on the negotiation outcome and warrant deeper conceptual treatments. In this regard, this study aims to conceptualize construction dispute negotiators’ perception of negotiation failure. Applying the construal-level theory (CLT) and the concept of psychological distance (PD), a psychological distance of negotiation failure (PDNF) framework was developed. With data collected from construction negotiators in Hong Kong, the PDNF framework was statistically supported by the partial least squares structural equation modeling (PLS-SEM) results. Four types of psychological distance of negotiation failure were identified: temporal distance, social distance, uncertainty, and frequency. The empirical findings provide a psychological perspective of how negotiators perceive the potential failure during negotiation process. Management can adopt the PDNF framework to gauge negotiators’ perceptions of failure. Timely interventions, such as inviting third-party neutrals and internal reviews with new information collection, are suggested to offset negotiators’ biased judgment of the potential negotiation outcome.

Keywords: Construal-level theory; Construction dispute negotiation; Negotiation failure; Psychological distance.
CHALLENGES AND OPPORTUNITIES TO THE USE OF DATA IN CONSTRUCTION
Overheating in residential buildings during extreme heat events can cause wide-scale health risks, particularly for older people who are more vulnerable to heat exposure and spend most of their time indoors. With increasing outdoor temperatures and heatwaves frequency as well as the growth in the senior population in Canada, such health risks can be expected to become more common in the future. Most experimental works on indoor overheating analysis during heatwave periods have been based on field measurements. However, due to practical constraints, these field studies usually relied on small samples and/or limited geographic distributions. The growth in the use of connected thermostats has allowed for such studies to be conducted without the limitations of traditional data collection methods. This paper presents the analysis of connected thermostat data from more than 3,000 Canadian houses over a period of four years. The data was leveraged to assess the health outcomes of indoor overheating on the vulnerable occupants. The results showed that 12% of houses under study experienced at least one overheating event. Furthermore, the extreme indoor overheating events with potential health risks to the vulnerable occupants were more common amongst houses without a central air conditioning unit across the selected cities.
Varieties of Real-time Employee monitoring Technology (REMT) are becoming popular and have aroused significant interest in recent years from the construction sector, where the industry explores the use of advanced monitoring technologies to reduce unsafe work behaviours and improve productivity. However, studies identified some concerns about applying these monitoring technologies at construction sites. Consequently, REMT devices and applications have not been well-received for tracking frontline workers. Lack of understanding of REMT, monitoring data protection and privacy management strategy set a barrier for the monitoring technologies to implement in the construction industry. Privacy has become a critical issue for the future digital construction site. This study adopts the literature review and a questionnaire survey, examined the readiness, summarised effects of REMT applied at the New Zealand construction sites, identified the influence factors, and discovered the theories that will potentially explain the factors and address the potential impact. Communication Privacy Management theory (CPM), Equity Theory (ET) and Control Theory of Privacy (CTP) are reviewed, and a theoretical framework is built upon REMT adoption in the construction sector. In conclusion, future studies are recommended for the international construction entities to get ready to adopt the real-time monitoring tools.
Emerging technologies in the construction industry are generating an astounding amount of data, pointing to an optimistic digital future with data analytics. Despite the potential benefits, many big data projects fail to deliver value. Talent and skill shortages are significant challenges in the journey to become data-driven. Construction project managers (CPMs) play the lead role in creating innovative ways for successful project delivery. Therefore, this study seeks to understand the capabilities of a CPM that are important for developing a data-driven team in which the potential of data is highly valued and leveraged to enhance project efficiency.

Through a literature review, the opportunities and challenges of data usage in construction project teams were identified. Questionnaire surveys were distributed to collect information on the data awareness and usage in the project teams and how the CPMs evaluated their peers demonstrating data-oriented capabilities. The Mann–Whitney, Kruskal–Wallis non-parametric tests and Pearson correlations were used for data analytics. The top three CPMs capabilities which were strongly correlated to project team data usage are: (1) Ensure basic tasks to be completed proficiently; (2) Keep a problem-solving mind-set; and (3) Maintain a high ethical standard when capturing and using data.

This study supports CPMs and maps the skills and training required for the future-oriented CPMs as they respond to the digital challenge in the construction industry. Outputs of this research that develops future capability in the digital age will support the construction industry in a journey towards a safer, more productive and sustainable future.
The productivity and progress tracking systems are currently used in construction projects to acquire the site works data and converting to various digital reports. To date, capturing and transferring data processes are slow or inefficient because significant human errors occur in the process. Therefore, project managers can omit critical information, and no timely decision can be made related to delay and low productivity. This study encompasses designing a real-time project productivity tracking system to register data and manage delays related to an Electrical and Instrument (E&I) service in construction projects. Unified Modelling Language (UML) method is used, and the proposed model includes a combination of smart devices and real-time monitoring systems to optimise the current site reporting procedure and workflow of productivity managing. This solution will contribute to developing a real-time delay management system of E&I trade but may also be used by other businesses with similar needs.
Using smartwatches to understand the relationship between construction workers’ travelled distance and time spent on direct work

Cristina Toca Pérez  
Aarhus University, Aarhus, Denmark

Stephanie Salling  
Aarhus University, Aarhus, Denmark

Hasse Højgaard Neve  
PricewaterhouseCoopers, Aarhus, Denmark

Søren Wandahl  
Aarhus University, Aarhus, Denmark

Construction production processes are, in general, improved by removing non-value-adding activities. This includes reducing workers’ movements (walking) for transportation, walking, inspections, etc. Therefore, this research analyses the relationship between construction workers’ travelled distance and time spent on Direct Work (DW) at a construction site. An exploratory case study of the tasks performed by the carpenter trade was conducted. This involved four main steps: (1) data collection preparation; (2) on site data collection; (3) workers’ feedback collection; and (4) result analysis. Several sources of evidence, tools, and techniques for gathering data at the construction site was adopted: (a) direct observation to characterize the main activities; (b) Work Sampling (WS) technique to estimate the distribution of work time spent on different activities; (c) smartwatches to collect the data on construction workers’ travelled distance on the site during workhours; and (d) questionnaire application to collect workers’ perception about the use of the smartwatches. The relationship between distance travelled by workers and the time spent on DW was tested using linear regression analysis. The regression analysis results indicate DW is indirectly correlated to how much workers walk on the construction site (R=0.445). This study presents a pioneering use of data gathered from smartwatches as a tool for collecting workers’ travelled distance. The use of smartwatches has the potential implication to significantly reduce the time spent conducting direct observations during the WS application on construction sites. In other words, automating the data collection to estimate the time spent on DW based on traveled distances.
Real estate properties and assets are continuously exposed to different types of hazards or damaging events that have significant societal consequences, which can be very costly and can endanger the health and safety of users. Typically, 50-80% of the total cost of a building is spent during the operational and maintenance phase. The need to improve the knowledge about building damages is imperative to better prepare and design for the future. Taxonomical structures specific to the construction real estate sector have been developed under the data model IFC, ontologies, data schemas and similar representations during the past decade. However, current taxonomical structures do not account for the part of building damages.

This paper proposes and showcases the application of a building damage-centred data structure – an extension of current building-related taxonomical structures that focuses on the building damage – that allows for structured data collection and analytics to unlock insights about building damages and its surrounding physical built environment. The data structure covers 35 building typologies, 82 building zones, 72 building elements, 126 building materials, and 51 building damages, with 30 variables and more than 700 multiple options grouped in seven categories to describe and classify them.
Data models are the backbone of digital information exchange, since they contain the data to be exchanged. Just as information requirements vary, so do data models – in level of detail, level of abstraction, and in domain coverage. These variations are the reason for the ease of communication between some data models and for the difficulty in communication between others. Regarding the Building Information Model (BIM) initiative, the IFC standard’s data model has varying detail and abstraction levels and large domain coverage. In contrast, the Austrian ÖGG guideline, for example, has a consistent detail and abstraction level and focuses on a single domain – subsurface modelling. In order for such data models to participate in loss- and distortion-free information exchange, a reliable translation via, e.g., third data models is necessary.

In this paper, we present formal criteria for distinguishing between semantics-carrying data models, such as IFC and ÖGG, and translating data models that provide reliable communication bridges between them, such as XML, CAEX and SIMULTAN. We will show that translating data models are an indispensable part of the data model infrastructure even within a single domain. In addition, we will derive the minimal set of attributes of such models and demonstrate their necessity on a use case from the subsurface engineering domain.
In recent years, under the combined effect of the rise of short-distance tourism in China and the upgrading of consumption structure, the scale of country house development has skyrocketed. But at the same time, the design of the homestay exposed the problems of single-function layout and poor living experience. Therefore, the purpose of this article is to efficiently grasp the design requirements of the country house and to construct an algorithm for automatically generating the floor plan of the house to improve the design output efficiency.

This paper takes the homestays surrounding the Paifang Street scenic spot in Chaozhou, Guangdong Province as an example, crawls the comment data of tourism websites through Python, classifies and constructs a portrait of the living needs of the country homes, analyzes the current pain points and opportunities of the country homes, and generates the subsequent plane personalized Plan the data research work; then combine the preliminary research and field research to put forward the principles of the graphic design of the homestay.

The paper proposes a method of the automatic layout of architectural functions based on a generative confrontation network, which can automatically layout the architectural functions of rooms according to the design requirements of different homestays, forming a more complete floor plan. First of all, collect a large number of floor plan layouts of homestays with room functions, use Python tools for batch preprocessing, and build a data set; use the pix2pix program for training, and get an automatically generated plane model.
A massive amount of customer complaint data is recorded in the house-building industry during the defect liability period. These data should be used to assess project performance and support decision-making. However, most construction companies do not properly manage customer complaints as data collection is unstructured and incomplete. This problem results in poor and unreliable information for feedback. Research studies on customer complaints in the defect liability period are scarce in the international literature, being usually limited to the context in which a company is in charge of facilities management, usually for commercial or governmental projects. Moreover, most studies related to customer complaints in building projects are limited to data analysis and do not propose improvements in data collection and processing. This investigation aims to propose guidelines to collect and process customer complaint data in residential building companies. Using the Design Science Research approach, this study was carried out in partnership with a large Brazilian housebuilding company. The sources of evidence used were: participant observations of warranty service, interviews, documental, and system information analysis. A set of variables that should be collected was indicated, and a mobile application prototype was developed for warranty services. The main contribution of this study is concerned with modelling and processing customer complaint data in the real-estate market.
Non-contact spatial data collection (remote sensing) techniques, such as LiDAR and photogrammetry on unmanned aerial vehicles (UAV’s), have been used in Architecture, Engineering and Construction for many years with various applications. These applications include as-built documentation, progress reporting, planning, damage assessment, and marketing. Unlike expensive LiDAR, photogrammetry technology with UAV platforms can be much more affordable for contractors and facilities managers, with only a slight compromise in accuracy. Compared to many of the large general contractors that have been exploring innovative applications of UAVs and LiDAR mostly through their VDC (Virtual Design and Construction) department, most small or medium size contractors have not taken advantage of these technologies. This research investigates applications of UAV’s and LiDAR for small and medium contractors in the US and China.
Since the world was shaken because of the globally spread Covid-19 Pandemic, starting in late 2019/early 2020, many societies, including their businesses and sociological/behavioral systems, seem to be—and have been— influenced and—moreover— even been “shaken on their foundations”. All around the world such related daily experiences have lead to reconsidering for example the way we live, how we work and how we relax.

Nevertheless, when focusing more into detail on the construction industry and their outcomes (buildings, infrastructure, etc.) it is challenging to see if the way the construction industry was organized still might be the way how it will be kept organized after the COVID-19 Pandemic; especially because it seems that the influence of the pandemic on daily lives and businesses is now gradually decreasing; at least in the western developed world…

This discussion-paper aims to analyse and reflect on construction processes, derived from experiences and practices within case-studies, related to the project-development of buildings, from an organizational-cultural viewpoint. And this is especially important not only because it has been proven that the “soft factors” are maybe even more important than the “hard” factors in construction industry, but—moreover— because construction is a people’s business….and it will stay so, despite—or even thanks to— increasingly “data-driven” (i.e. behavioral) developments.

Conclusions and recommendations are focusing on the future of building, being part of the construction activities that are used and/or needed to keep building our future.

**Keywords:** Buildings, Construction-Process, Data-Driven, Future, Organizational-Culture, Project-Development.
The rise of Artificial Intelligence (AI) and Machine Learning (ML) in many aspects of construction management has helped this industry to further improve the management, design, and planning of construction projects. This trend happens in many construction sectors, including in New Zealand. Whilst relatively smaller compared to construction sectors in other OECD countries, the construction sector in New Zealand carries a similar degree of complexity and with its own unique characteristics. Various studies showed that AI and ML can be used to analyze construction data to generate further insights and to predict future trends in construction sectors. However, the AI approaches have their own set of challenges such as complexity, high cost of training, failure, and change.

Aiming to better understand the trends and requirements of New Zealand building projects, this study started with a review of the existing AI methods that are currently being applied. Accordingly, compare and evaluate the accuracy of two AI prediction methods. The two methods of Decision Tree and Artificial Neural Network methods are selected based on their predictive power and accuracy. These methods are conducted by using available historical building data which is available in Stats NZ. A portion of the data is used for testing and evaluation purposes and the rest of the data is used for training the AI methods.

The study is part of a research programme funded by the Ministry of Business Innovation and Employment (MBIE).
The accuracy of any projections depends on the comprehensiveness of the report and the ability to gather appropriate data for the study. Inaccurate portrayals of any study will misguide the investor and result in project failure and loss of resources. Due to the current depressed state of the South African Economy, the construction industry’s value fell sharply and there was significant job loss. To help economic recovery, the South African government announced a ten-year infrastructure investment plan in housing among other sectors. The considerable deficit in infrastructure and housing in South Africa means that changes in building costs are important because of the implications of changes to affordability. This paper examines the trends in building costs in South Africa over five years and reconciles these indicators with other key socio-economic factors. The study analysed the indicators of Building Cost in the Medium-Term Forecasting Associates (MFA), Department Trade and Industry (DTi), and StatsSA database using descriptive and inferential statistics. The findings suggest a positive correlation between population growth, unemployment, poverty, and the growth in building costs. While it can be inferred that inflation and corruption have a negative impact on growth in building cost. The study recommends that investors should plan ahead and make projections on population, unemployment, and poverty to avoid project failure and loss of resources due to increased building costs.
Quality and buildability are important issues in construction, and both emerge at the earliest stages of design. However neither are well-defined concepts. Our premise is that behaviour, values and culture impact on quality and buildability in the design stage, but these are also vulnerable to precise definition and difficult to investigate within a typical hypothesis-driven positivist approach. A better method may lie in a theory of personal constructs or ‘constructivism’ which takes the human experience as a whole. Qualitative research methods and data collection techniques are critically reviewed to assess those methods best fitted for purpose in approaching the research problem. Personal Construct Psychology (PCP), using repertory grids emerges as a suitable candidate and is applied in two pilot studies in Australia and Singapore. Preliminary results show the appropriateness of the approach for engaging in buildability studies.

Keywords: Construction, buildability, Cognitive science, personal construct psychology, cultural dimensions, decision-making
Academic institutions have faced substantial issues and difficulties since the novel coronavirus disease became pandemic. Traditional class attendance-based pedagogy rapidly became compromised, and universities were forced into alternative ways of delivering learning to students who themselves faced restrictions, even to the point of not even being able to enter the countries where they had enrolled for their studies. In the haste to implement projects for alternative learning delivery systems, there was little time to develop proactive approaches to project risk management for such implementation. By default, delivery risks were addressed re-actively, and a “lessons learned” post-implementation approach prevailed. Two case studies have been used to explore risk management practices used in alternative learning delivery environments. The findings show emerging teaching and learning dynamics in particular with risk-managing delivery of course learning experience and content quality. Lessons learnt are summarised and recommendations drawn.

**Keywords:** Learning and teaching, Risk management, Technology platform
181. Implementation of integrated BIM-VR into construction management curriculum: lessons learned and development of a decision support system

Behzad Abbasnejad  
RMIT University, Melbourne, Australia

Guillermo Aranda-Mena  
RMIT University, Melbourne, Australia

Araz Nasirian  
RMIT University, Melbourne, Australia

Peter SP Wong  
RMIT University, Melbourne, Australia

Alireza Ahankoob  
RMIT University, Melbourne, Australia

Several educational institutions and universities have introduced Building Information Modelling (BIM) and Virtual Reality (VR) courses separately in the construction management (CM) programs around the globe, and some others are under the process of integrating them into their curricula. However, fewer institutions have included integrated BIM and VR into their courses. The industry needs for integrated BIM-VR are not fully recognised by universities due to the lack of a guideline and cognitive dissonance between academia and industry. As a result, most of the universities do not have a rigorous strategy for developing BIM-VR teaching topics and plans. This study firstly aims to report on some of the employed processes by university lecturers and academics in an Australian University to integrate BIM-VR education into CM curriculum. The review of the secondary sources indicates that the integration of BIM/VR education requires the consideration of three aspects including industry needs, course contents, classroom size, and software and hardware selection. The second aim of this paper is to develop a decision support system by utilising the PROMETHEE method as one of the Multi-criteria decision-making approaches. The findings of the secondary sources and development of the decision support system help the educational institutions and practitioners for their future BIM-VR implementation initiatives.
With the ever-growing digitalisation of the built environment, specifying information requirements (IR) is crucial to control the Building Information Modeling (BIM) data. However, the way of encoding these requirements is subject to a wide range of possibilities, making it difficult for the users to choose the most suitable method. The paper presents a comparative analysis of methods to define IR based on document study and expert group discussions. The study covers Data Dictionaries (ISO12006), Information Delivery Manual (IDM), IFC Property templates, Information Delivery Specification (IDS), Level of Information Need, Model View Definition (mvdXML), and Product Data Templates (PDT), as well as other, non-standardised methods such as Linked Data with SHACL. The comparison is based on criteria from the review of use-cases and covers aspects such as value constraints, properties of fields, geometry representation, metadata, expressiveness and dependency. The paper concludes that no single method covers all the discussed aspects, and selection should be made consciously based on a purpose. The results are relevant to information managers to understand the relations and differences between IR methods, suggest standardisation bodies a way forward to harmonise, integrate or differentiate the standards, and provide a framework for evaluating IR methods.
Due to traffic loading and environmental conditions, pavement deteriorates over time, which leads to high roughness and surface distresses, greatly compromising the ride quality and increasing safety risks and vehicle operating costs. Typically, pavement condition assessment is conducted by using laser profilometers and response-type road roughness measuring methods (RTRRMs). Recently, attempts were made to leverage smartphones for roughness assessment and distress detection due to their increasing sensing capability and prevalent use among motorists. This research aims to analyze the body of knowledge in smartphone-based roughness assessment, and consequently, report knowledge gaps and cast light on future research directions. First, a systematic literature search found 88 academic publications in relevant fields. These works were critically reviewed with regard to sensor selection, pre-processing methods, and assessment algorithms. Special attention was given to practical factors that are expected to affect the accuracy and robustness of smartphone-based methods, including data collection speed, vehicle type, smartphone specifications and mounting configuration. Findings from this research are expected to provide a thorough understanding of the potentials and limitations of smartphone-based roughness assessment methods and inform future research and practices in this domain.
Crane operator training is an essential part of construction safety and is attracting extensive attention from researchers worldwide. Virtual reality (VR) is considered an effective tool to improve training outcomes by providing users with an immersive, risk-free experience in various environments. However, previous VR-based training platforms mainly focused on the scenario and task design; few studies attempted to investigate the impact of simulation fidelity on training efficiency. This research aims to explore the effect of simulation fidelity on training outcomes by comparing user performance in two scenarios. A typical construction site was modelled in a game engine using two rendering approaches; an eye-tracking system was adopted for data collection. The results from a subject experiment indicated the high efficiency of VR in operator safety training, and demonstrated the usefulness of eye-tracking in measuring hazard detection performance. Findings showed that a higher level of simulation fidelity might not significantly improve the training efficiency, especially in hazard detection aspects.
Machine learning and computer vision techniques contribute to the automation roof pathologies identification from images collected with Unmanned Aerial System (UASs). However, one of the challenges for practical machine learning model tuning is the small-data problem. One strategy is to adopt data augmentation to generate more training data from existing images in such cases. This paper aims to evaluate data augmentation in detecting pathologies in roof inspections with UASs images. The study adopted data augmentation for training two models in an image processing system. The training and tests using data augmentation images obtained superior results in accuracy, precision, recall, F-score, negative precision, and specificity metrics compared to the study using only original photos. These results indicate that data augmentation improves the adopted system’s performance in identifying roof pathologies in UAS images.
The wider Architecture Engineering Construction (AEC) industry has recently seen a growing number of platform-based approaches, focusing on the deployment of DFMA and industrialised construction. A common aid to this approach is the digital configurator, a software platform that allows for users to explore options of a particular solution space, within a predetermined set of constraints, such as kits of parts and other contextual factors. Recently, a growing number of such solutions have been developed by AEC practices, technology start-ups, and others, which aim to improve design efficiency.

This paper argues that the fundamental limitation of such examples is that they are developed as standalone products, conceived to solve very specific problems for a specific environment, without allowing for information-rich interaction with and combination of other configurators, precluding the ability to solve the complex problems within the widely distributed and fragmented construction industry.

Under the UK-led Construction Innovation Hub research programme, this research proposes a Common Configurator Framework, which will enable the communication between, and combining of, multiple discrete configurators by providing a mechanism for authoring and sharing design objects and object specifications. This can be achieved by ensuring and formalising a process of verification and validation through common object specifications, which can be standardized and reused alongside the associated kits of parts, within a distributed client and AEC chain.

Furthermore, the presented paper will demonstrate an adoption of the open-source Framework, through a reference implementation and additional case studies of prototypical configurators, utilising standard industry approaches and existing technologies.
Construction industry professionals suffer regularly from poor cash-flow which is a reflection of non-payment or payment delays down the hierarchical chain. This issue is important as the construction industry has the highest rates of insolvency in Australia, the UK and many other countries. Payment conditions under current construction contracts have proven to be inefficient in delivering timely payments as human interference has control over processing claims. This paper investigated the current status of contracts and contract law in Australia and the potential of smart contract technology in improving payment issues in the industry. Qualitative data was collected from secondary literature sources which included observations from industry professionals, real case studies, secondary research and government surveys. It found that smart contracts feature self-executing digital contracts, immutable data, require no intermediaries and provide transparency on all levels. Although these features are fit for purpose in resolving current contractual issues, smart contracts are not yet available in the construction industry. Findings also included that smart contracts do have the potential to provide a trusted and reliable payment system in the construction industry, although there are some aspects it is unlikely to replace such as human performance. Research limitations and future research directions were provided at the end of the paper.
The construction industry is one of the most dangerous sectors with poor safety performance. With recent technological developments, Unmanned Aerial Vehicles (UAV) is demonstrating the potential to be a valuable innovation to improve construction safety. To date, several studies have been conducted to evaluate the applications of UAV for safety in the construction industry. In order to systematically assess the research status on UAV to improve construction safety, this research investigated published journal articles (in English) within the Scopus database to determine the current research gaps and future work suggested by the publications. Thirty-three articles and reviews were included in the study. The analysis revealed a positive trend in publications in this area. Publications were also analysed based on the country of origin of the research and the journal. Prototype and experiments were identified as the most frequently used research methods. The majority of the studies, irrespective of the type of construction, focused on the construction stage. Where health and safety aspects were concerned, the use of UAV for visualisation and identification of hazards were found to be the most frequent applications. Some research gaps and recommendations for future research are also discussed in the paper.
The smart city model for operation and governance of modern cities requires huge quantities of data about people and the environment to support related applications, and crowdsourcing is effective for collecting and processing such data. Numerous reviews of the literature on crowdsourcing and smart cities as separate research fields have been published. Research on the intersection of the two is relatively new and lacks a systematic literature review. This study applies bibliometric research method and the research tools to study 367 related publications retrieved from the Web of Science database to find the distribution of publications, research cooperation, and major research areas. The analysis results clarify the research content and evolutionary context and reveal emerging research trends.
There has been increased interest in Smart and Ongoing Commissioning solutions to address the performance drift in existing buildings. Autonomous/autonomic systems are valuable tools to support the development such solutions, working towards a set of goals while sensing changes in their environment and adapting to them without human intervention. An autonomic approach to smart building design can thus maintain optimum energy efficiency while reducing operating costs. To support this development, this paper presents B-SMART: the first reference architecture for autonomic smart buildings to support smart commissioning. This research was informed by a comprehensive review of existing autonomic properties and domain-relevant autonomic properties and conceptual architecture. By decoupling conceptually distinct layers of functionality and organizing them into an autonomic energy optimization control loop, B-SMART facilitates the autonomic optimization of smart buildings.
Earthwork excavator, as an all-terrain and high-efficiency earthwork excavation equipment, has been widely used in earthwork sites. It is very necessary to analyze the work of earthmoving excavator by means of machine vision. In this paper, the action segmentation method based on long video was applied to the analysis and recogniton of the excavator’s action, and compared with other two current best action segmentation models using the real construction site video. Firstly, the sequence features of the excavator’s work video obtained at the construction site was extracted through 3D convolution method, and then two different networks with the extracted sequence features were trained and tested. The experimental results showed that the average frame accuracy of MS-TCN model and ASRF model in excavator action segmentation were 82.6490% and 86.1042% respectively. However, for the recognition task under different working environment, the performance of the two models is quite different. The experimental results manifest that the motion segmentation model based on long video reached good results in excavator motion recognition in earthmoving operation. It’s helpful to analyze the long video working behavior sequence of excavator. This research contributes to the identification of critical elements that explains serial action and to the development of a new application scenario for vision-based behavior segmentation network. Additionally, the results of this study were helpful to automatically analyze the working efficiency and monitor the productivity of earthmoving excavators. Using this kind of data-driven decision improves the work efficiency of earthmoving excavator and promote the project progress.
A vital element in working with BIM are standardised exchange formats that enable the exchange of information from digital building models between different software solutions and project participants. In this context, the Industry Foundation Classes (IFC) defined in DIN EN ISO 16739 represent a central standard for implementing the open exchange of information. Although approaches for integrating risk management are already available in IFC, they do not sufficiently reflect the needs of the construction industry. In order to increase project quality through risk management and the universal application of the Building Information Modelling (BIM) method, it is essential to map the generally valid information on the risk management process in IFC. The following article thus presents starting points for the further integration of risk management in IFC. The aim is to link all relevant risk information in a digital building model through an analysis and the development of an approach.
Adopting low-cost (shoestring) digital solutions in organisations should be followed by assessing the business and digitalisation impact. Evaluating the impact of low-cost (shoestring) digital solutions on improving business and digitisation benefits becomes essential for small organisations. This paper introduces an impact assessment model for digital shoestring solutions developed through the digital shoestring program. The proposed model assesses the impact of the low-cost digital solutions on 1) the business and 2) the digitalisation benefits after their installation. The model’s suitability is tested through a single exploratory case study performed with a small construction supplier. The case study highlighted that some of the digital solutions in the digital shoestring solutions catalogue affect only a part of the business benefits. The case study results also showed that the digitalisation benefits are not comprehensive enough to assess the digitalisation level achieved. Motivated from the case study results and inputs from literature, we propose an updated and novel impact assessment model that can be used uniformly across industries and adheres to multiple commonly accepted IoT reference architectures. This model will output the levels of digitalisation achieved and provides a comparative score of the achieved business impact for the digital solutions deployed at the small organisations.
There have been numerous research studies on understanding buildings better and finding ways to improve water and energy consumption while making them more comfortable for occupants. With technologies such as Building Automation Systems, IoT devices, mobile applications and BIM software, more data can be generated and stored for intelligence and more effective facility management. The next big thing is the digital twin concept, where a virtual model is created from the physical building that brings together real-time information from all data capture devices, allows monitoring, historical analysis, predictive analytics, and simulation as well as interaction and intervention to be carried out.

Many research studies have covered the characteristics, architecture, and benefits of digital twins and examined the potential implementation issues. However, the literature on evaluating return on investment (ROI) and acceptance of digital twins for the built environment at the individual user level is limited.

This study aims to develop a conceptual model to examine the motivational intent and behavioural choice by individual users to utilise the digital twin technology to improve their performance. The objectives of this study are to examine technology acceptance theories and develop a conceptual model that measures the relationship between the tasks involved and the digital twin technology characteristics.
The lifecycle of a building is characterized by precise compliance with regulatory specifications for both traditional planning as well as digital planning methods such as Building Information Modeling (BIM). Currently, this regulatory information is mostly available in the unstructured and non-machine-readable form of guidelines, regulations, and standards. To effectively use the knowledge contained in the documents during the BIM process, the unstructured data sources must be converted into a structured interoperable knowledge base. Since ontologies provide such techniques that allow raw data to be formally transformed into domain knowledge, in this paper, an ontology is developed based on the data format for data catalogs, properties, and groups of properties described in the ISO 23386. The acquisition and conversion of unstructured data are increasingly being automated using natural language processing in ongoing research. For this purpose, a multi-step process utilizing the developed ontology as a fundamental data structure is intended. The main contribution of this paper is the systematic requirements analysis based on existing literature, standardization, and existing ontologies. By using an example of data from real-world applications of German building codes, the evaluation of the resulting ontology is presented and demonstrated to show how the modeled properties can be applied to a feature of interest. In addition, an exemplary property validation using the SPARQL Protocol and RDF Query Language (SPARQL) and generated Shapes and Constraint Language (SHACL) shapes is performed to show how the collected data can be used for automatic constraint checking.

**Keywords:** Building code interpretation, ISO 23386, ontology requirements engineering, property assignment, SHACL
Building Information Modeling (BIM) models require sufficient semantic information and consistent modeling style to conduct Quantity Take-off (QTO) smoothly. However, BIM models created by different BIM modelers may have various mistakes about these requirements and auditing such BIM model behavior involves tremendous human effort for manual inspection or the development of rule sets. This study proposes an automatic and efficient BIM model auditing framework for QTO utilizing knowledge graph (KG) techniques. It begins at establishing a BIM-KG definition via identifying required information for auditing purposes. Subsequently, BIM data is automatically transformed into the BIM-KG representations, the embeddings of which are trained using a knowledge graph embedding model. Automatic mechanisms are then developed to utilize the computable embeddings to effectively identify mistake BIM elements. The framework is validated using illustrative examples and the results show that 100% mistake elements can be identified successfully without human intervention.
The emergence of the digital twin concept can potentially change the way people manage built assets thoroughly. This is because the semantics-based model and linked data approach behind the digital twin, as the successor of classical BIM, provide strong capability in integrating data from fragmented and heterogeneous sources and thus enables better-informed decision-making. Taking buildings as the case, this paper demonstrates the ontology-based Information Management Framework and elaborates the process to integrate data through a common data model. Specifically, the Foundation Data Model (FDM) representing the operation of buildings and embedded systems is developed and two patterns of integration architecture are compared. To conceptualise all the essential entities and relationships, the building topology ontology and BRICK ontology are reused and merged to serve as a feasible FDM. According to the characteristic of asset management services that digital twin supports, two integration architectures are compared, including the data warehouse approach and mediator approach. A case study is presented to elaborate the implementation of these two approaches and their applicabilities. This work sets out the standardised and modularised paradigms for discovering, fetching, and integrating data from disparate sources with different data curation manners.
Exploring quality issues in building information models via structural design reviews

Esat Candir
METU, Ankara, Turkey

Guzide Atasoy
METU, Ankara, Turkey

Building Information Models (BIMs) are being used widely in the construction industry. BIMs generally contain some errors and mistakes, if not identified, might result in long review processes with the employers or cause issues during code compliance checks or construction. Since the quality requirements vary according to the projects and even the stakeholders within the same project, it is challenging to establish a standard quality check procedure. In order to focus on the model quality, custom procedures tailored according to the needs of the design teams should be prepared. Hence, there is a need to explore the BIM quality issues and develop formulations to identify and eliminate them in time. Currently, there are no guidelines and formulations to determine the overall quality level of a Building Information Model and propose Quality Assurance (QA) and Quality Control (QC) procedures. In this study, design and model reviews from the owner are used to analyze the items to be checked for satisfying a structural model’s integrity. The design reviews are classified and analyzed to understand the existing issues. This study contributes to a better understanding of BIM quality issues and proposes a direction towards BIM quality assurance and control formulation that can be tailored by practitioners and design teams.
The Architecture, Engineering and Construction (AEC) industry faces several challenges every day, which are pushing this sector to start a process of innovation. In this contest, Additive Manufacturing (AM) represents an innovation and digitalization opportunity for the construction sector. This work will focus on an assessment of AM as an enabling technology for this industry, especially from a cost perspective. Indeed, since there is not yet a suitable cost model for AM in construction, a cost model will be developed to assess whether it is cost effective to use 3D printing in the building industry. The results obtained from the application of the cost model are very promising as they open up new avenues for considering 3D printing as a valid alternative to traditional construction methods.
Wayfinding signage is essential in a large building to find one’s way. Unfortunately, there are no methodologies and standards for designing signage. A good sign system therefore depends on the experience of the signage company. Getting lost in public infrastructures might be disorienting or cause anxiety. Designing an efficient signage system is challenging as the building needs to communicate a lot of information in a minimum of space. In this paper, we propose a model to study wayfinding signage based on BIM models and the BIM open library, which allows the integration of signage design into a BIM model to perform analyses and comparisons. The study of signage is based on the user’s perception, and virtual reality is a tool that best approximates this today. Our model helps to perform signage analysis in building design and to compare objectively the wayfinding signage in a BIM model using virtual reality.
716. Digital Twin based built environment asset management services development

Nicola Moretti  
University of Cambridge, Cambridge, United Kingdom  
Centre for Digital Built Britain, Cambridge, United Kingdom

Xiang Xie  
University of Cambridge, Cambridge, United Kingdom  
Centre for Digital Built Britain, Cambridge, United Kingdom

Jorge Merino Garcia  
University of Cambridge, Cambridge, United Kingdom  
Centre for Digital Built Britain, Cambridge, United Kingdom

Janet Chang  
University of Cambridge, Cambridge, United Kingdom

Ajith Kumar Parlikad  
University of Cambridge, Cambridge, United Kingdom  
Centre for Digital Built Britain, Cambridge, United Kingdom

The digital twin concept emerged recently in the Architecture, Engineering, Constructions and Operations domain and the interest for digital built asset management service implementations is increasing. However, most of the applications are developed according to custom approaches, preventing the generalisation and modularisation. This article presents a methodological framework for digital twin-based applications development, enabling data-centric built asset management services. Digital twin-based applications support effective data-centric processes in the management of critical built assets. The proposed approach is based on a flexible and federated data modelling approach, enabling the dynamic data management operations. The federated data model provides an interface and connection among different knowledge domains. The service requirement definition provides the input specification for the digital twin-based application development, accomplished through the modelling of three fundamental components: data, processes, and algorithms. These components are assembled through Application Programming Interfaces (APIs), supporting the implementation of the DT-based services. The proposed approach is applied to the West Cambridge Digital Twin research facility. In this context, the implementation of asset management services is demonstrated through a building energy sub-metering strategy. The developed approach allows flexible and interoperable data-centric applications development, contributing to the generalisation and scalability of digital twin-based built asset management applications. This aims at providing a consistent approach that can be employed in different asset management domains, where the digital twin technologies play a central role in service innovation.
The history of the design decisions directly related to the construction of the Sydney Opera House remains largely anecdotal. A rich group of items recently discovered in Australia may now start filling this gap, as documents brought to light include the drawings issued by the general contractor to build the concrete formwork for the shells, drawings of the temporary structures and falsework, site images, and contractor’s notes. All in all, the drawings display sophisticated combinatory solutions for attaining the structural form required whilst introducing repetition and flexibility in the making of the discrete pieces. While suggesting a remarkable combination of manufacturing and structural shrewdness, these blueprints call into question the canonical history of the building roof’s famous ‘sails’, the rhetoric of the ‘spherical solution’ used to arrive at them, and, most importantly, the information production and knowledge management model we conventionally work within.
This contribution investigates research opportunities in the field of architecture, design and design management focusing on user health in high traffic spaces. The field of application is Airport Passenger Terminals. Looking at the COVID-19 pandemic and anticipating the possibility of events of the same magnitude, it is necessary to approach the problem of the safety in public spaces interested by high traffic. Based on the State of the Art about antimicrobial material studies, Science of Architecture could propose innovative solutions that are compliant with health safety and prevention for high-use surfaces. These solutions combine antimicrobial materials with a digital solution that could manage data about surfaces, allowing the maintenance team to evaluate and optimize operations. After few hours the hygiene level of copper-based surfaces is higher than any other material: copper has positive ions that break the external membrane of most of bacteria and viruses, killing them. Copper-based furniture could be paired with sensors that send data to management software. Data are aggregated in relation to their location, to the number of users in the environment, how many times a surface has been touched and when. Combining the use of scientifically demonstrated antibacterial surfaces with high-performance management tools could be the best option to achieve health safety and contribute to social sustainability. Airport terminals are the ideal high-traffic buildings to use as test model because they have all the characteristics that could be analysed concerning the safety and the perception of safety of architectural spaces by users.
One of the most significant considerations to all BIM educators is how to develop curriculums that can equip students with the most practical skills and make them become job-ready graduates. This study aims to narrow the gap between educational outcomes and industry by strengthening the relationship between educators and industry partners. It presents an institution-industry collaboration model for training BIM technicians with a case study of a TVET College in Vietnam. Through the consultation with the industrial partners, the College defined six learning outcomes and 18 competencies for their BIM-technician program. Furthermore, the study used a questionnaire survey with the participation of 111 graduated students and 20 industrial partners to review the program and further understand the importance of designed competencies. The findings of this study would be a valuable reference to other colleges and universities in developing BIM educational and training programs.
722. Improving posture recognition among construction workers through data augmentation with generative adversarial network

Junqi Zhao  
The Pennsylvania State University, State College, USA

Esther Obonyo  
The Pennsylvania State University, State College, USA

Qin Yin  
The Pennsylvania State University, State College, USA

Deep Neural Networks (DNN) models have shown high potential in recognizing workers’ risky postures using data from wearable Inertial Measurement Units (IMUs). However, there is a data paucity challenge - DNN models require a large dataset with annotation for desirable performance. The research discussed in this paper proposes to address this problem through a data generation framework that leverages Generative Adversarial Network (GAN) to i) synthesize motion data, ii) augment training data, then iii) improve the recognition performance. Its potential was validated using naturalistic posture data of workers. Three GAN models were developed for data generation. A Train on Real and Test on Hybrid approach was used to quantitatively assess synthesized data and select sufficiently-trained GAN models. The performance of three commonly-used DNN models was compared after data augmentation. Results showed that the augmentation with GAN-synthesized data improved recognition accuracy by 1.2%-3% for varying postures. These findings suggest the feasibility of applying motion data augmentation with GAN models to advance automated construction safety monitoring.
The research discussed in this paper is part of a Belmont Forum disaster risk reduction project aimed at enhancing the resilience of low-income housing. This paper examines the feasibility and viability of using emerging simulation, modeling, and visualization tools to enhance the resilience of low-income housing based on the requirements of resource constrained, low-lying coastal areas in selected parts of Kenya and Tanzania. The authors focus specifically on the need to facilitate data and knowledge sharing across domains to concurrently: 1) reduce or avoid the potential property loss from flooding events through mapping the interdependencies and interconnectedness across natural and human systems; 2) coordinate the provision of temporary shelter for displaced victims to be provided promptly, and 3) building (back) better quickly during the recovery phase. The deployment of Artificial Intelligence, Internet of Things, BIM, Digital twin, VR/AR in disaster risk management is still an emerging area of research. In general, cutting-edge digital technologies are deployed as standalone solutions to address existing data and knowledge sharing needs that are unique to a sub-group of stakeholders. A more holistic and comprehensive solution will require an integrative framework that supports the seamless flow of heterogenous information across the applications used by various stakeholders. We propose to address this need through an artificial intelligence enhanced data, information and knowledge sharing platform that can be used to synthesis content from heterogenous sources into actionable insights.
Building Information Modelling (BIM) for Facilities Management (FM) has gained considerable attention. Despite considerable research works done in this area, several reasons are associated with less BIM adoption for FM. Issues such as lack of standardized process to develop FM data during design and construction stages, Standardized data format for data transfer, and fragmented databases are highlighted in multiple BIM-FM research. COBie datasheets are conceptualized as a standardized electronic format for minimum FM handover extracted from the BIM model and supplemented with information from other sources. COBie defines when, how, and what data needs to be captured for FM purposes. However, previous research combined with explorative studies highlighted several challenges with handling the COBie datasheet, especially its widely used spreadsheet format. This study aims to identify the issues associated with COBie handling (especially its spreadsheet format) and propose a COBie Dataset Management System framework (CDMS), which can help solve these issues.

In developing the proposed CDMS framework, a critical review of the published articles related to the COBie datasheet has been carried out. An exploratory study using a BIM Model was conducted along with the literature review to understand the key challenges highlighted in the reviewed articles. Based on the identified key issues, underlying reasons were recognized, and key ideas for the framework have been developed, potentially solving these key challenges. The research finding will help develop COBie centric applications and enhance the entire COBie data capturing workflow.
While in the last decade, digital tools and technologies have made their way into the construction industry, digital growth is still slow and incremental. The challenge is the consequential need for a collaborative and trustworthy environment with cooperation and concurrence among stakeholders. Blockchain technology holds promise and potential in providing this environment, infusing transparency and security in the mix. This study is thus motivated to explore the emerging information and communication technologies (ICT) in the architecture, engineering, and construction (AEC) industry and their integration with blockchain technology. Greater amounts of real-time digital information and automated systems with the security and transparency of blockchain could be a game-changer in planning and executing construction projects. It will affect not just the decision-makers at the top managerial level but will assist individuals down the line on-field to make decisions based on real-time data available to them.
The development of the digital twin (DT) has been focused greatly after the concept was brought from manufacturing and aerospace areas. In the architectural, engineering, construction and facility management (AEC/FM) sector, DTs are capable of integrating heterogeneous metadata and cutting-edge technologies like artificial intelligence and machine learning to create a dynamic digital environment for various purposes. Although building information modelling (BIM) appears to be a significant contributor to DTs, one of the major limitations for DT development is how to construct and provide a shared data environment for all stakeholders to collaborate throughout the life cycle. Furthermore, as the stakeholders’ requirements range of DTs expands from a single building to multiple buildings and regional/city levels, the information and data management gaps (e.g. BIM and GIS data integration) are more challenging and critical. To address these gaps, this paper aims to 1) review the current data management for building and city level DTs from a technical perspective; 2) summarise their major data management issues from building to city levels based on the review; and 3) introduce the concept of city-level Common Data Environment (CDE) that addresses the issues identified above, and discuss the possibilities of developing a CDE for a dynamic city-level DT.
Prefabrication construction has gained popularity in the construction industry during the last few years. Due to the complexity of prefabrication design, digital technologies are adopted in the design stage of prefabrication construction to improve efficiency and accuracy. Many previous studies have examined the adoption of building information modelling (BIM) in the design stage and explored the current practice of BIM adoption in prefabrication construction, however there is a lack of first-hand data from the designers. This study aims to identify the opportunities and challenges of utilizing BIM technology in the design stage of prefabrication construction from the perspective of designers. A semi-structured interview is conducted for qualitative data collection and the data are analysed by thematic analysis. A total of eight designers from Chinese prefabrication construction projects were interviewed. The research identified 8 opportunities and 15 challenges of BIM adoption in prefabrication construction. The top four challenges are: (1) inaccurate prefabrication production drawings generated by BIM software, (2) late adoption of BIM in the design stage, (3) lack of communication platform for different designers, and (4) lack of sharing the updated design model among designer, manufacturer and onsite engineer. These findings provide directions for improving BIM adoption in the design of prefabrication construction, and it has practical value to improve the designers’ work efficiency and the overall performance of prefabrication construction industry.
The Intergovernmental Panel on Climate Change (IPCC) recently released a report emphasizing the importance of reducing carbon emissions, indicating that the construction industry is a key player in this process. Whole Building Life Cycle Assessment (WBLCA) is the most efficient method for evaluating buildings’ environmental impacts. It considers the effects of energy consumption during operation and the environmental impacts of extracting, manufacturing, transporting, assembling, and maintaining the building’s components. However, numerous obstacles prevent WBLCA from being fully applied by decision-makers during the building project process (BPP). This paper discusses and suggests improvements to the challenges of integrating WBLCA and BPP. An online survey was performed with nine WBLCA software developers worldwide, examining the critical challenges and how to overcome them. Most participants agreed that increasing WBLCA demand is the most pressing issue. It would encourage the entire construction sector to adopt a life-cycle mindset, pushing WBLCA software developers to improve software tool integration with the BPP. Results from this study will assist software companies and policymakers develop tools and regulations more aligned with the interests of designers.
BIM Information Management, namely how information is introduced in and consumed from building information models, have an impact on the efficacy and efficiency of BIM workflows. Implicit reliance on all the information contained in a model may result in non-value-adding work from model authors. The recommended alternative is creation and use of information according to the Project BIM Execution Plan specifications. Regardless the adopted approach, model asseveration is demanded from authors (i.e., the verification that all required information is reliable and is available on a released model). International standards, such as ISO 19650, require clear and rigorous specification of information need, but anecdotal evidence indicates that the current practices in local markets are far from those recommended by these standards. An extensive online survey was conducted to assess current practices of professionals from the Brazilian market. Results showed that about half of the respondents adopt document-based (MEA/MET) recommended practices when dealing with model information, while the other half kept a behaviour more akin to the older CAD workflows. The implicit reliance (without checking MEA/MET documents) on model information varies according to professional role, being lower for design professionals and coordinators and higher for construction managers. As standards evolve and introduce new concepts for deeper and more granular information management, such as the Level of Information Need, it is necessary that professionals adapt their practices for increased efficiency on their BIM workflows.
Heat recovery chiller systems have significant strategic value to reduce building greenhouse gas emissions although this potential remains unrealized in practice. Real-time optimization using model-free reinforcement learning provides a potential solution to this challenge. A full-scale case study to implement reinforcement learning in a 6,000 m² academic laboratory is planned. This paper presents the methodology used to translate historical data correlations and expert input from operations personnel into the development of the reinforcement learning agent and associated reward function. This approach will permit a more stable and robust implementation of model-free reinforcement learning and the methodology presented will allow operator-identified constraints to be translated into reward functions more broadly, allowing for generalization to similar heat recovery chiller systems.
754. Lessons learned from implementation of Key Technological Developments to improve occupational safety and health processes in a complex UK-based construction project

Manuel Tender  
ISLA-Polytechnic Institute of Management and Technology, School of Technology, V.N.Gaia, Portugal  
ISEP – Instituto Superior de Engenharia do Porto, Porto, Portugal

Alistair Gibb  
University of Loughborough, Loughborough, United Kingdom

Paul Fuller  
University of Loughborough, Loughborough, United Kingdom

Alex Vaughan  
Ferrovial Laing O’ Rourke Joint Venture, London, United Kingdom

Marc Long  
Ferrovial Laing O’ Rourke Joint Venture, London, United Kingdom

Peter Damien  
University of Loughborough, London, United Kingdom

João Pedro Couto  
University of Minho, Guimarães, Portugal

Firmino Silva  
ISLA-Polytechnic Institute of Management and Technology, School of Technology, V.N.Gaia, Portugal

Francisco Reis  
BIMMS Management, Porto, Portugal

Ricardo Reis  
Xispoli Engineering, Braga, Portugal

The use of new Key Technological Developments to transform the way Occupational safety and health (OSH) is managed is now becoming a viable option for contractors to consider. These developments can be used to modify the traditional approaches to OSH to minimize the risks and costs associated with accidents at work and occupational diseases. The research reported in this paper aims to examine the benefits, barriers and challenges associated with the introduction of new technologies (such as BIM, AI, VR…) in OSH settings. A longitudinal case study of a complex construction project based in the UK is reported, which will be used to identify practical solutions and guidelines that can assist organisations in the adoption of these technologies. The lessons learned, both positive and negative, from this project are shared to provide valuable insights to the wider construction industry. The main focus is in the following areas: training; risks identification; site planning. The results of the study can be used to optimize how Health and Safety risks are managed in non-UK construction projects. The main benefits from this is the resulting productivity gains which can improve project outcomes significantly.
Performance measurement in construction has been a topic of academic and industry inquiry in the UK since the 1990s. Despite the time elapsed, there is little evidence of a consistent industry-wide performance framework that drives decision-making and supports consistent measurement of performance on construction projects. A review of academic advancements and industry practices has been conducted to understand performance measurement in the construction industry, including the metrics assessed, processes for collecting and analysing data, and current limitations. The adoption of digital technologies on construction projects can support timely measurement of performance metrics, allowing for feedback and corrective action to improve performance. However, organisations struggle to connect the top-down measurement value with the bottom-up data capture technologies. The study of an exemplar commercial project was used to inductively develop a data-to-dashboard strategy that supports decision making in construction. The proposed strategy aligns performance metrics, digital tools and processes, and data analysis techniques in a considered approach to interpret performance-related data and understand key issues. The development and review of the strategy on a live construction project highlights the challenges experienced with multi-source data integration and the translation of information into knowledge that drives decisions and deployment of timely corrective measures. The application of the strategy would ensure a consistent definition of metrics early in the project, and the continuous measurement of leading indicators. Future research will review the proposed strategy on further case study projects and develop an industry-wide multi-level performance measurement framework that uses the proposed strategy to improve performance.
Construction plays an integral part in the social and economic development of countries worldwide. Construction site safety is a crucial concern in both developed and developing countries. Because the preponderance of safety practices is mitigation-oriented rather than prevention-oriented, the construction industry has poor safety and health conditions. Falls are the primary cause of accidents involving roof and ladder falls on site. With the ability of Artificial Intelligence (AI) based techniques, the safety of ladders can be effectively managed, and the rate of accidents can be reduced. This study presents the AI-driven safety checking for a ladder in the pre-use stage. The checks are performed in Python programming language and various libraries such as math, Numpy, and Opencv. The AI-driven safety checking can decide for ‘fitness for the use of the ladder in terms of its structural rigidity before use. Compared to conventional safety practice, this process is less time consuming, an inspection can be done throughout the project lifecycle, data can be stored and shared virtually, and needless to say, the ladder-related hazards can be reduced.
Wearable technology has been playing an increasingly essential role in the construction domain, especially for construction safety and health related research. Musculoskeletal disorders (MSDs) is one of the most prevalent health problems among construction workers due to the physical demanding feature of the construction work. In the U.S., construction related MSDs account for 30% of workplace injuries and result in billions of direct and indirect costs every year. To solve this problem, wearable sensing technology has been applied for MSDs prevention. In our previous study, we designed an IMU-sensor based MSDs prevention system. However, the large-scale adoption of wearables has encountered challenges and barriers. This study firstly reviewed recent literature on the factors influencing wearable technology adoption and designed a survey based on the review to further investigate adoption barriers and strategies using our proposed MSDs prevention system as a case study. The results demonstrate that the discomfort and fatigue caused by wearing devices for a long period of time is the main concerns hindering wearable adoption in our case. Construction managers expressed concerns on the indirect costs of implementation and workers expressed their concern on the invasion of privacy. To address these concerns, strategies to promote wearable adoption identified in literature such as worker training and education and providing personalized features were discussed. This study provides insight into the factors contributing to the large-scale adoption of wearable technology for MSDs prevention from the application perspective.
Due to the dynamic and complex nature of construction sites, the conventional method of construction safety monitoring which relies mainly on manual observation by inspectors is highly susceptible to human errors, is time-consuming, and is also becoming increasingly difficult to identify all incidents. Wearable Internet of Things (WIoT) in the construction industry creates a lot of opportunities in safety and health management such as identifying real-time locations of workers, body temperature, heart rate, stress level, breathing rate, which can all be used to ensure that workers are always in safe environments and good health conditions. The use of WIoT for safety and health monitoring however presents research need on the privacy and security of the construction safety and health data collected, transmitted, and processed over the internet. This study examines the concept of privacy and security in WIoT, the security challenges, infrastructure requirements, and legal issues associated with WIoT. A review of privacy and security regulations for safety and health data is also presented in this paper. This study is expected to generate scientific information that can be used to develop an effective privacy and security framework to foster the adoption and implementation of IoT-based WSDs for safety and health monitoring in construction.
Computerising building regulations to allow reasoning is one of the main challenges in automated compliance checking (ACC) in the built environment. While there has been a long history of translating regulations manually, in recent years, natural language processing (NLP) has been used to support or automate this task. While rule- and ontology-based information extraction and transformation approaches have achieved accurate translations for narrow domains and specific regulation types, machine learning (ML) promises increased scalability and adaptability to new regulation styles. Since ML usually requires a large number of annotated examples as training data, we take advantage of the long history of building code computerisation and use a corpus of manually translated regulations to train a transformer-based encoder-decoder model. Given a relatively small corpus, the model learns to predict the logical structure and extracts entities and relations reasonably well. While the translation quality is not adequate to fully automate the process, the model shows the potential to serve as an auto-completion system and to identify manually translated regulations that need to be reviewed.
This large-scale study aims to get insight in the level of BIM adoption and maturity in the Dutch construction industry. The focus is on BIM users, BIM non-users and those that are unaware and do not use BIM in six subsectors (principals, architects, engineers, contractors, suppliers and mechanical engineers) and the construction industry as whole. In total 725 respondents participated in this interview-based study, 235 of them actually used BIM (the BIM-users) and 342 knew about BIM but did not use it (the BIM non-users). The remaining 148 did not know about BIM and therefore were not able to answer the questions related to BIM and BIM-use. The architects and suppliers have the highest number of BIM-users, mechanical engineers and contractors the lowest. One third of the contractors and mechanical engineers in this study was not aware of BIM. For measuring BIM-maturity, firms were asked questions about BIM-strategy, organization-and project-structure, human & culture, BIM-processes, IT and data(-structure). The score for each criterion is a mean of the sub criteria that are part of that criterion. The overall BIM-maturity is a mean of these sub criteria. The overall BIM-maturity of the architects was the highest and of the principals and engineers the lowest. ICT component is the highest scoring BIM-maturity component within the entire construction sector while BIM-processes the lowest scoring component. The findings from this study can be used to inform organizations in specific subsectors of construction in which aspects of BIM they have to invest to increase maturity.
The market of smart building solutions aiming at improving the comfort, well-being and health of occupants, but also the inclusiveness and accessibility of the building to people with more specific needs is growing. More and more smart solutions, as well as standards, certifications and public regulations are currently being developed, but a more global and systemic approach seems to be missing. The paper reviews the status of research related to the means and methods enabling interactions with occupants in smart buildings, which feeds an iterative approach with European industry and research actors aiming at collectively identify barriers and opportunities in this area.
The UN Sustainable Development Goals (SDGs) offer a framework for a better future by focusing on people, planet, prosperity, peace and partnerships. SDGs directly relating to the built environment are SDG 11 focusing on sustainable cities and communities, SDG 9 on resilient infrastructure and SDG 12 on responsible consumption and production. Cross cutting SDGs include SDG 7 on Energy and SDG 6 on Water. The SDGs do not explicitly mention circular thinking or practices for the built environment. Yet, the principles underpinning sustainability and circularity are the same, especially those focusing on resource efficiency and conservation.

The aim of this paper is to map the SDGs against circular built environment indicators in the Global South. In doing so, not only is the alignment between the National Determined Contributions (NDCs) and the built environment established, but the significant position that the built environment plays in the rapidly growing cities of the Global South is also strongly supported. Using secondary research, this paper first investigates the primary and secondary SDG indicators for achieving circular built environments by the One Planet Network’s Sustainable Buildings and Construction programme. This is then validated by undertaking workshops with experts in the Global South to determine an interim set of SDG indicators that provide circular economy related outputs such as local jobs, design for mitigation, resilience and adaptation and other indicators. The paper recommends priority indicators for achieving circular built environments in the Global South and suggests further research needed to finalise these indicators.
95. What does low-carbon living look like in Europe in various types of built environment?

Juudit Ottelin
Aalto University, Espoo, Finland. Finnish Environment Institute, Helsinki, Finland

Consumption-based carbon footprints are declining in several European countries. Yet, the average carbon footprints of European citizens are still high compared to the global average. However, there are many available options for individuals to reduce their personal carbon footprints. This study illustrates the impacts of low-carbon living on personal carbon budgets in urban, suburban, and rural areas in four European countries. The main research material is the Eurostat’s Household Budget Survey 2015, which is combined with a global multi-regional input-output model, Exiobase, to assess the carbon footprints. The dataset includes 250,000 households from 23 EU countries in total, but the study focuses on four countries: Belgium, Spain, Poland, and Sweden. The estimated impacts of low-carbon and carbon negative solutions are based on previous literature. The analysis focuses on housing related solutions, including renewable energy, low-carbon construction materials, and carbon sequestration and storage of private yards. The findings reveal that it is possible for a typical European citizen with an average income to have a low-carbon or even carbon negative lifestyle. In order to create a momentum at the societal level, stronger incentives are needed and current lock-ins and barriers need to be addressed.
116. Precursor considerations for new circular economy business models

Paul Clapham  
Independent Researcher and Consultant, Welshpool, United Kingdom

Usha Iyer-Raniga  
RMIT, Melbourne, Australia

Guillermo Aranda-Mena  
RMIT, Melbourne, Australia

Circular economy thinking encourages society to adopt sustainable patterns of consumption and production. This basic principle aligns with the objectives of the United Nations’ Sustainable Development Goals (SDGs), which include improving human welfare through equal access to drinking water and sanitation; together with reliable, sustainable, and modern energy supplies for all. Traditional approaches to delivering public utility services have been rooted within the Baconian view that the environment is a pool of resources that exist for the betterment of humankind. Whilst this tradition has delivered water supply, sanitation, electricity generation, and waste management services, that have improved the lives of countless humans, the provision of these services largely relies on business models and technologies that have had significant adverse impact upon the natural environment. To inform the development of new sustainable business models, this paper explores circularity concepts from the perspective of decision makers and actors responsible for the delivery of public utility infrastructure. Through a review of the secondary literature, this paper examines core circular economy principles and maps these against fundamental business model elements to synthesise a framework of precursor considerations for future business models. This framework has potential application in testing the extent to which existing business models in the utility sector support the transition to a circular economy and how current business models can be adapted to assist the achievement of sustainable development.
The rapid growth of population and associated urbanization and economic development calls for increased demand for infrastructure development to meet ongoing and future demand. A better understanding of the waste management (WM) processes would help to manage large volumes of waste effectively at construction sites, maximise the value of resources and improve environmental and economic performances. This research aims to investigate the WM processes associated with different types of Construction and Demolition (C&D) waste generated by a mega infrastructure project through a case study approach, combining expert interviews and project-specific documentary reviews. The case studied project demonstrated the high environmental and economic sustainability outcomes and exceeded the C&D WM targets, signifying more than 90% landfill diversion rates for both spoil and construction waste generated during the construction stage. As such, the infrastructure projects have a great potential to maximise re-use of high-value waste through waste exchange across projects and gain economic and environmental benefits. The outcome of this case study is a WM process flow diagram (PFD) that maps out the WM processes, waste fates and associated waste flows involved with the diverse range of C&D waste throughout its life cycle. The PFA developed in this study serves as an operational tool to develop effective WM plans for construction projects with similar nature and thus helping to achieve higher landfill diversion rates. The outcome of this study also can contribute to the development of a generic WM PFD for the C&D waste stream.
A significant amount of embodied energy, materials, and economic capital is tied to vacant and underused buildings. Sharing is an effective way to reduce the excess use of space. Beside sharing, much more focus should be placed on maximizing the functional use of existing buildings. Adaptive reuse can be effective not only in mitigating obsolescence, but also in enhancing the vitality of site surroundings. This study aims to explore the potential of sharing and adaptive reuse in delivering circularity, with special focus on the social dimension. We engage in a qualitative, in-depth case study method using interviews, site visits, as well as document and social media reviews as data sources. We study two adaptive reuse projects, where the buildings have been repurposed for collaborative use. The first case is a former museum turned into co-working space, the second is a former industrial site turned into an arts center. Our findings show that while adaptive reuse is inherently environmentally sustainable, the value delivery is through the social impact of the projects. The social impact can be divided into aesthetic experience, delivered through the preserved historic building, attractive site surroundings and creative content, and social inclusion, delivered through community engagement and accessibility.
The impacts of climate change require a strategic improvement in design decision-making. Leading-edge professionals are aiming for carbon-positive buildings that can achieve carbon sequestration by adding vegetation to buildings. Multiple references and case studies explored in this paper suggest that there is a theoretical potential for cities to become carbon sinks by constructing carbon-positive buildings. However, determining effective strategies, and quantifying and monitoring carbon sequestration in buildings, requires a standardised approach so that this carbon sequestration potential can be measurably established. This paper provides two key outputs: firstly, the paper identifies strategies that could shift buildings towards being capable of active carbon sequestration. Secondly, the paper provides a methodological framework with four key considerations for pre-design and design phases that building professionals can use to design for carbon sequestration. These are: understanding the site’s ecological, climatic, cultural and legal context to recognise issues and opportunities; identifying response, pressure, state and benefits indicators to set carbon sequestration targets; considering site ecosystem functioning and carbon dynamics to strategise carbon sequestration through design; and preparing long-term monitoring, evaluation and management plan. This paper identifies two areas for further investigation: linking manual quantification methods with computer-aided methods; and biomass data and growth models at the landscape, regional, and global levels that could be utilised for carbon sequestration assessment. The paper concludes with the suggestion that carbon sequestration through building-integrated vegetation has multiple co-benefits that can synergistically work towards climate change mitigation and adaptation agendas, increased biodiversity, and enhanced human wellbeing.
278. Comparison of green building rating systems from LCA perspective

Fatma Abdelaal
University of Canterbury, Christchurch, New Zealand

Brian H.W. Guo
University of Canterbury, Christchurch, New Zealand

David Dowdell
Building Research Association of New Zealand, Porirua, New Zealand

Buildings account for a considerable proportion of carbon emissions throughout their lifecycle. Therefore, Green Building Rating Systems (GBRSs) have been developed globally to evaluate building environmental performance and mitigate their impacts on climate change. Recently, Life Cycle Assessment (LCA) as a science-based method has been recognised in the GBRSs to enhance the building environmental assessment. Regardless of the wide implementation of GBRSs, buildings CO2 emissions have continued to rise by nearly 1% per year since 2010. Furthermore, no academic research has been conducted to compare GBRSs assessment criteria from the LCA perspective in respect of the recognition and weighting of (1) Whole Building LCA, (2) embodied carbon emissions and (3) operational carbon emissions. To this end, this research aims to evaluate the efficiency, validity and reliability of five international GBRSs (i.e., LEED, BREEAM, BEAM Plus, Green Star and Homestar) in terms of assessing and auditing the building total carbon emissions; embodied and operational emissions. Results show that the assessment requirements of the operational carbon emissions make up the major portion of the total weighting in the existing GBRSs. However, the rating systems ignore the operational emissions during the water use stage of the lifecycle of buildings. By contrast, the assessment of building embodied carbon emissions is overlooked. Moreover, Whole Building LCA is an optional assessment criterion with negligible weighting. Based on the results, shifting focus from operational carbon towards a full life cycle perspective is urgently needed to achieve the emissions reduction targets and so decarbonising the built environment.
The circular economy and digital transformation are two of the major trends over the last decade. Circular economy seeks to improve environmental quality and provide economic prosperity by prolonging the life cycle of materials and products. This has given rise to numerous models, approaches and systems that seek to support the key principles and features of the circular economy. Integrative methodological advances such as life cycle assessments, material flow analysis, and input-output tables are some of the current trends towards quantifying the impacts of circular economy case studies and scenarios. However, more efficient processes are required and methods need to be adapted to the unique attributes of circular economy systems to identify and compare these approaches and systems demonstrating their strengths and weaknesses. This paper presents a descriptive analysis of current trends in the circular economy and explores the extent to which those that have a positive impact on the construction industry can be enhanced using emerging digital technologies. For example, applying data-driven design in the field of circular economy using innovative information and communication technologies (ICTs) offers new possibilities for optimizing existing integration methods. New circular economy approaches and systems could emerge based on taking advantage of technologies such as: artificial intelligence (AI), Internet of Things (IoT), Advanced Data Analytics, etc. The paper concludes with an outline of how emerging technologies can facilitate the achievement of circularity at systemic levels. It also identifies a number of research directions.
This paper contributes to increasing resource efficiency by providing a method for calculating the environmental impact in the context of the infrastructure sector. For this purpose, the LCA method is linked to a parametric BIM model for road construction. Municipal existing road structures and characteristics were considered for the development of the approach.

The research topic is motivated by the sector of infrastructure construction and especially road construction, which is enormously resource-intensive. Therefore, resource efficiency indicators such as raw material consumption, energy consumption and climate warming must be adequately implemented in the information model for the entire life cycle of a road construction project.

The aim of this work was to combine the two areas of resource efficiency calculation and parametric BIM modeling and to generate added value from this combination. In this way, relevant indicators can be extracted that can also be used to define the information needs in terms of resource efficiency and further developed as recommendations for municipal operators. The extension of the methodology to other infrastructure areas has been identified as a further starting point. In the future, it must be ensured that resource flows are recorded holistically to increase resource efficiency.
The Architecture, Engineering and Construction industry is allocated 40-60% of the worldwide raw material extraction. Construction waste accounts for a significant share of the total waste volume. Therefore, careless handling reduces the volumes of natural resources and waste deposits (landfills). Furthermore, material reuse and recycling can reduce resource and energy consumption and environmental emissions in some cases. Therefore, waste management concepts in the fields of AEC are more and more in the focus of the European Union and worldwide. Circular Economy can be seen as a system in which resource input, waste, emission, and energy leakage are minimised due to closed material loops. Therefore, implementing a consistent Circular Economic requires a holistic approach in which material, emissions, and energy are put into context. This paper aims to analyse dismantling, recovery, and recycling processes and link relevant parameters to assess material sustainability. The technical effort that must be made and the associated costs are compared with the influence of eco-indicators. Furthermore, the data required can be used for the following three areas: Facilitating demolition planning and on-site waste management; resource management at local/regional/state level; and governmental tax mechanisms.
This research aims to critically review the current body of knowledge on the Circular Economy (CE) within the construction industry to identify gaps in knowledge in which to prioritise future research. The methodology followed a review of core literature and government documents surrounding the CE as a whole and in the context of the construction industry. The findings in this research revealed that frameworks and business models for CE implementation are present but they are still in their infancy, and they require application analysis to determine the impact and feasibility in practice. In other words, sufficient theoretical knowledge has been generated to move into the next phase, that is, practically applying the CE within the construction industry, and then analysing the impact value. The contribution of this paper to knowledge is threefold: (i) the progress and limitations of prior studies on the CE in the construction industry are revealed, (ii) the barriers to CE implementation within the construction industry are analysed to provide insight into the reasons hindering the development and application of the CE in the construction industry, (iii) analysis of current literature and barriers of the CE within construction provides novice researchers and practitioners with a pivotal basis for the development of effective solutions in the development, application, and transition to a CE in the construction industry. Future research should aim to practically apply theory to analyse the impact value in which to reinforce government and organisation decision making in the development and transition to a CE.
The role of design in transitioning towards a circular economy (CE) is strategic in the building construction industry, as the potential for creating, developing, and sustaining circular value throughout the whole building life cycle is largely determined by the building design. Circular building design approaches that are being commonly deployed are often based on technical perspectives that assume buildings to be static products of the building construction industry. However, buildings are complex and dynamic with components and materials having their own individual life cycles, interacting dynamically with each other over space and time in a continual state of change. Moreover, changing stakeholder needs and expectations and other external factors add further layers of complexity in developing and sustaining the circular value created by the initial building design. Therefore, a holistic approach that accounts for the above contributors and integrates the building dynamism across its life cycle including stakeholder involvement, was ideated, based on the extant literature gap and the industrial need. The study conceptualised a holistic ‘design for circularity’ (DfC) framework based on a comprehensive literature review. The literature review was followed by 07 preliminary semi-structured interviews of relevant experts, so as to address relevant industry needs in developing this framework further. The findings enable the formulation of an overarching design centred framework to not only create, but also to develop and sustain circular value throughout the whole building life cycle, as presented in this paper.
As an alternative to the linear economy concept, the circular economy (CE) is growing in popularity among researchers, governments, and organisations. It is a waste-elimination concept that takes, creates, uses, and regenerates materials. Although the CE concept has been adopted in a variety of industries and countries, its application in Africa, particularly in the built environment sector, is still in its early stages. A lack of adequate research on the subject could be one of the reasons for the slow uptake in the built environment. In this context, the study provides an overview of publications focusing on CE in Africa’s built environment from 2001 to 2021. Through the Web of Science database, this study identifies various key topics and CE implementation methods in Africa using bibliometric analysis. The findings show that 27 publications in Africa focused on CE and the built environment over a 20-year period. Using the VOS viewer software, data analysis focused on the document type, year of publication, journal distribution, top authors, most cited publication, and keywords. In conclusion, the study suggests that vigorous research on the CE concept be conducted, with a focus on waste minimisation, in order to reduce pollution in the long run.
For several years the pursuit of sustainable development resulted in a narrow focus on environmental sustainability in construction. In recent years a holistic approach to the concept of holistic sustainability in the construction sector has gained traction. Green certified buildings have been instrumental in driving the sustainability agenda in the industry. However, studies have shown that green building certification does not necessarily embrace holistic sustainability. Whilst the evaluation of environmental sustainability is exhaustive, social and economic sustainability are rarely evaluated. As in many fields, construction alike, the conceptualisation of sustainability has remained a challenge. Lack of understanding of sustainability is often seen as a barrier to industry fully embracing sustainability principles. Under this premise, a study was carried out with industry practitioners on green-certified projects to explore their understanding of sustainability in construction. The study conducts semi-structured interviews with construction professionals involved in three green building certified projects. Based on the content analysis of the interviews, the findings revealed that although green building practitioners have a considerable understanding of the concept of sustainability, the certification process limits the operationalisation of the concept. Although the study is limited to South Africa, the results are relevant to other contexts with similar settings and green certification tools. The implications of this study include the need for further research on the operationalisation of social and economic sustainability concepts in green building certification.
The construction industry is responsible for a significant portion of the solid waste that industrialised nations dispose of each year. In some countries up to 60% of solid waste comes from construction and demolition waste. One reason for this is the low rates of reuse and recycling, largely due to the difficulties in deconstructing buildings and an inability to easily separate materials and components from each other and from the building structure. If buildings were designed to facilitate deconstruction and the easier separation of the parts, then future material and component recovery would be easier. Previous research into historic examples of deconstruction has identified numerous principles for design for disassembly to facilitate future material recovery. This paper presents research that expands on this understanding of design for disassembly though the application of these principles in architectural design projects. A methodology of ‘research through designing’ is implemented to test the principles of design for disassembly and assess their suitability for integration into mainstream construction practice. Several domestic scaled architectural projects, some realised and some hypothetical, were used to trial the principles and the overarching philosophy of design for disassembly. This experimentation and research through creative practice, has confirmed the value of the principles of design for disassembly as strategies for the potential reduction of future demolition waste. Further to this, it has made explicit some of the otherwise unrealised consequences or constraints of designing for future disassembly.
DURABILITY & CLIMATE CHANGE: IMPLICATIONS FOR BUILDING DESIGN & CONSTRUCTION PRACTICE
The need to mitigate climate change calls for the construction industry to achieve net-zero greenhouse gas (GHG) emissions for new and existing buildings by 2050. Zero carbon refurbishment (ZCR) for existing buildings is a significant area of interest, as many existing buildings will still be there in 2050. This paper investigates the global development, knowledge structure and gaps in the research field by conducting a systematic literature review. The final selection of 147 up-to-date journal articles was analysed using mixed-method data analysis, including quantitative (science mapping) and qualitative (thematic) analysis. Quantitative results reveal evolving research topics such as energy performance and efficiency, life-cycle environmental impacts, energy resources and policy, and decision making. Research in ZCR is well-established in European countries and there is much interest and activity around the world. ZCR research on residential and office buildings provokes much consideration compared to other building types. The qualitative discussion demonstrates the mainstream research areas (e.g. multi-objective optimisation), determines research gaps (e.g. carbon characteristics), and recommends the future research agenda (e.g. a holistic multi-objective methodology considering whole-of-life carbon, economic factors, co-benefits and other impacts). The study offers academics a comprehensive understanding of ZCR research to link current research areas into future trends. It also provides construction professionals with current practices and an interdisciplinary guide to better deliver ZCR projects.
49. Climate actions versus design conditions: the impact on the maintainability of architectural concrete façades

Cláudia Ferreira  
Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal

Ana Silva  
Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal

Joana Barrelas  
Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal

Jorge de Brito  
Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal

Ilídio Dias  
Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal

Inês Flores-Colen  
Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal

Architectural concrete façades are exposed to different environmental and climatic degradation agents during their service life (e.g. precipitation, damp, prevailing winds, temperature variations). These actions contribute to the degradation of the façades, having practical implications on the buildings’ life cycle, namely in terms of maintenance needs and related costs and, at an environmental level, regarding the premature replacement of the facades. But are the environmental factors the most relevant parameters in the maintenance needs of the architectural concrete façades? Won’t the choice of materials as well as the design and execution conditions be equally important? This study analyses the impact of environmental conditions on the maintainability of architectural concrete façades, commenting on the results obtained with some design details of the façades. To perform this analysis, a stochastic maintenance model based on Petri nets is used, and three maintenance strategies (MS) are considered: MS1 - total replacement only; MS2 - combination of minor interventions and total replacement; MS3 - combination of cleaning operations, minor interventions, and total replacement. The different strategies are compared considering the impact of the local climate on the service life, maintenance costs, efficiency, and number of interventions of 289 architectural concrete façades. The knowledge regarding the impact of environmental variables on the maintenance of architectural concrete façades can be a relevant instrument for the adaptation of these façades to climate change, concerning the adoption of an adequate maintenance strategy, critical to ensure an adequate performance and delay the end of service life of these façades.
Concrete is one of the most widely used construction materials, and this industry is responsible for a significant portion of CO2 emissions. In this scenario, bio-concretes emerge as an alternative since they can incorporate several types of biomaterials, especially residues, which can reduce this impact. The use of a life cycle assessment (LCA) to evaluate the environmental performance of these materials becomes fundamental in order to identify the main points for improvement. This study performed a systematic literature review that analysed the published works about the LCA of the different types of bio-concretes, and identified limitations and possible improvements for future studies. Because bio-concrete is a relatively new material, only 16 publications were found on this topic; though an increase in the number of studies in the recent years was observed. This indicates a trend towards an awareness of the relevance of performing LCAs when evaluating a material’s performance. It was also noted that there is no standardization of the functional unit studied and the possibilities regarding the end-of-life of bio-concretes. Hempcrete was the type of bio-concrete most commonly evaluated, global warming potential (GWP) was the most studied impact category, and binder production was observed as being the main contributor for CO2 emissions. When compared with conventional building materials, bio-concretes can afford great reductions in GHG emissions, and reach more than 100% reduction in some cases. It was also found that biogenic carbon has a big influence in the GWP results of bio-concretes and this must be addressed correctly.
Climate change and its impacts on building stock is already a challenge for the current scientific society. How to predict buildings’ performance under new and unknown climate conditions is one of the new questions of the architecture, engineering and construction sector. In this study, a set of 72 timber buildings in South Chile, which have reached the end of their physical and functional service life, were analysed. Concerning the novelty of the study, two methodologies have been used to define the end of their physical and functional service life, establishing a hierarchical scale concerning the priority of intervention in timber buildings. Usually, timber buildings in South Chile do not present climate change resilience regarding thermal insulation, which causes extreme heating of indoor spaces and triggers outdoor contamination, due to the use of firewood for heating. In this sense, three thermal energy situations have been modelled, considering basic, current and deep thermal energy rehabilitation. This study can provide relevant information, and can be a new approach for helping in the establishment of future preventive maintenance plans towards building stocks restoration, considering their thermal energy performance and also climate change resilience in the South regions of the country. In this sense, the approach proposed in this study could be readapted to the analysis of new climatic and environmental contexts.

**Keywords:** Timber buildings, functional performance, physical degradation, thermal energy performance, South Chile.
Facade failures due to rainwater entry are common in Turkey although to date, few systematic studies has been completed to determine the types of defects and failures and their causes as would permit developing appropriate repair solutions. The intent of this study is to determine the types of defects and failures caused by rainwater ingress to building facades based on existing case studies of envelope failure in Turkey. From this effort, defects and failures can be both characterized and classified, such that the most common types of failure can be revealed and adequate repair solutions proposed. Hence, a review of literature was conducted of studies undertaken in Turkey on rainwater entry and building defects published between 1996 and 2020. Additionally, information regarding the failures in public buildings was gathered from local authorities and field inspections were carried out for 16 public buildings located in Istanbul. Based on data as were evaluated from case studies of previous research and that obtained from field inspections, it was determined that a great majority of the buildings had cladding walls with stucco being the most commonly used cladding material. The types of failures that had occurred in cladding facades with stucco included detachment of cladding, staining, and cracks; the most common failures were that of blistering and exfoliation. Air and rainwater leakage due to defects to the jointing sealants as arose from aging, and water vapor between glass panes were the common failures in buildings with panel and stick wall systems.
Canada employs a prescriptive-based code for residential buildings. The minimum requirements as prescribed in the 2015 National Building Code were developed based on historical climate which was assumed static. It is now evident that the climate is changing and it is anticipated that wind-driven rain events will be more frequent, of longer duration and of increased intensity. These changes may affect the durability of wall assemblies designed following the minimum requirements set in the building code. In this study, the moisture performance of residential wood-framed walls using brick veneer as cladding and meeting the minimum requirements of the National Building Code were evaluated for different climatic regions of Canada. Various types of brick veneer were evaluated using hygrothermal simulations and projected future climate loads. The mold growth index on the sheathing panel was used as performance indicator. Results showed that the future moisture performance of brick veneer walls depends on the brick properties and varies with climatic region. In particular, for brick veneer having relatively high water absorption coefficient and lower vapor permeability, there may be a heightened risk to mold growth in the future if used in locations on the east and west coasts of Canada. As consequence, the minimum requirements for brick veneer walls may need to be reviewed in these locations to ensure their long-term performance.
Climate change will inevitably affect the atmospheric conditions to which existing building envelopes will be subjected in the future. In respect to current approach to the design of wall assemblies, only historical or current climate conditions are considered which may very well compromise their moisture performance when subjected to future projected climate loads. To permit understanding the moisture performance and resilience of wall assemblies to future projected climate loads, there is an urgent need to investigate the likely risk to premature degradation of wall components due to moisture load over projected future time periods. In this study, a full-scale hardboard siding-clad wood frame wall assembly was constructed and tested in the Dynamic Wall and Wind Testing Facility, a test facility capable of subjecting wall test specimens to designated rates of water spray concurrently with dynamic differential air pressure, thereby mimicking the effects of wind-driven rain (WDR) on an envelop assembly. Watertightness testing using this apparatus permits estimating the moisture load to a wall assembly based on hourly WDR and hourly driving-rain wind pressure (DRWP) as these two parameters are the primary factors affecting water entry into wall assemblies. Subsequently, a set of future projected climate data for selected Canadian cities was generated using a climate model from which the moisture load to this hardboard siding-clad wall assembly was subsequently calculated. The moisture load distributions for a historical climate, and that for future projected climate periods were generated, changes in moisture loads between historical and future projected time periods were discussed.
356. A holistic framework for determining the trade-off between embodied and operational carbon emissions of high-rise residential buildings

Wei Pan  
Department of Civil Engineering, The University of Hong Kong, Hong Kong, China

Yue Teng  
Department of Civil Engineering, The University of Hong Kong, Hong Kong, China

Yefei Bai  
Department of Civil Engineering, The University of Hong Kong, Hong Kong, China

Cong Yu  
Department of Civil Engineering, The University of Hong Kong, Hong Kong, China

Jiayi Xu  
Department of Civil Engineering, The University of Hong Kong, Hong Kong, China

Buildings’ carbon emissions consist of embodied carbon (EC) associated with the production and transportation of materials and operational carbon (OC) generated from consumed energy during daily use. However, previous studies concentrated on either EC or OC but ignored an integrated analysis of their relationships. Therefore, this paper aims to explore appropriate building envelope design solutions by examining the trade-off between EC and OC of high-rise residential buildings. To achieve this aim, the life cycle assessment method was used to evaluate the EC and OC of the residential buildings using SimaPro and DesignBuilder software. A building information modeling (BIM) model was developed to extract the geometric data and material consumptions. A typical 30-story public residential building in Hong Kong was examined. The EC and OC of the case building were calculated as 561 kg CO$_2$/m$^2$ and 50.18 kg CO$_2$/m$^2$/yr, respectively. Different low carbon design scenarios were identified from the literature review and the semi-structured interviews with designers and contractors. Results indicate that low carbon concrete is an effective approach for not only reducing the EC by 5%-15%, but saving a mild percentage of OC, and is therefore encouraged. However, changing the thickness of external walls leads to a very limited life cycle carbon reduction (0.99%). Lower U-value of envelopes is recommended as 2.84% and 2.89% life cycle carbon is reduced when adopting insulations for external walls and triple-glazing windows. The findings are valuable for examining the relationships between EC and OC and can support low carbon building decision-making.
To assess the impact of future climate on the hygrothermal performance of walls when considering different types of walls, geographical locations, and various climate change scenarios, a significant number of simulations will be required. To address this issue and thereby reduce the number of simulations and calculation time, regression models can be developed and used to provide an estimate of wall performance. This study focused on developing a regression model using Partial Least Squares (PLS) regression to predict the mould growth risk in wood-frame walls. Hygrothermal simulations were performed for a wood-frame wall having brick veneer as cladding using hourly historical and projected future climate data for the city of Ottawa, Canada. The mould index calculated at the exterior layer of OSB sheathing and the most relevant climate parameters were used to construct a PLS model. Explanatory variables to the model included: wind-driven rain, normal solar radiation to the façade, temperature, relative humidity, and wind speed. The model was then used to predict the mould index for other years and wall orientations not included in the training set and compare with results from hygrothermal simulations. To evaluate the model’s reliability, different statistics were used including the coefficient of determination (R2) and the Root Mean Square Error (RMSE). Results showed that with the proper selection of training dataset, the model can be effectively used to predict the hygrothermal performance of the wood-frame wall assembly studied.
The use of External Thermal Insulation Composite Systems (ETICS) has been consistently growing over the last decade. However, these systems are continuously exposed to weathering and anthropic factors which can affect their long-term durability. This paper intends to evaluate and compare the durability of four commercially available ETICS after two-year of natural aging (at an urban site in Lisbon, Portugal) and after artificial aging (hygrothermal cycles, and exposure to UV and SO2). The systems were selected in order to have different composition, i.e., thermal insulation (EPS, ICB, MW), base coat (with cementitious or hydraulic lime binders) and/or finishing coat (acrylic, silicate, or lime-based). Physical and aesthetical properties of sound, naturally and artificially aged systems were assessed. The biological susceptibility of the finishing render of the systems was also investigated. Results showed a significant loss of surface hydrophobicity after aging and traces of mold growth on the surface of the systems. Considerable color change for all systems was observed after aging, confirming aesthetic change. The correlation of the results can contribute to enhanced performance and durability of ETICS by mitigating the causes of damage and to the definition of adequate repair or maintenance strategies.
A changing climate requires our built environment to be adaptable to better serve the communities for which it was intended. However, little is known about how climate change, especially rising temperatures, will impact housing and thus affect at-risk populations. Using a questionnaire survey, this research carried out a pilot study to investigate the potential effects of rising temperatures on the elderly in Auckland, the largest city of New Zealand, and the role they perceive housing plays in reducing these effects. The results show that although the general health of the respondents was, on average, very good and free of pre-existing illnesses, many reported experiencing discomforts in their houses due to rising temperatures. The most reported effects were difficulty sleeping, feeling tired, personal discomfort, and decreased productivity. The use of cooling devices, reduction in clothing layers, drinking more fluids, and opening windows were the most commonly used strategies for improving thermal comfort levels in the home. The respondents considered the availability of heating/cooling appliances, extra insulation, double-glazed windows, and shadings to be useful for making their houses more climate-adaptive. Some respondents indicated climate change had only a minimal effect. This suggests the need to increase people’s awareness of the impact that climate change may have on them. This study has laid the foundation for further research into housing measures needed to ensure that the elderly have access to climate-adaptive dwellings and a better understanding of the most viable solutions for achieving improved housing performance in light of climate change.
Climate change is accelerating and can seriously affect the built environment, if not properly acknowledged in the design and maintenance stages. Despite the globally expected warming, climate changes will differ depending on region and climate type. What implications will temperature, precipitation and wind changes have on the degradation of the building envelope, in Southern Europe? How will the performance of façade claddings be affected by the end of the century? The purpose of this research is to determine the expected impact of climate change on the degradation of rendered façades, in a dry and hot summer temperate climate. This study is based on the complex relationship between climate parameters projections for Portugal and the known effects of environmental agents on the degradation of renderings. Projections indicate the increase of mean temperature and heat waves, reduction of precipitation and wet days, intensification of rainfall in shorter periods and decrease of wind speed. Notwithstanding the projections’ inherent uncertainty, more cracking and fewer stains are expected. Due to the cracking increase, more loss of adhesion is probable, if rainwater thoroughly penetrates the cladding. Further research is necessary to assess the risks of intense rainfall events. Defects induced by rainwater are common and highly dependent on rain-wind action and drying conditions. Knowing the local context and microclimate is important to understand the renderings’ degradation induced by environmental agents. The detailing of climate projections and parameters’ combined action could be useful to deepening the knowledge on climate change impacts on rendered façades’ service life.
As an alternative to mitigate the urban heat island effect, materials known as “cool surfaces” are a suitable passive technology for reducing heat transmittance into buildings and therefore, diminishing the electricity demand for cooling. However, due to ageing, the performance of cool surfaces becomes less effective, with decreasing solar reflectance generated by dust accumulation and microbial growth. Studying the durability of cool surfaces is important to understand the degradation agents and use this information to manufacture materials with improved long-term performance. However, there is little literature on the subject and the data usually present a local perspective in durability which makes harder to compare with other cases. This research conducted a systematic review on works approaching natural ageing of highly reflective materials to identify the main factors that influence the albedo durability of cool surfaces. The main factors found were macroclimate, microclimate, the tilt of exposure, materials characteristics, and substrate. The data analyses conducted in this research highlight the importance of having a general perspective when studying reflectance durability, since agents that don’t seem relevant when evaluating a local case can be important when comparing the general figure. The inspection promoted by this study might help future research to better analyze their results and connect the diffuse knowledge in the current state of the art.
ENHANCING THE EDUCATION & WORK ENVIRONMENT FOR PEOPLE IN CONSTRUCTION
21. Investigating into the causes and prevention of mental illness among construction workers: Analysis of case studies

Robert Osei-Kyei
Western Sydney University, Sydney, Australia

Chukwuma Nnaji
The University of Alabama, Tuscaloosa, USA

Yunus Ozdemir
Western Sydney University, Sydney, Australia

In the construction industry, mental illness is present among construction workers. Mental illness among construction workers can be caused by a variety of factors. Essentially, some mental illness in the construction industry include depression, suicide and anxiety. Although, quite several research studies have in recent times explored mental illness in the construction industry, very few have holistically explored the root causes of mental illness from case study approach. Case study analysis provides holistic and in-depth insight into a phenomenon especially on new and emerging issues and topics such as mental illness. Considering this, this paper investigates the causes and prevention of mental illness by analysing two case studies. The cases include the Hinkley Point C project in the U.K and Tokyo Olympic Stadium project in Japan. Based on the analysis of case studies through comprehensive review of reports and other available literature, it was found out that the major causes of mental illness (i.e. suicide) in these projects include, long working hours, loneliness, relationship breakdown, extreme workplace pressure and lack of social support. Some preventive measures identified include increase in social support, workplace screening and developing coping strategies. The outputs of this study inform practitioners of the emerging causes of mental illness in the construction, which will help them to properly plan on appropriate preventive strategies to adopt in order to curb the increasing psychological illness among construction workers.
Efforts to mitigate climate change should strive for climate justice to combat the current global crisis in which extreme weather events are becoming frequent and have dire consequences for vulnerable communities. As the built environment contributes considerably to greenhouse gas emissions, it is imperative for cities to implement changes to eliminate carbon pollution. Considering the magnitude of problems generated specifically in American cities, this paper focuses on such localities. In the context of climate justice, such changes can consist in making green jobs available to those who need them the most. Upon reviewing previous studies, we noticed that very few studies had been conducted on the role of local-led green job training programs as a strategy to improve low-skilled workers’ livelihoods and combat climate change in ways that further justice. Even more in the context of urban built fabrics. The aim of this paper is to provide a systematic literature review combining how local governments in the U.S. are engaging in climate change mitigation and climate justice, green jobs that improve the built environment, workforce development and training for vulnerable residents. The findings are used to provide recommendations for research and action.
109. Scholarship of teaching and learning for construction management education amidst the fourth industrial revolution: recommendations from a scientometric analysis

John Posillico
Birmingham City University, Birmingham, United Kingdom

Todd Stanislav
Ferris State University, Big Rapids, USA

Mark Shelbourn
Birmingham City University, Birmingham, United Kingdom

David Edwards
Birmingham City University, Birmingham, United Kingdom

Purpose: The scholarship of teaching and learning (SoTL) has gained traction in a wide range of academic disciplines as a legitimate and compelling form of scholarly and creative work for faculty. SoTL has explored questions about teaching strategies; student engagement, growth and learning; and other aspects of the teaching and learning process. Like the Fourth Industrial Revolution, SoTL is a disruptive force in higher education by, at its very core, making clearer how to support and enhance students' learning. The research presented here contextualises SoTL in Construction Management Education (CME), seeks to enrich CME models for teaching and learning, spur collaboration and advance SoTL as a whole.

Methodology: The overarching epistemology adopted both interpretivist and pragmatist philosophical stances embedded within inductive reasoning to critically analyse extant literature as a secondary data source. Groupings of SoTL research activity were established and common themes identified using scientometrics.

Findings: Research findings illustrate that, whilst SoTL has received increasing attention and development within higher education, a considerable scarcity of SoTL in CME is present. A comparative analysis between CME and select disciplines with a high representation of SoTL research allowed for the establishment of shared themes among the disciplines resulting in an initial set of recommendations for advancing SoTL in CME.

Originality: This research highlights the lack of SoTL inquiry and practice within CME and, in so doing, underscores the urgency for collaboration both within and outside of built environment disciplines to optimise future CME practices amidst the Fourth Industrial Revolution.
Quality of the workforce causes the quality of construction projects. It involves the ability and competence of the construction workforce that contributes to the success of the construction projects. The paradigm transference towards liberalization leads to opportunities for collaboration between countries, and on the other hand, it brings about tough competition. A competent workforce will survive facing such a paradigm. Indonesia, as a developing country, faces challenges in improving the abilities and competencies in the construction workforce sector. This paper reviews the existing literature to explore factors that can influence successful education and training in improving the competent workforce. It founds the readiness of the construction workforce facing liberalization and the lack of clarification in existing legislations, language in gaining international competence certification, financial problems as the main obstacles in improving workforce competence. To overcome these obstacles, this paper proposes a relook at existing legislation to provide more guidance on improving workforce competency, the need for stakeholder and private sector role in improving competence workforce, giving affordable and accessible training and education and English course to the construction workforce.

**Keyword:** education, training workforce, competence, construction industry.
369. Learning on the job through collaborative learning: analysing the appropriation of BIM knowledge in micro-enterprise architectural design companies

Rita Ferreira
Universidade de Sao Paulo, Sao Carlos, Brazil

Pedro Rocha
Universidade Estadual Paulista Julio de Mesquita Filho, Bauru, Brazil

Lucas Pereira
Universidade Estadual de Londrina, Londrina, Brazil

Ricardo Codinhoto
Bath University, Bath, United Kingdom

Marcio Fabricio
Universidade de Sao Paulo, Sao Carlos, Brazil

The lack of Building Information Modelling (BIM) knowledge appropriation by Architectural, Engineering, Construction and Operation (AECO) professionals is often considered one of the main obstacles to successful BIM implementation. Although barriers to implementation have been substantially investigated, a literature review on knowledge appropriation revealed that this area is poorly investigated and biased towards small and medium construction companies. The review also shows that no published research has addressed micro-enterprise design firms, despite these representing approximately 90% of the firms in the AECO sector. In this context, this research investigates whether collaborative learning can be a teaching and learning strategy for appropriating BIM knowledge in architectural design micro-enterprises. The Zone of Proximal Development concept and the Collaborative Learning method were the theoretical lenses to study BIM knowledge appropriation. The research method involved documental analysis of four years of data from a micro-enterprise. The data was classified into vertical collaboration, diagonal collaboration; horizontal collaboration; and individual action. Results show a progressive development of the professionals’ (BIM knowledge) autonomy, as they gradually moved from individual action and vertical collaboration relationships to diagonal and horizontal collaboration actions. The evidence indicates that teaching and learning strategies can contribute to the appropriation of BIM knowledge in the context of micro and small companies.
Collaborative construction delivery methods such as Design-Build (DB), Integrated Project Delivery (IPD), and Construction Management at Risk (CMR) have a need for a person that manages the design phase of a project made up of many different stakeholders.

A course was recently developed for a construction-based Design and Construction Integration (DCI) program that focuses on the unique role of managing the construction project during the design phase. The course covers a number of issues including: 1) effectively building and managing a team that is made up of owners, architects, engineers, contractors, and sub-contractors that have diverse educational and experiential backgrounds, 2) building team expertise by bringing in key subcontractors and specialty designers under various contract methods, 3) risk management of the different types of delivery methods are explored along with the legal issues associated with the delivery methods, and finally 4) managing the design phase costs and how stakeholders are compensated during the design phase to ensure a quality designed project that will be on budget and has a feasible construction schedule.

The course introduces many of these topics with the underlying concepts of lean design and construction best practices. This paper details the development of the course, class activities associated with the course, and lessons learned from implementing the course in a DCI program.
Falls from height (FFH) are an enormous public health jeopardy causing monetary as well as human loss (Hu, et al., 2011). Tripping, slipping, and falling are considered as reason of all the major injuries (48%) and fatalities (30%) (Hu, et al., 2011), marking it among the leading unintentional fatal workplace events. This makes the need of safety at heights a prerequisite in safety management culture of the construction sector. Traditionally complying with OSHA rules on safety at height practices remained minimal with persistent negligence. In this research, Building Information Modelling (BIM) is used to develop an Application Programming Interface (API) in Autodesk Revit. The developed API helps to visualize the OSHA rules and SOPs for construction workers to work on building projects at different heights, in the BIM environment. The OSHA clauses are indicated as per the chosen height in BIM that facilitates and eases the process of following rules and regulations as per international safety standards. The industry’s feedback revealed that the developed API will help safety managers to prepare for precautionary measures to be taken and train the workers for job safety related to FFH well before the scheduled job, and attributes other than height should be added in the API to help improve safety environment on construction sites.
The new digital world resulting from creative disruption of technological innovations is demanding the future workforce proficient with a new set of data skills. Quantity Surveyors being one of the key actors in the construction industry have no exception. Data collection, data processing, data analysis, data ethics and data privacy are identified as five categories of data skill which are synthesised from the 13 sub-categories grouped from 30 data skills summarised through the literature reviewed. The questionnaire framed around the five categories of data skill is developed. It aims to explore how the quantity surveying undergraduates and graduates perceived their own level of data skills respectively and their agreement on data skills to be taught in quantity surveying programmes offered by the higher education institutions. The questionnaire survey participated by 574 of undergraduates and graduates concluded that data analysis skill is valued higher than the data processing skill. The second urgency skills and related competencies needed to be heightened by the higher education institution is data collection even though it has been self-perceived as the most competent skill within the five data skill categories. Data ethics was rated as the moderate among the total participant in the study as a skill to be thought by the higher education institution. The findings can be served as an input to the providers of QS programmes to enhanced the nurturing of data skill in their course curriculum. Data skill is a critical skill set needy to promote better embracing of state-of-the-art technology.
For many years, there has been an assumption that the UK construction industry is devoid of gender diversity. Part of this assumption was predicated on the representation of workers in construction sites, who are predominantly male. However, there are many positions in the construction industry that are not public-facing, and the question is whether the assumption that males fill most of these roles is also true. This issue has existed in the construction industry for many years; it appears that placing the sole onus on construction companies to employ more women may not be producing the desired level of progress.

This research aim to establish whether clients can influence gender diversity in the construction industry with an objective of determining the current position of inequality in the construction industry; and existing incentives and frameworks.

The research adopted an exploratory approach, with data collected through existing literature and records of 20 major construction companies, followed by interviews with Six individuals working for UK construction companies and clients of varying sizes. The study will awaken the construction industry and how it can initiate new proposals or support schemes that have worked previously, to encourage more women to join the construction industry. It reveals that clients have an important role to play if the construction industry is to improve on gender diversity through contractual commitments that could be monitored regularly throughout the duration of a project.
556. Evaluating the need for recovery from work for site-based construction practitioners in Australia

Chenjunyan Sun
Queensland University of Technology, Brisbane, Australia

Carol K.H. Hon
Queensland University of Technology, Brisbane, Australia

Nerina L. Jimmieson
Queensland University of Technology, Brisbane, Australia

Kirsten A. Way
The University of Queensland, Brisbane, Australia

Bo Xia
Queensland University of Technology, Brisbane, Australia

Site-based construction practitioners face high levels of job stress and need to recuperate from work-induced fatigue. Insufficient recovery from work will lead to work fatigue and health problems. While need for recovery (NFR) is an important concept to the wellbeing of construction practitioners, there is limited study in this area. Thus, this study aims to evaluate NFR for site-based construction practitioners in Australia and identify patterns of NFR as a function of demographics and work characteristics. A survey was conducted with site-based construction practitioners in Australia. Descriptive statistics, correlation analysis, and analysis of variance (ANOVA) were employed to analyse collected data. Results showed that the mean NFR of site-based construction practitioners in Australia was 17.96 (range = 6 – 30, 6 items). Age and work hours explained differences in NFR mean scores according to both the one-way ANOVA and correlations. NFR increased with work hours and decreased with age, with $r = 0.19$ and $r = -0.24$ respectively. The correlation analysis also indicated the negative relationship between work experience and NFR ($r = -0.21$). Work experience and work hours interacted to influence NFR according to the two-way ANOVA. The positive relationship between work hours ($\leq 60$ hours) and NFR was weaker in those with more work experience while this moderating effect of work experience did not apply to people working more than 60 hours. The significance of the study lies in providing insights to increase the work capacity of construction practitioners and help them to recover from job stress.
The coordination process plays a vital role in construction projects during the design phase when interferences and clashes between design systems are identified to reduce the risk of costly reworks. Despite the fact that coordination has been studied commonly in BIM research, limited research has explored the impact of virtual reality (VR) to understand how it can enhance the process. This research study examined the effectiveness of coordination processes in a building renovation project following an innovative approach based on virtual environments (3D-BIM VR) compared to the conventional approach (2D CAD). This research uses the Cyclotron Charette Test method to analyse both approaches in terms of accuracy, speed, and usability. Fifteen participants from engineering backgrounds participated in the prototype testing divided into two experiments. The first experiment involved visually identifying clashes from multiple 2D CAD drawings, while the second involved visually identifying clashes from 3D-BIM-based VR models. The results showed that the virtual reality environment not only helped uncover clashes quickly but also made it more accurate and helpful. A further finding from this research indicates that motion sickness hinders users’ participation in VR environments. Finally, future research pathways are discussed to improve the coordination process using VR technology.
727. How personality affects construction workers’ vigilance to repeatedly exposed struck-by hazards in road work zones

Namgyun Kim  
Texas A&M University, College Station, USA

Laurent Grégoire  
Texas A&M University, College Station, USA

Brian Anderson  
Texas A&M University, College Station, USA

Patrick Suermann  
Texas A&M University, College Station, USA

Changbum Ryan Ahn  
Seoul National University, Seoul, Korea, Republic of

In road work zones, fatal accidents between pedestrian workers and construction vehicles continuously occur. Pedestrian workers’ inattention toward approaching vehicles is one of the main causal factors of those accidents. Previous studies have claimed that individual personality traits may influence workers’ low levels of vigilance to the surrounding environment. However, little research has empirically examined how personality traits affect pedestrian workers’ vigilance to repeatedly exposed struck-by hazards in the context of road work zones. This study aims to reveal the relationship between construction workers’ locus of control (LOC) personality, an index related to risky behaviors, and vigilance to struck-by hazards in road work zones through a virtual reality experiment. In the experiment, workers’ vigilance to approaching construction vehicles was measured using eye-tracking sensors. The result supports that workers with external LOC tend to show low levels of vigilance to repeatedly exposed struck-by hazards. The findings of this study provide empirical evidence of the potential usefulness of identifying workers’ personality traits to provide personalized safety training rather than conventional one-size-fits-all safety training, thereby contributing to reducing fatal accidents in road work zones.
The rate of suicide among construction workers is high in Australia and other developed countries. Suicide has many negative consequences on the families of the deceased, the construction sector, and the economy. This literature review paper discusses several factors underlying the suicide of construction workers, including relationship problems such as divorce or separation, untreated psychiatric conditions, job stress, workplace injury, job insecurity, and substance abuse. However, seasonality or weather has not been indicated as one of the triggering causes of the suicide of construction workers. Construction workers, especially blue-collars, perform work on sites that are exposed directly to the weather. As a result, workers often suffer from different physical problems such as heat stress and fatigue. Research in the psychology field and among the general population has established the influence of weather on mood, behaviour, as well as intentional self-harm. However, it is still unclear if suicide among construction workers follows a seasonality pattern or not and if weather factors such as temperature are triggering factors of suicide. Therefore, the purpose of this paper is to shed more light on the suicide issue in the construction industry and the potential role of weather on increasing the suicide rate. Our review suggests that there is a potential for suicide to follow a seasonality pattern with a correlation between the suicide rate and temperature, sunshine, and humidity. This notion is yet to be confirmed using an empirical study in the future.
Concrete can be completely recycled in theory. In the Australian context, waste concrete recycling rate has been raising to a high value, preventing the landfilling from construction and demolition waste. Although most of them are downcycled to road base material, the resource shortage issue is not effectively solved owing to the enormous need of structural concrete. Nowadays, the alternative option closed-loop recycling has been valued, since the recycled aggregate (RA) used to concrete production is able to reduce the demand of natural mineral resources. The structural application of RA is still a lack of confidence concerning its inferior quality. Despite that, an innovative recycled concrete product CO2 Concrete gains the similar engineering property to virgin concrete by injecting the certain amount of carbon dioxide (CO2) into RA. Its overall environmental performance is also competitive through conducting life cycle assessment (LCA). However, emission allocation is an important issue in LCA that has no consensus on which one is the most suitable. Especially, distributing the upstream environmental burden to RA is normally neglected in LCA as the difficulty in evaluating the avoided burden. As a result, this study will apply the mainstream allocation methods that cut-off, partitioning rule, mass allocation, and economic allocation to the recycling process of RA, and investigate how different choices influence the final LCA interpretation of CO2 Concrete. Moreover, the comparative LCA between virgin concrete and CO2 Concrete will be presented in this study.
Concrete is one of the most highly consumed materials in construction. Recycled concrete is considered as a comparable product to virgin concrete, which has significant potential to conserve land resources and contribute to reduction in environmental impacts. However, the embrace of recycled concrete in construction market is very slow, because of loss in mechanical properties and unpredictable prices. Material selection is largely determined by costs rather than its environmental friendliness, while recycled concrete is found to be less price-advantaged than concrete. Therefore, to increase in its popularity, it is of great importance for recycled concrete to be less costly. Increasing popularity of recycled concrete requires a strong market. Many countries have provided political support to reduce hesitation of customers and stimulate use of recycled concrete, including obligatory use ratio of materials recycled from construction and demolition (C&D) waste in construction, tax deductions and subsidies for recycling activities, and formulation of standards for acceptable application of recycled aggregate in concrete. However, impacts of those policies on the price of recycled concrete remains unknown. This paper will review past literatures to derive a list of policy factors which might affect the price of recycled concrete, deliver survey questionnaire to potential respondents and conduct mean score analysis through SPSS to analyse the importance of each factor. Findings of this paper could help policy makers to enhance the performance of C&D waste recycling and stimulate development of market for recycled concrete.
Life cycle assessment (LCA) has been widely recognised as a standardized tool for quantifying the environmental and economic impacts of building products. Integration of building information modelling (BIM) with LCA tool can improve the effectiveness of LCA implementation. There are three types of BIM-LCA integration approaches (i.e. manual, semi-automated and full-automated BIM-LCA integration approaches), among which semi-automated BIM-LCA integration approaches have been highly recommended to conduct LCA analysis. However, there has been limited relevant research in performing LCA analysis from the integrated perspective of environmental and economic performance by using semi-automated BIM-LCA integration approaches. To address this issue, this research proposes a semi-automated BIM-LCA integration model based on Dynamo for conducting the environmental and economic assessment of a building over its life cycle. The applicability of the proposed model is validated by comparing three possible alternatives for non-structural external walls of a real residential building in China. This model allows to quickly and accurately determine the non-structural wall systems that have better economic and environmental performance. It is expected to assist in decision making of a building project by using this model at design stages.
264. The barriers of lean construction application in Australian construction industry: literature review

Mitchell Hughes  
Western Sydney University, Sydney, Australia

Wenchi Shou  
Western Sydney University, Sydney, Australia

Jun Wang  
Western Sydney University, Sydney, Australia

Lean Construction (LC) is one management philosophy that can be applied to improve both efficiency and sustainability of construction activities by concentrating on waste minimisation and value creation. LC has also been embraced by Australian construction companies but to a lesser extent. A systematic analysis on LC practices within the context of the Australian Construction industry is limited. Therefore, this paper aims to identify the current status of LC research in Australia and investigate the limitations in LC practices. The primary research methodology for this thesis is a Systematic Literature Review. A total of 40 papers achieved the selected criteria and provided key insights regarding the barriers that impede lean implementation. Twelve barriers contributing to effective LC implementation were identified utilising a qualitative approach of interpretation. Identified barriers were classified into groups, namely, Managerial, Cultural, Financial and Technical Barriers. It provides a theoretical framework enabling results to be analysed and discussed. It is hoped the discussions contained within this paper will enhance the existing body of LC literature and assist future qualitative studies to analyse the inherent challenges of LC implementation in the Australian Construction Industry.
301. Life-cycle impacts from environmental friendly bricks: the case of Nu-Rock bricks and blocks

Vivian Tam  
Western Sydney University, Sydney, Australia

Khoa Le  
Western Sydney University, Sydney, Australia

Chethana Illankoon  
University of New South Wales, Sydney, Australia

Cuong Tran  
Ho Chi Minh City University of Technology, Ho Chi Minh City, Vietnam

Daniel Rahme  
Nu-Rock Australia Pty Ltd, Sydney, Australia

There are growing stockpiles of industrial by-products world-wide and Australia is not an exception. Recycling these industrial by-products in an innovative way is a common challenge faced by many industries. “Nu-Rock” is a reliable solution to the industrial by-product dilemma by converting waste from coal fired power stations, steel mills, non-ferrous smelters and alumina smelters into a range of unique and superior masonry products for the building, construction and civil engineering industries. Nu-Rock produces a range of products including common or rendered bricks and blocks, masonry bricks, blocks, pipes, pavers, tiles, sheeted products and any other shaped building products. This research study conducted a detailed, and robust life-cycle analysis from cradle-to-cradle considering two parameters: cost and greenhouse-gas emissions. A model has been prepared using GaBi software for calculating the greenhouse-gas emissions. The life-cycle analysis has been prepared for illustrating current and likely future expenditure arising from block manufacturing process focusing on Nu-Rock and the customers/end-users. Nu-Rock technology can process approximately 250,000 tonnes of ash per annum and manufacture the equivalent of up to 330,000 tonnes volume of traditional building materials. The initial cost of Nu-Rock brick fall within the rage of a common brick in Sydney, Australia. The only difference between Nu-Rock blocks and common bricks is that Nu-Rock blocks derive a waste range of environmental benefits. Nu-Rock blocks emit GHG emissions approximately 27kg CO2-e per tonnes in the initial stages of the manufacturing process including transportation.

Keywords: carbon emissions, environmental impacts, industrial by-products, life-cycle analysis
Digital transformation has become a key strategy for companies to enhance service innovation performance. BIM is an enabler of this digital transformation in construction companies, but there has been little research on how this digital transformation affects service innovation performance. By using structural equation modelling and surveying 148 construction companies from China, this study analyzes how the digital transformation of BIM-enabled companies and their business models can influence service innovation performance. Later, research results are validated and practical management suggestions are provided by conducting semi-structured interviews with 5 project managers and senior engineers. The study shows that BIM-enabled digital transformation has a direct positive effect on service innovation performance, and also has an indirect effect through the mediation of the business model. Finally, four suggestions are proposed to improve service innovation performance: adopt a top-down digital culture; pay more attention to resource integration and process optimization; increase the technological competence; and improve coordination relationships among construction companies and their customers. This study associates BIM adoption with digital transformation. It investigates the relationship between BIM-enabled digital transformation, service innovation performance, and the business model of construction companies.
649. Automated assembly of reciprocal frame structures using robotics

Cheav Por Chea
Monash University, Victoria, Australia

Yu Bai
Monash University, Victoria, Australia

In this paper, the robotization of structural construction was studied in preference to the undemanding assembly of the reciprocal frame (RF) structures. Formulas were developed to automate the process of geometric forming and component evaluation. Subsequently, the robotic cooperative system was established to assemble the structure according to the positions and orientations of each component from the geometric forming module. The robotic system consists of two robotic arms, two navigating robots, depth cameras, and customized grippers. The structure was made from pultruded glass fibre reinforced polymer (GFRP) members owing to their lightweight, high strength and corrosion resistance. Concepts of temporary connections were also proposed to eliminate the offset generated during the construction. Finally, the comparative studies of the constructions in different light environments and with different ground obstacles were investigated through experimental investigations. The results showed that the structure can be successfully assembled with the proposed robotic system and the assistance of the temporary connection in most of the light conditions and ground obstacles.
656. An investigation of the drying shrinkage of CO2 concrete

Vivian Tam
Western Sydney University, Sydney, Australia

Anthony Butera
Western Sydney University, Sydney, Australia

Khoa Le
Western Sydney University, Sydney, Australia

The uptake of CO2 gas into recycled aggregate to create CO2 Concrete both improves the properties of recycled aggregate and traps the greenhouse gas. This paper aims to investigate and compare the performance of CO2 Concrete against that of the ordinary virgin aggregate concrete in terms of drying shrinkage. Whilst utilising optimal carbonation variables with a 120-minute duration and a 25 kPa pressure CO2 Concrete can consistently achieve similar to greater performance than the virgin aggregate concrete for drying shrinkage. The CO2 Concrete always surpassed the performance of the untreated recycled aggregate concrete. CO2 Concrete with 30% and 50% recycled aggregate content surpassed the virgin aggregate concrete in many cases whilst the 100% replacement could provide a similar performance with optimised carbonation variables.

Keywords: Carbonation, carbon-conditioning, CO2 concrete, recycled aggregate, recycled aggregate concrete
Automatic recognition of construction workers’ activities contributes to improving productivity and reducing the potential risk of injury. Kinematics sensors have been proved feasible and efficient to recognize construction activities. However, most of the sensors need to be tightly tied to workers’ bodies, which might result in uncomfortableness and workers’ reluctance to wear the sensors. This paper proposes a less physically intrusive construction activities recognition method with a single in-pocket smartphone to solve the problem. The smartphone was placed in the pocket in a natural and non-fixed manner, with its built-in accelerometer and gyroscope collecting motion data. Machine learning-based classifiers were trained to recognize construction activities. An experiment simulating rebar activities was designed to verify the effectiveness of the proposed method. The experiment results showed that the proposed method could identify rebar activities (with an accuracy over 94%) in a non-invasive manner.
The increasing demand for nearly-Zero Energy Buildings contributes to a broader discussion of implementing building-integrated photovoltaics (BIPV) on building envelopes. Existing research indicates that BIPV products should be digitally represented in Building Information Modeling (BIM) to facilitate the design process. The Industry Foundation Classes (IFC) schema as data exchange standard needs to support the relevant BIPV use cases to enable the exchange of relevant BIM data between stakeholders. However, there is a lack of clear identification of BIPV use cases which are needed as a basis for assessing IFC’s ability to capture and represent BIPV products digitally. The identification of BIPV use cases is also necessary for the proper development of a Model View Definition (MVD) for IFCs in the BIPV domain. This study uses the technical pre-design consideration as sample use case to demonstrate the processes of developing an MVD for BIPV digital products in the Australian context. A three-step research approach is employed, including a collection of use cases through a literature review and interviews, defining exchange requirements and proposing an initial MVD based on IFC4 ADD2 TC1. This paper contributes to the BIPV area by providing a BIPV use case description for the Technical Pre-design Consideration use case in the Australian context and identifying existing challenges in the current IFC schema related to representing BIPV product information.
Sustainable buildings are designed to provide a better built environment that reduces environmental impacts, supports communities for social needs and preserves economic gains. Despite a growing interest in sustainable development over the past few decades, there has been surprisingly little research focusing on the implications of human factors to a sustainable built environment. Sustainable building solutions shall be informed by the needs of building occupants and made in adaptive response to environmental, economic and socio-cultural changes. Interactions between users and buildings are of great importance to determine how successful a sustainable building is. Literature revealed that a failure of putting users at the pinnacle of designing sustainable solutions could be one of the main underlying reasons of underperformance of sustainable buildings. This paper presents a conceptual framework to demonstrate how human centric solutions contribute to improving user-environment interactions in sustainable buildings. By considering human centric solutions, sustainable building performance can be optimised by integrating users’ needs and aspirations into the design and development process. This paper helps increase the understanding of the roles of human factors in sustainable buildings, hence supporting the development of social sustainability which has been greatly overlooked in the pursuit of sustainable development.
As prefabrication becomes more prevalent in the construction industry, sustainable practices involving it is starting to become more significant. Although prefabrication reduces emissions through reducing construction time and wastes during production, at the end of the building’s life the material waste produced is still the same. Sustainability generally involves three components namely, economic, environmental, and social sustainability. This study aims to investigate the sustainability impacts from reusing prefabricated concrete panels sourced from buildings reaching the end of its service life. The main framework used revolves around lifecycle assessment (LCA) in terms of embodied energy. The LCA includes processes and materials used starting from the deconstruction of the donor building to the construction of the host building. Testing the framework uses a model of the host building was made. Providing a realistic representation of the proposed construction technique. After the creation of the flow diagram, the embodied energy is converted into emissions to gauge its environmental impact. Next, financial analysis is done to quantify the economic benefits gained by adopting this construction technique. Sensitivity of this framework is tested by altering the donor building locations. Although there are additional processes involved in reusing concrete panels, a general reduction of energy consumption leading to greenhouse gas emission reductions. Apart from the environmental benefits, reusing prefabricated components is also shown to be financially viable when the parts are sourced from the Indo-Pacific region. Briefly, reused concrete panels can serve as a sustainable construction material for the mainstream construction industry.
This paper is focused on enhancing the computational efficiency of stress-based topology optimization (SBTO). In theory, a solution to the SBTO problem can be acquired via a traditional optimization procedure. However, hundreds of iterations are often required in the solution process, which significantly increases the computational cost. To accelerate the optimization procedure, an iteration-free method based on the convolutional neural network (CNN) is proposed in this paper. The p-norm stress aggregation scheme is adopted for the measure of global stress level, and the method of moving asymptotes (MMA) is utilized to generate datasets consisting of various load conditions and volume fractions. The framework of U-Net is employed to improve the performance of the proposed neural network. With a well-trained network, the optimized structures can be generated in real-time without any iterations with little sacrifice on the performance of the design scheme. The integration of the deep learning method and SBTO has enormous potential for future practical applications in design practice.
675. Personal protective equipment compliance monitoring enhanced by worker re-identification across multiple cameras

Kok Yiu Wong
Hong Kong University of Science and Technology, Hong Kong, China

Han Luo
Hong Kong University of Science and Technology, Hong Kong, China

Mingzhu Wang
Loughborough University, Loughborough, United Kingdom

Pak Him Leung
Hong Kong University of Science and Technology, Hong Kong, China

Chin Pang Cheng
Hong Kong University of Science and Technology, Hong Kong, China

Construction sites are highly hazardous due to the dynamic interaction between workers and moving equipment, with high fatality rates caused by collision and falling from height, etc. Hence, identifying unsafe behaviors among workers is crucial for enhancing site safety, such as tracking their on-site movement and personal protective equipment (PPE). Vision-based video processing has been actively used to automatically recognize workers and their behaviors on construction sites. However, existing studies mainly monitor workers within a single camera capturing only a small sub-region. As workers typically move around fairly large sites, continuously tracking their movement across multiple cameras would enable more comprehensive behavioral analyses. Hence, this paper proposes a framework, which combines worker re-identification (ReID) and PPE classification, for safety compliance monitoring among workers. An incident reporting mechanism is developed to log any incident of workers not wearing the necessary PPEs. An actual construction site dataset is collected to validate the effectiveness and practicality of the proposed framework in reporting missing-PPE incidents. Compared with existing practices monitoring workers in individual camera, our framework can track the workers consistently across multiple cameras, monitoring their non-compliant behaviors comprehensively over space and time.
As two essential components of Industry 4.0 in the construction industry, building information modelling (BIM) and Internet of things (IoT) tend to be integrated. Research in the field has increased significantly in recent years, yet previous reviews on this field are limited, and a review study with both quantitative and qualitative analysis of BIM-IoT integration remains wanting. Thus, this review paper investigates 107 peer-reviewed journal articles in the field of BIM-IoT integration using the mixed scientometric-content analysis. The findings reveal that the research in this field is promising, and collaboration has achieved well-recognised outcomes, while more collaborations are expected. Besides, the analysis reveals that the research is evolving from traditional construction themes, such as safety, energy efficiency and thermal comfort, to evolutionary concepts, such as digitalisation, Industry 4.0, digital twin and smart cities. Finally, five research opportunities are outlined, including reliability and robustness, interoperability, integration with other emerging technologies, security and privacy, and reluctance from the construction industry. This review is the first attempt to conduct a scientometric analysis of the research of BIM-IoT integration. The findings provide directions for future research.
The technical and management issues that existed in traditional healthcare institutions, such as relatively lagging technologies, untimely information, have received increasing attention. In recent decades, the reconstruction or transformation of smart healthcare system has emerged as a new research trend. Especially with the outbreak of the COVID-19 epidemic, the smart healthcare system realizes the timely allocation of medical resources and sharing of information. Therefore, this paper aims to develop an indicator framework for assessing the hospital’s readiness in transforming towards smart healthcare. First, based on the literature review, an indicator framework of readiness of smart healthcare transformation is developed for smart healthcare transformation, which includes three hierarchies of “smart facility management (smart FM)”, “medical system (MS)” and “organizational management (OM)”, which can reflect the readiness towards smart healthcare transformation of medical institutions’ level comprehensively. Secondly, an online questionnaire survey is conducted to test the validity of the indicator framework. Based on factor analysis, the indicator framework is proved to be effective as a whole, and all the 26 indicators are significant. Finally, the readiness of case hospital “A” in the smart healthcare transformation is examined using the developed evaluation framework and fuzzy synthetic evaluation method. The findings of this paper provide an assessment tool for medical institutions to self-evaluate their status in the information construction process.
681. Effect of engineering training on teamwork skills in a multi-user virtual reality platform

Peng Wang
Southwest University, Chongqing, China

Peng Wu
Curtin University, Perth, Australia

Due to the rapid evolvement from the technology at Architecture, Engineering & Construction (AEC) fields, providing sufficient training programmes to improve collaborative construction skills of employees has played an important role in the industry. Collaboration during the learning process is regarded as an important factor that contributes to student learning. VR-enabled training provides an efficient environment for trainees. However, there is a lack of studies on how VR collaborative training strategies can be evaluated and improved with productivity concerns. The purpose of this study is to evaluate the effect of VR collaborative training on teamwork skills, including coordination, decision making, leadership, adaptability and communication. The results indicate that VR collaborative training exercise can have positive effect on teamwork skills, especially in coordination, decision making, adaptability and communication, but there is no significant difference in leadership and interpersonal skill after VR collaborative training exercise.
In order to reduce the number of building construction accidents (BCA) and ensure construction activities safety, investigators analyzed BCA in China with recent representative 10 year data. Firstly, the investigators collected BCA information in the research period, determined accident trend and pattern in various dimensions. The development of safety management strategies for tower crane accidents (TCA) and collapse accidents (CA) was essential for construction safety control. Secondly, the investigators collected major construction accident (MCA) information in China in the research period, established AHP models for TCA and CA respectively. The second-level accident causes of the AHP model can provide targeted evaluation feedforward factors for quantitative checklist. Finally, the investigators formulated an audit method for TCA management measures and CA prevention management measures. It was found that there were specific trend and pattern in the occurrence of BCA, such as hourly trend, monthly trend, annual trend, regional pattern, type pattern, and cross pattern. Two MCA, TCA and CA, were screened out in this study. The corresponding feedforwards were obtained by analyzing the MCA.
Environmental impact assessment (EIA) is becoming a critical part of road asset management. EIA-related knowledge and information are often sporadic, and traditional management approaches are considered inefficient in collecting fragmented project information and making such information available to project managers. Some studies have tried to establish basic ontologies to solve such problems using the resource description framework (RDF). However, these studies have not sufficiently identified all special concerns for EIA ontology, and RDF-based ontologies have limitations such as large storage space when dealing with large volume of data and poor visualisation performance. To overcome these challenges, this study aims to investigate a framework for organising, transferring, and visualising EIA information flow using Labelled property graphs (LPGs) based on the Neo4j graph database. Two scenarios in a real-life project, including searching for featured and hidden information are investigated to validate the improved performance of LPG-based EIA ontology (EIAO). The results show that the framework can provide support to project managers through the development of a smart decision-making system to reduce the time required to collect and analyse EIA information. By applying a novel data model to store and present ontology, storage efficiency and visualisation performance for managing environmental information are improved. In addition, the EIAO provides quicker search and reasoning functions to replace part of the manual work in traditional EIA, which can reduce time and cost in performing such activities.
Despite an increasing emphasis on collaborative innovation in megaprojects, it is still empirically not known how the combinations of drivers could lead to collaborative innovation. Using a configurational approach, this study investigates the combinations of drivers contributing to collaborative innovation. First, questionnaire surveys were used to collect data from a sample of Chinese megaprojects. Data were then analysed by fuzzy-set qualitative comparative analysis (fsQCA). The findings demonstrate that four equifinal combinations can promote collaborative innovation: (1) learning, responding to project and clients’ requirements, improving efficiency, responding to competition, and responding to external changes; (2) learning, responding to project and clients’ requirements, and improving efficiency; (3) learning, gaining rewards, and responding to competition; (4) responding to project and clients’ requirements, improving efficiency, gaining rewards, and responding to external changes. Overall, this study contributes to collaborative innovation research and provides practical suggestions to better manage and promote collaborative innovation.
A tailored artificial intelligence model for predicting heat strain of construction workers

Wen Yi
The Hong Kong Polytechnic University, Hong Kong, China

Yijie Zhao
Chang’an University, Xi’an, China

Albert P.C. Chan
The Hong Kong Polytechnic University, Hong Kong, China

Traditional multilayer perceptron models have been used to predict the heat strain of construction workers. A major drawback of these models is that their black box nature may generate predictions that contradict domain knowledge and this casts doubt to construction managers on the effectiveness of the models. To overcome this limitation, a tailored multilayer perceptron model is developed to predict the heat strain of construction workers that guarantees the monotonicity of the predicted heat strain with some input features (e.g., temperature). The main finding is the tailored multilayer perceptron model never predicts results that contradict domain knowledge, making it more acceptable to construction managers. The tailored multilayer perceptron model is validated by a Hong Kong based smart solutions company.
With societies and economies developing rapidly across the world, a large amount of energy is consumed at an alarming rate. Unfortunately, its huge environmental impacts have forced many countries to take energy issues as urgent social problems to be solved. Even though the construction industry, as the one of most important carbon contributors, has been constantly and academically active, researchers still haven’t arrived at a clear consensus for system boundaries of life cycle energy. Besides, there is significant difference between the actual and estimated values in countless current and advanced energy estimation approaches in the literature. This paper proposes an intact framework for building life cycle energy estimation, which includes three major energy sources: embodied, operational, and mobile energies. A systematic review is conducted to summarize the selected 109 studies published during 2012-2021 related to quantifying building energy consumption and its major estimation methodologies and key influence factors. Proposed results show that the method limitations and the variety of potential parameters lead to significant energy estimation errors. An in-depth qualitative discussion is conducted to identify research knowledge gaps and future directions.

Keywords: Life cycle energy estimation of building, Quantitation models, Science mapping, Systematic review
When regarded as a socio-technical system, the cognitive building represents the next generation of safe, resilient and sustainable building systems. The cognitive building provides promises, but the promises have not been consciously explored, particularly within the context of modular construction, an emerging novel construction technique, which seems to offer an unexploited opportunity. This study aims to develop a framework for the modular construction of a cognitive building as a socio-technical system (STS) to ensure effective human-technology interaction, stakeholder acceptance and engagement. The framework was examined with a mock-up project of a student smart residential building in Hong Kong, similar to a cognitive building, which adopted a modular construction technique. The case demonstrated that the framework effectively ensures multi-perspectival involvement of key stakeholders at the design and manufacturing phase to produce modular units cleanly embedded with appropriate and operable cognitive building technologies for users and facility managers before being transported to the site. By considering socio-technical system requirements, the developed framework optimises the modular construction approach to design and develop cognitive buildings and other digitally-enabled buildings for smart living. Due to technological advancement, as buildings are taking different forms, future research is encouraged to explore the modular construction approach’s possibilities.
Underground utilities (UU), as the lifeline of urban operation, plays a vital role in ensuring the life of urban residents. According to the China National Bureau of Statistics, 797,000 million kilometres of water supply pipelines, 11,716 million kilometres of gas supply pipeline, 630,000 million kilometres of drainage pipe, and 276,000 million kilometres urban central heating pipelines have been constructed by the end of 2017. Therefore, there are a large number of UU projects need to be maintained every year. Ground penetrating radar (GPR) is the most widely used and efficient tool in underground utilities maintenance engineering. Although GPR is not a new concept, the GPR application on Underground Utilities field has generated interesting updates with the continuous iterative advances in engineering equipment and practical experience in recent years. This report on the following new developments in this field: 1) The new progress of GPR equipment technology was updated; 2) Limitations and the best performance were reported; and 3) Research trends on Underground Utilities applications were proposed in this paper.
Terrestrial Laser Scanning (TLS) has been applied in construction measurement industry because of its high efficiency and precision. At present, the method of measuring the dimensions of the indoor door opening still depends on manual measurement. The research on the recognition of the indoor door opening has achieved outstanding results, it has not made intuitive and efficient measurement of the door opening. Therefore, this study proposed a method for automatic measurement and visualization of indoor door opening dimensions based on TLS. This method can efficiently pre-process the high-density scanned data, and automatically identify and extract the door opening according to the inclusion relationship and the extension direction of point cloud data. Then, the method simulates the manual measurement process to automatically measure and visualize the dimensions of indoor doors. Finally, through a case study of a residential room, the effectiveness of the proposed method is further verified.
703. Experimental study of condensation characteristics and operation strategies of induction radiant air-conditioning system

Qiang Si
Changzhou Vocational Institute of Engineering, Changzhou, China
Zhifang Engineering Design Co., Ltd, Nanjing, China

Jianjun Wei
Changzhou Vocational Institute of Engineering, Changzhou, China

Yuan Li
Zhifang Engineering Design Co., Ltd, Nanjing, China

To study the operation and condensation characteristics of the induction radiant air-conditioning system as a novel system which combines the induction ventilation and radiant air-conditioning, the characteristics of the convection and condensation of the indoor terminal device radiant in-duction-unit were studied. The mass transfer coefficients, condensation temperatures, condensation rates were experimentally analyzed. The time spent to achieve indoor thermal environment steady state was collected. It was found from the results that the primary air flow rate and temperature mainly affected the mass transfer coefficients, condensation temperatures, and condensation rates. And when the indoor thermal environment achieves steady state, heat transfer performance of the radiant induction-unit is mainly affected by the primary air temperature. When condensation occurs, the primary air flow rate has more influence on the condensation rate. The startup and response performance of the system is better than those of the traditional radiant air-conditioning system. In condensation condition, the reasonable control strategies are maintaining the primary air temperature and adjusting the primary air flow rate which can ensure enough heat transfer and stabilize indoor thermal environment faster.
Prefabrication relies very much on the upstream design stage and the communication efficiency of the information flow. To facilitate data interoperability, processing building data from BIM model plays an essential role in maintaining efficient communication in collaborative design. And it is important to keep a record how these parameters of design model were created and changed. This paper proposes an approach utilizing Building Information Modeling (BIM) and blockchain technologies for design collaboration. It starts with the information processing including information extraction and Industry Foundation Classes (IFC) extension, which involves the creation of identifier based on prefab-related information and a change detection algorithm established to automatically resolve clashes caused by simultaneous work in design collaboration. The detected changes are recorded and uploaded by a proposed blockchain network for better traceability and immutability of design information within the whole construction lifecycle. The proposed framework is implemented with JupyterLab and Hyperledger Fabric in illustrative examples, the results of which indicate that the proposed change detection algorithm and blockchain network perform well in the efficiency of design information processing and tracking.
When planning to build greenways in jungles, accurate topographic information of the target area is significant. The traditional topographic survey is usually manually conducted with several tools, which is not only labour-intensive and time-consuming, but also has limitations in accuracy and efficiency. Therefore, this paper presents a method to generate a digital elevation model based on unmanned aerial vehicle (UAV) and ground equipment supplements the ground area covered by vegetation where UAV-based equipment cannot reach. Iterated Closest Point (ICP) is first used to register the point cloud data from UAV and ground mobile equipment. Then, point cloud classification is used to non-ground point cloud. Finally, the digital elevation model and contour line are obtained. A real experiment is conducted to validate the presented method. The results show that this method not only overcomes the UAV’s limitation of having difficulty in collecting point cloud data from the covered area, but also realizes large-area point cloud data collection that ground mobile equipment cannot. Compared with the traditional base station and multi-person assistance measurement, the presented method is more efficient and effective.
707. Defect analysis for condition assessment using IFC

Shuyuan Xu
School of Civil Engineering and Architecture, Zhejiang Sci-Tech University, Hangzhou, China

Jun Wang
School of engineering, design and built environment, Western Sydney University, Kingswood, Australia

Xiangyu Wang
School of Design and the Built Environment, Curtin University, Perth, Australia

Given the importance of bridges in modern infrastructure system and their aging problems in recent years, road agencies conduct programmed inspections on their bridges. Documentation of defects identified during inspections in an integrated bridge BIM is an efficient solution for lifecycle management of civil assets. To take advantage of bridge BIMs and effectively utilise the defect information included, this paper proposed an IFC-based method to conduct element-level condition assessment and document the resulting condition levels. The procedure is first clarified through documentary research and appropriate IFC entities are chosen. Based on the above, a python-based tool is developed to automate the condition evaluation using the IFC-based bridge BIM. The developed tool is validated through case study, proving its applicability within an integrated and dynamic BIM environment.
Recycled concrete aggregate (RCA) differs from natural aggregates in that its surface is encased in cement mortar. Due to the increase in waste concrete brought about by economic development, it is imperative that RCA is used as a new environmentally friendly material to replace natural aggregates and promote low carbon recycling. However, RCA has characteristics such as greater water absorption and a rough surface. Improving its performance is therefore a key issue in the promotion of recycled aggregate concrete. This paper reviews the existing methods of RCA enhancement, pointing out the advantages and disadvantages of each approach. The conclusion is that carbonation is the best enhancement method that balances efficiency and environmental friendliness. Future research on RCA reinforcement should focus on carbonation.
One of the essential challenges of 3D modeling from LiDAR point clouds is in classifying object shapes. Unfortunately, accurate and robust classification of complex piping components is difficult and professional interpretation generally needs experts to handcraft descriptors, which is inefficient. Recently, deep learning (DL) based methods for point cloud classification have been successfully applied in many construction fields, and several attempts have been made on classifying piping components. However, these methods do not exploit local context and adopt deep residual learning for learning features, leading to inefficient representation learning on point clouds and inferior performance. To address these limitations, a new DL framework is proposed to classify piping components from point clouds, which efficiently learn local context hierarchically, and adopt very deep residual settings to construct very deep networks. First, a sole public piping dataset named Pipework is selected, canonicalized, and benchmarked using six representative DL-based methods. Second, a new squeeze-excite based local aggregation operator (SE-LAO) is developed to efficiently learn descriptive features by introducing an SE mechanism for the local context learning. Based on the new SE-LAO and a strong baseline PseudoGrid, we construct a new network named SE-PseudoGrid. To validate the proposed method, comprehensive experiments are conducted on the Pipework to compare the effectiveness and efficiency of our SE-PseudoGrid with the baseline. Experimental results manifest our SE-PseudoGrid outperforms the baseline by a noticeable margin, achieving an overall accuracy of 96.3% and average class accuracy of 97.5%.
Carbon dioxides and solid wastes are produced by building construction, aggravating the problem of soil pollution and climate warming. The 3D concrete printing (3DCP) technology applied to fabricate cementitious materials has been verified to obtain advantages, especially in significant construction intelligence automation without formworks. Consequently, varying solid wastes added into composites are combined with 3DCP to improve sustainable, environmental-friendly, economical, and intelligent construction degrees. This study aims to comprehensively review the solid waste characteristics, categories, multiple solids wastes (MSW) incorporation, and benefits for solid wastes incorporated cementitious materials using the 3DCP method. Moreover, mechanical capacity improvement methodologies combining solid wastes, reinforcement, and engineering applications are determined. The present research status of the combination of 3DCP and solid wastes incorporation are summarized in this review. Besides, printed functional composites and MSW incorporated concretes, combined 3DCP, building information modeling, and machine learning technology are proposed to accelerate the development for practical application of solid wastes incorporated printed structure.
Concrete, as an important part of the infrastructure and construction sector, has been explored by many researchers. Its strength prediction and mixture optimization were explored by many researchers. Hence, this paper summarizes three frequently used machine learning models, involving Artificial neural network (ANN), Support vector machine (SVM), Decision trees. From their inherent principles to evolved variants in construction sector, this paper aimed to provide an overview of these popular machine learning techniques.
Shear wall structure using composite shear with rib as a new prefabricated concrete component, the precision of its connection system is more difficult to control than grouting sleeve. With the rapid and high-precision technical characteristics of “real scene replication” of three-dimensional laser scanning, the deficiency in ignoring the site variability of BIM technology can be solved. The integrated application of BIM and three-dimensional laser scanning technology can improve the precision control. It has been used for high-precision detection in the whole process of production and installation of shear wall structure using composite shear with rib. By analyzing the technical problems and policy background, this paper studies the influencing factors and the process of applying BIM and 3D laser scanning technology to shear wall structure using composite shear with rib. A prism target method for high-precision scanning is proposed, where the station scheme is developed with considering the complex environment of fabricated buildings. Based on the case study, the distribution law of error data is summarized based on the tolerance theory. The research results can provide reference for the high-precision production and installation of shear wall structure using composite shear with rib and other prefabricated components, and promote the application of a new generation of intelligent detection and monitoring tools in the construction of prefabricated buildings.
735. A framework of optimal procurement decision-making of prefabricated component based on BIM component library

Jizhuo Huang  
College of Civil Engineering, Fuzhou University, Fuzhou, China

Jun Wang  
School of Built Environment Western Sydney University, Sydney, Australia

Wenping Pan  
College of Civil Engineering, Fuzhou University, Fuzhou, China

Zhenyuan Cao  
College of Civil Engineering, Fuzhou University, Fuzhou, China

Yong Wang  
College of Civil Engineering, Fuzhou University, Fuzhou, China

Gang Chen  
College of Civil Engineering, Fuzhou University, Fuzhou, China

This study provides an optimal decision-making framework for the procurement of prefabricated building components. The framework is that in the structural design stage, the designer first uses BIM to carry out structural design and structural splitting of the prefabricated building based on the mechanical properties and space requirements of the decision-maker, and then imports the feasible splitting scheme into the BIM component library. Then, the decision-maker can input relevant management information into the optimization decision-making system according to the project management requirements, such as cost, construction duration, carbon emission and other management information. After that, according to the type of management demand information input by the decision maker, the optimization decision system automatically selects the objective function and constraint function from the objective function library and constraint function library to form a mathematical model, then matches the most relevant optimization algorithm from the algorithm library, and uses the optimization algorithm and all known information to solve the mathematical model, and obtained several sets of optimized component procurement schemes. Finally, decision makers analyze and select these component procurement schemes according to subjective and objective factors, which can be used to guide the application of practical engineering.
736. An analysis on the existing BIM delivery standard system in China

Jizhuo Huang  
College of Civil Engineering, Fuzhou University, Fuzhou, China

Jun Wang  
School of Built Environment Western Sydney University, Sydney, Australia

Jinbing Lan  
College of Civil Engineering, Fuzhou University, Fuzhou, China

Yanhong Li  
College of Civil Engineering, Fuzhou University, Fuzhou, China

Yuxuan Chen  
College of Civil Engineering, Fuzhou University, Fuzhou, China

Gang Chen  
College of Civil Engineering, Fuzhou University, Fuzhou, China

In the process of application and development of BIM Technology, which application level is also expanding. With the advancement of engineering projects and the increase of the number of projects, the amount of information will increase geometrically. In order to ensure the integrity of various information related to the project at the time of submission and the consistency of information received by all project participants, this paper first analyzes the problems arising from the application background of city level BIM, then traverses and compares the contents of relevant domestic BIM delivery standards, and summarizes the shortcomings of existing BIM delivery standards. Finally, the improved compilation principle of BIM delivery standard is put forward. Therefore, the ideas proposed in this paper can provide some reference for solving the problems in the process of BIM application.
741. Smart governance of urban ecological environment driven by digital twin technology: a case study on the ecological restoration and management in S island of Chongqing

Aobo Yue
Chongqing University, Chongqing, China

Chao Mao
Chongqing University, Chongqing, China

Shuming Zhao
Chongqing University, Chongqing, China

China is undergoing rapid urbanization, which has caused undesirable urban sprawl and ecological deterioration. Combining information technology for ecological environment governance is an effective measure to improve governance efficiency. In this paper, based on the analysis of the ecological restoration and governance case of S Island in Chongqing, an ecological intelligent governance system architecture based on the integration of multiple information technologies such as digital twin is extracted. The research shows that the S Island is based on the technical concept of digital twin, and integrates a variety of information technology integration, collects and processes a large amount of data generated in the whole process of S Island repair and operation, and builds it based on the digital twin concept and accurately maps the physical space. This system model can be stored and processed based on the integrated data, realize knowledge graph visualization, algorithm optimization and iterative integration for different objects and application scenarios, and finally serve different functional modules in ecological governance, which can be used to support Smart governance of cities.
Logistics Park, as a large-scale construction project, has many risk factors that may affect the normal operation of the project in its construction. If the influence of risk factors is ignored, it will bring irreparable losses. Therefore, according to the characteristics of logistics park construction project (LPCP), it is of great practical significance to propose a new risk management model for the risk research of LPCP. Considering the whole project, this paper puts forward a new risk analysis model for construction projects, establishes a risk evaluation index system according to the causes and possible consequences of risks, describes the uncertainty and hesitation of failure mode and effects analysis (FMEA) team members’ risk evaluation information based on the uncertainty language Z number, calculates the expert weights by means of dynamic weight adjustment method, and then uses fuzzy C-means clustering algorithm to deal with the risk evaluation of LPCP.
The COVID-19 pandemic has resulted in significant social and economic losses worldwide. The pandemic puts forward great challenge and higher requirements for future hospital construction especially for building layouts. How to conduct reasonable hospital building layouts design to meet different requirements building performance for peacetime (high efficiency) and emergency (low risk) has coming to be a highlighted problem. This study proposed a performance-oriented approach of automatically generative design and optimization of hospital building layouts in consideration of peacetime and emergency in the early design stage. Firstly, the key points and parameters of hospital building layout design are analyzed and summarized. Then, to meet the requirement of high efficiency and low risk performance, adjacent preference score and infection risk coefficient are constructed as constraints. On this basis, automatic generative design is conducted to generate building layouts schemes. Finally, the comprehensive score of schemes was calculated by normalization formula to obtain the optimal scheme. The method proposed in this study has been applied and verified in an actual hospital building layout design, which was proven to be its reliable and practicable and can help systematically explore the solution for better decision making.
755. Method on pose estimation of excavators based on onboard depth camera

Jingyuan Tang
Department of Civil and Environmental Engineering, Hong Kong University of Science and Technology, Hong Kong, Hong Kong

Xiao Zhang
Department of Civil and Environmental Engineering, Hong Kong University of Science and Technology, Hong Kong, Hong Kong

Peter Kok-Yiu Wong
Department of Civil and Environmental Engineering, Hong Kong University of Science and Technology, Hong Kong, Hong Kong

Jack C.P Cheng
Department of Civil and Environmental Engineering, Hong Kong University of Science and Technology, Hong Kong, Hong Kong

Pose estimation of construction machines describes their motions and orientations in 3D space, which provides basic information for remote control, safety monitoring and productivity analysis. Among the commonly used construction machines, the excavator is an important one whose pose information has significant value in the development of automatic driving systems and operation safety monitoring. Regarding vision-based pose estimation of excavators, previous studies mainly rely on image data from digital cameras installed on sites. However, their robustness may drop due to occlusions by surrounding clutters. To address these problems fundamentally, this study proposes a method on partial pose estimation of excavators, with an onboard depth camera installed on the cabin of the targeted excavator. This solution is inspired by the visual effect produced by the operator’s eyes, according to the Bionics principles. First, by processing the depth camera data, the spatial coordinates of several pre-defined keypoints of an excavator are obtained. Afterward, by combining the keypoint coordinates with prior knowledge of the geometric relationship of excavators, a pose triangle is computed which describes the pose of the excavator. Finally, the feasibility of the proposed algorithm is preliminarily verified by experimental data from real construction sites. This study contributes not only to solve the problem of occlusion when using visual sensors on sites, but also to provide a theoretical basis for the design of onboard control systems for excavators.
Thermal environment has a significant impact on the safety, energy consumption, and comfort of the building systems. However, indoor environment inspection and energy auditing are labour-intensive and costly because of limited tools and complex working conditions. Unmanned aerial vehicles (UAVs) have become more and more accessible in recent years. They have been applied in many industries including building inspection. In GPS-denied environments such as tunnels, UAVs could only rely on visual and range sensors for localization and mapping. While in tunnels where illumination condition is poor and texture structures are hard to find, thermal cameras offer a complementary perception. The thermal information of the construction is also a key component for tunnel inspection and energy auditing. Motivated by this, we proposed a real-time 4D (3D geometric and thermal) mapping system for UAV construction inspection in GPS-denied environment such as subway tunnels. Combining a RGB-D camera and a thermal camera, the proposed system builds a dense 4D map for the environment in real-time, which can be used for building inspection, energy auditing, and retrofitting. The system performance is verified through field experiments.
The world has been in a period of rapid development in the digital era, and the production activities in all walks of life have begun to turn to technological innovation and management improvement in the globalization, personalized, virtualization, intelligent and socialized environment. With the continuous expansion of the construction project scale, the informatization of the construction project management is becoming more and more extensive. We will organically integrate the Internet, big data, VR, BIM, 5G, artificial intelligence, cloud computing and other technologies to play a positive role in the modernization of governance and governance capacity in the field of construction.

From the perspective of the whole life cycle of the project, and on the basis of the existing BIM and cost engineering research, this paper conducts in-depth research on how to use the Internet, big data, artificial intelligence and other science and technologies to build an intelligent platform for engineering project management. So as to realize the construction project management of information, intelligent, scientific, international.

Keywords: engineering, management, wisdom, platform
Concrete has been a global widespread material in the construction industry with a utilization quantity of 10 billion per year. Eco-friendly concrete becomes a focus of research due to the environmental influences from traditional aggregates. Coal gangue (CG) is industrial solid wastes generated in coal mining and washing, which leads to land occupancy, environmental pollution, and security issues. Therefore, this paper explored CG as an aggregates source in the preparation of lightweight shotcrete (CGLS), aiming to mitigate the depletion of concrete raw materials and the disposal of CG. Coal gangue aggregate (CGA) will be coated by silica fume slurry manually or in the desiccator, namely CGACM or CGACD method, respectively. The effects of CGA ratios, the particle size of CGA, and surface pre-treatment methods on CGLS were experimentally studied on the compressive strength, split tensile strength, and density. The result of the density indicated that CGA was an ideal material for lightweight shotcrete. Compared with the non-activated series, the compressive strength of the CGACD and CGACM series experienced a downward trend as the CGA ratio increased, especially when the size of CGA was 200μm and 500μm. CGACM showed relatively more efficient results than CGACD considering both compressive strength and split tensile strength. The most optimal mix proportion for CGLS was 40% CGA with a particle size of 200μm, pretreated by CGACM.

**Keywords:** Coal gangue; compressive strength; shotcrete; split tensile strength; surface pre-treatment methods.
Self-compacted concrete (SCC) with stone chips has received a lot of attention from the construction industry owing to its outstanding flowability compared to conventional concrete. However, this innovative concrete suffers from similar brittle properties, which can be solved by jute fibers, as they provide a significant improvement in SCC hardening properties. In this study, the mechanical performance of SCC containing stone chips (Zeolite, Wollastonite) and activated fibers (N/A, alkali activation, ultrasonic vibration coating) were investigated. The results demonstrated that Wollastonite improved the mechanical characteristic more than Zeolite. In terms of fiber activation, ultrasonic fiber treatment improved mechanical properties greater than the other two methods. The combination of fiber (ultrasonic vibration coating) and Wollastonite (75 μm) possessed the highest unconfined compressive strength (UCS) and flexural strength (FS) among all the mix designs.

Keywords: Self-compacted concrete; cementitious material; stone chips; Jute fiber.
Cement stabilized soil (CSS) yields wide application as a routine cementitious material due to cost-effectiveness. However, the mechanical strength of CSS impedes development. Construction and demolition (C&D), polypropylene fiber, and sodium sulfate were introduced in this research to assess the feasible enhancement on unconfined compressive strength (UCS), flexural strength (FS), and shear strength. The laboratory tests obtained at 28-day curing age were analyzed, indicating that mechanical properties evolved significant improvement with the increasing Portland cement, C&D waste, and sodium sulfate. The improvement caused by polypropylene fiber on FS was also evaluated from the 81 experimental results. In addition, C&D waste demonstrates outstanding enhancement on CSS shear performance through direct shear tests, while the specimen with 20% C&D waste proportion performed the best-enhanced shear property.

**Keywords:** Cement stabilized soil, Fiber-reinforced soil, Mechanical strength, Waste utilization.
3D building models have been widely used in the construction industry. Image-based 3D reconstruction methods support rapid 3D reconstruction that captures building geometry, color, and texture information. Many existing 3D reconstruction methods operate on feature points, and the accumulated error of point position often distorts building edges. This paper proposes a feature line-based reconstruction method, Edge3D, that recovers 3D lines to avoid building edge distortion. It employs geometry constraints and progressive screening technology to improve the robustness and precision of line segment matching. An innovative bundle adjustment strategy based on endpoints is designed to reduce the global reprojection error. Edge3D was tested on Challenging real-world image sets and achieved matching precisions of 96% and 94% on the two image sets, respectively.
LEARNING FROM THE PANDEMIC
FOR A SMART AND SUSTAINABLE FUTURE
New York City administration has invested on digital technologies since 2015, when Mayor de Blasio announced the release of “One New York: The Plan for a Strong and Just City” a comprehensive plan for a sustainable and resilient city. But at the beginning of 2020, COVID-19 disrupted its implementation. The negative impacts of the pandemic include: public health impacts, housing and food insecurity, increase of unemployment rate and closure of small businesses, among others. Digital technologies played an important role during this period, as the city’s administration offered reliable information about the pandemic through applications and websites. Considering the importance of NYC for the economy of U.S., and the huge impact that COVID-19 pandemic had on the city, this paper is part of a research that explores a smart city approach (i.e. New York) during a pandemic scenario through an empiric perception, presenting an early analysis of the actions adopted during the COVID-19 pandemic, and its relation to the Sustainable Development Goals (SDG’s). A case study has been conducted, with the mapping of actions adopted by the New York City administration during the first wave of COVID 19 pandemic (March-June, 2020). Results indicate a close relation among those actions and the basic SDG’s, signaling that a city to be smart must be sustainable. Conclusions indicate the necessity to review priorities on cities administration aiming the strengthening of a more resilient-inclusive society, particularly considering the challenges during and after a pandemic.
The COVID-19 pandemic represents a major global health crisis that threatens public health and safety. There is growing concern about limiting the spread of the SARS-CoV-2 virus and avoiding its negative and often unpredictable impacts. Some concerning impacts to construction companies are reduced productivity, increased costs, scarcity of inputs, and construction delays due to movement restriction or lockdown measures. Previous studies on Building Information Modeling (BIM), 360-degree cameras, and Unmanned Aerial Systems (UASs) associate these digital technologies with improvements in planning and safety at construction sites. Therefore, the opportunity arises to apply these technologies to help implement health and safety measures to prevent the spread of COVID-19 at construction sites and allow companies to continue their projects quickly. This study aims to identify interactions, positive or not, between the COVID-19 construction safety measures and the functionalities of three industry 4.0 digital technologies: BIM, 360-degree cameras, and UAS. Fifty-four positive interactions and four negative interactions were identified through inductive logical reasoning. The matrix of relationships is not fully complete, but it can be a starting point for researchers and practitioners. Researchers can corroborate or refute the number and nature of the identified interactions or add other technologies. Construction managers can also benefit from the matrix to choose the appropriate technology when implementing COVID-19 and other types of virus safety measures at construction sites.
239. Rethinking the influence of the Intelligent Building Systems (IBSs) on productivity, health and well-being for enhancing the quality of life during mandatory Working From Home (WFH): lessons learned from the COVID-19 pandemic

Selin Bicer
Dokuz Eylul University The Graduate School of Natural and Applied Sciences Department of Architecture, Izmir, Turkey

Fahriye Hilal Halicioglu
Dokuz Eylul University Department of Architecture, Izmir, Turkey

In the light of the recent global phenomena of the COVID-19 pandemic, there become evident changes in the habits and digital services usage in daily life. At this juncture, working from home (WFH) which is highly in need of Information and Communication Technologies (ICT) support for work productivity and occupant well-being, has recently become a popular and almost mandatory way of working due to lockdowns all around the world. The fact remains that providing a better quality of working-life has a potential for using intelligent building technologies that lead to the rapid advancement in global information services when such crises arise. Buildings that integrated with the systems based on intelligent technologies aim to enhance the productivity and well-being flexibly to meet the changing requirements of occupants. Therefore, this study focuses on the mandatory WFH concept emerged during COVID-19 pandemic, and in this context the need for the intelligent building systems in residential buildings. The findings of this study would form a pathway for rethinking the influence of the intelligent building systems into the prevention of health issues that we faced during mandatory WFH due to the COVID-19 pandemic.
Establishing indicators for reducing the transmission of airborne viruses in buildings

Amna Salman
McWhorter School of Building Science, Auburn University, Auburn, USA

Keith Rahn
McWhorter School of Building Science, Auburn University, Auburn, USA

Anoop Sattineni
McWhorter School of Building Science, Auburn University, Auburn, USA

SARS-CoV-2/COVID-19 (Severe Acute Respiratory Syndrome Coronavirus-2/Coronavirus Disease 2019) has affected all trades in the built environment, but facilities management (FM) divisions were hit the most. Anecdotal evidence suggests that most of the facility managers did not know how to minimize/mitigate the virus spread and could not maintain the full functionality of buildings. Many FM organizations immediately created a “Task Force” to come up with viable solutions. Many measures were taken, however, most of these measures were reactive measures and their effectiveness is not fully known. We are still not out of the woods as data shows COVID related deaths, individuals contracting COVID-19 despite the vaccinations, and virus mutation. Current research proposes layers of defense in the post-pandemic era which should involve close collaboration between the architects, facility managers, mechanical engineers, healthcare professionals, epidemiologists, virologists, and builders. Therefore, there is a need for interdisciplinary research to explore indicators to reduce the spread of the virus indoors. The current literature proposes engineering control, design controls, air disinfection strategies, and the use of the latest technology. This study aims to explore possible indicators for virus mitigation through extensive literature review, brainstorming sessions with the research team, and focus groups with the experts. Delphi technique will be used to rank and weight the indicators. This is ongoing doctoral research with the ultimate goal of creating a readiness index for building preparedness against an outbreak/pandemic. The detailed readiness index will be presented at the conference.
The global COVID-19 pandemic has impacted the construction industry. The pandemic caused wide international disruption to employment, supply chain, costs, skills, and other aspects, and it caused huge uncertainty. Around the world, governments dealt with the crisis in different manners. This study investigates the ways New Zealand responded to this pandemic and examined the effects of its governance on the construction industry. This is done through examining and analysing government records and guidelines in response to COVID-19 at different stages and alert levels. Relevant government information portals and websites such as “Ministry of Business, Innovation and Employment”, “Construction Sector Accord”, and “Covid.govt.nz” are investigated to find guidelines and information to help the construction industry respond to the impacts of COVID-19. These guidelines and information were compared to understand how similar these recommended responses were. The findings show the mitigating implications and solutions to the construction industry’s current disruption and demonstrate the similarity of the recommended solutions.

Keywords: COVID-19, disruption, construction, effects, responses, New Zealand
Due to the pandemic of COVID-19, many industries worldwide have implemented various measures to reduce the spread of the virus. For example, the construction industry in Melbourne practices social distancing and downsizes the number of workers on the job site to reduce the risk of worker exposure to COVID-19. The surveillance system integrated with deep learning models has been extensively utilised to enhance construction safety efficiency. However, such 2D-based approaches suffer from occlusions, and the workers may not be accurately detected under this circumstance. To this end, this paper proposes a novel context-guided data augmentation method to enhance deep learning models’ performance under occlusions. The context-guided method can automatically augment images by adding occlusions to the objects. Using this way, deep learning models can learn the object’s features in various occlusion scenarios. Later, the effectiveness of this method is validated by a real-time social distancing violation detection system. Specifically, this system utilises a modified YOLOv4 model to detect workers by bounding boxes. Then, the DeepSORT algorithm is used to track the workers’ trajectories. Finally, homography transformation is used to calculate the distance between workers in each frame. The system has revealed robust results by using the data augmentation method, and promising results indicate that the system can well support workers’ health and well-being during the pandemic of COVID-19.
The COVID-19 pandemic has resulted in substantial disruptions and hardships across nations and industries. Like others, the construction industry has also been impacted by the pandemic in a number of ways. Reported adverse impacts include significant delays in projects, failure to deliver materials on time, decreased productivity rates, and increases in material prices. Declining revenues and increasing project delivery difficulties due to the current crisis have also affected the industry. The purpose of the study is to evaluate the effects of the Covid-19 pandemic at the construction sites from the perspective of the employer, contractor and the employees. A survey has been conducted with the construction professionals to explore the measures undertaken against the pandemic, how these measures were financed, suspensions, delays, disruptions, non-payment and cash flow issues, employee motivation, procurement and recruitment problems, interpretation of the force majeure clauses in the contracts, extension of time and additional payment claims arisen due to the pandemic. The findings is expected to be useful to all construction industry stakeholders and researchers for identifying the prominent problem areas and seek relevant solutions to decrease the adverse effects experienced during the pandemic.
Specific elements of building services such as heating, ventilation or water supply systems can play a key role in infection prevention and control (IPC) within hospital buildings and links between the design of such systems and increased rates of healthcare associated infections (HAI) have been identified. These links are complex and multifactorial and several key issues have a bearing on this relationship during the construction of a hospital building. One such issue is the nature and efficacy of the engagement of IPC specialists employed by the client end user during the development process. Good management of IPC issues not only supports effective IPC specialist engagement but depends upon it to achieve key aims. Research suggests, however, that the quality of IPC specialist engagement is not always optimal and there is a gap in knowledge around how this can be addressed.

This research focuses on a qualitative evaluation of the nature and efficacy of the engagement of IPC specialists in the construction lifecycle development of new hospitals. Using in-depth interview data, the experiences of IPC specialists will be explored and barriers and facilitators to high quality engagement identified. This data will be used to develop the foundational principles of an improvement strategy for the engagement of IPC specialists within the construction lifecycle development of new hospitals in Scotland. Post-pandemic, the role of the built environment in the spread of infection and the processes developed to manage this will be under increased scrutiny. This paper adds to this growing body of research.
COVID-19 has become a long-term pandemic and pushed the re-interpretation of normality. Fighting against the pandemic and building a new normal in the post-COVID era requires constant and innovative approaches. Building information modeling (BIM) based facilities management (FM) has been advocated as a powerful method to overcome the huge public health-related challenges of FM in clinical and public buildings. However, studies investigating the role of BIM-facilitated FM in the pandemic era are fragmented, and holistic knowledge is limited. Research objectives of this study are twofold: (1) to identify varying FM requirements after the outbreak of COVID-19, (2) to investigate how BIM-facilitated FM copes with changing requests in the pandemic period. To achieve the objectives, a systematic literature review was conducted based on quality academic papers. Currently, FM tends to be public health-centric, and highly emphasized requirements encompass the flexibility of space transformation for emergency purposes, effective and sufficient ventilation, reliable biosecurity (e.g. decontamination and sterilization), and strict anti-infection management. Based on centralized database and visualized model, BIM-facilitated FM enables space optimization, simulation and prediction of infection risk, monitoring and managing equipment operation, and effective information management, which enhances both hard and soft FM. More innovative BIM adoption is expected. Existing studies mainly rely on case study or demonstrating technical methods by specific cases, which calls for various research methods to give rich insight. This paper sheds light on the applications and directions of future BIM-facilitated FM research in protecting public health in the post-COVID era.
The outbreak of COVID-19 has triggered an unprecedented health crisis across the world. Previous research indicated that the fear of being infected in public place has transportation hindered the commuters’ choice on. In fact, underground transportation systems, especially those located in high-density cities, have been perceived as high risk environments under the pandemic. In addition, the prolonged COVID-19 outbreak, together with the negative public impression towards underground environment, have to certain extent triggered various mental health responses amongst citizens (e.g., 42.3% increase of anxiety in Hong Kong). This study thus aims to investigate the impacts of FM on underground development users’ mental health in metro stations in Hong Kong. To achieve this aim, a questionnaire survey approach is adopted. The survey is designed to contain three parts: background information, satisfaction towards underground FM (space management, building services, and supporting facilities related to the pandemic), and mental health level (emotional exhaustion, depersonalization, and claustrophobia). Data is collected over four underground subway stations in Hong Kong. Person correlation and regression analysis are conducted to determine the statistically significant relationships between underground FM and users’ mental health. The results indicated that satisfaction towards visual access, immediate access, and hygiene practices have negative relationship with the occurrence of emotional exhaustion and depersonalization, except for claustrophobia symptoms. The study results provide empirical evidence for practitioners to make informed decisions in FM plans for enhancing mental health of underground development users under and after the pandemic.
MANAGING RISK THROUGH KNOWLEDGE MANAGEMENT
Seismic events pose a significant threat, particularly to rural communities, with poorly developed construction practices. This has resulted in the loss of life and considerable economic losses owing to substantial numbers of house collapses. The application of best practice in disaster construction knowledge as a means of significantly improving housing resilience is, therefore, a key challenge for most rural construction practices. In this context, effective utilization of available, and feasible technologies in rural areas can help to solve the problem of the inadequate facilitation of communication that is needed to deliver knowledge on the construction of long-term disaster-resilient housing. The study examines the potential for improvement of housing resilience from a disaster knowledge perspective. It responds to the challenges of the effective application of best building practice guidelines in such contexts. The main question of our research is, “Are communication technology tools capable of having a positive effect in establishing a knowledge transfer framework in rural Pakistan?” The study employs both literature and questionnaire survey and explores the availability and usability of technologies. It takes a premise in which effective knowledge transfer via reasonably available technological tools can be actionable and made operational. Our findings support the creation of a knowledge transfer framework for rural housing construction to improve disaster mitigation. The approach can assist rural communities in reducing losses and improving response and recovery, thereby improving housing resilience and lowering vulnerabilities. Finally, certain conclusions are drawn that indicate further useful lines of development in this approach to resilience research.
Considerable progress has been made in the development and deployment of knowledge management (KM) systems in the construction industry. These have included a variety of technology and non-technology-based solutions that have had varying levels of impact on organizational knowledge management. Very few of the technology-based solutions adopted any artificial intelligence (AI) techniques. The current resurgence of AI and data analytics presents a tremendous opportunity to re-engineer knowledge management systems such that they are a much more powerful and critical component of an organization’s business infrastructure. This paper will start with a review of the state-of-the-art of knowledge management in construction sector organizations, covering processes, tools, corporate infrastructure, cultural provisions, etc. It will also discuss the resurgence of AI and data analytics, and highlight the key drivers for this resurgence and the opportunities for construction KM. Drawing on specific KM processes and previous systems, it will explore the applicability of AI techniques to organizational KM processes and systems. The advantages of the proposed AI/KM integration will also be presented.
Professional service firms in the built environment are subject to externalities. Whether these forces are related to economic downturns, changes in the regulatory environment, natural disasters, trade wars, armed conflict, mass migration, hyperinflation, climate change, global pandemics, entropy, or even the never foreseen, firms must adapt, reposition, and rebound from negative events. The ability to adapt is best personified by the people that make up a firm. When one firm’s major commission was completely altered overnight due to the passing of major legislation that changed the mission and mandate of the agency that commissioned the work, the firm was nimble enough to pivot, make judgments about what scope could still be accomplished within the deadline, and determine who to assign the necessary tasks to get the job accomplished. The experience forced mentors to step up, mentees to step out of their comfort zones, the team to congeal under pressure, and resulted in an unmanageable deadline being met despite difficult odds and a myriad of factors beyond the firm’s control. Only mentorship, knowledge sharing, resilience, and dedication allowed a positive result for the firm, the client, the user agency, and those served by the institution. It also furthered the standing perception of the firm as the trusted advisor that finds a way. This case study in the mitigation of exogenous shocks through a ‘people first’ strategy will highlight potential A/E/C industry responses to similar events.
Housing was identified as one of the greatest challenges faced by the Nelson Mandela 1994 South African government. The government provided low-cost housing since then, have been efficient in numbers, but have proven ineffective to address this social problem. This paper will present data on how knowledge management may be utilised to contribute in aiding a shift, from government provision to government facilitation of housing. This paper presents a critical comparison, of the information, included in the contract documentation and outline specifications, of nine different hypothetical low-cost housing typologies, for varying climatic regions in South Africa. Housing information is often inaccessible to those affected by the housing problem. It is a premise of this paper that knowledge management will contribute to address the housing problem. Such knowledge management furthermore has the potential to address in part, other social ills such as unemployment and government corruption. The research findings indicate that there is a noteworthy overlap in information of the nine typologies presented. It is argued by this paper that the knowledge management of this information may have an impact in providing knowledge power to those affected by the housing problem. The findings are new and significant as such research has not been published before. Therefore, the paper will contribute to the body of existing research, by addressing the limited academic research available on knowledge management, for the low-cost housing sector in South Africa.
For too long the construction industry has been divided by factionalism and conflict, which has contributed to poor performance, dangerously low profit margins and poor morale among consultants, constructors and suppliers. This paper explored the professionals and stakeholders’ assessment and comparison of critical success factors as a tool for project partnering with a view to recommend measures to encourage project partnering in a typical West African construction industry using Nigeria as a case study. It was effected using a structured questionnaire distributed to a total of a hundred and forty (140) respondents comprising of construction professionals, contractors, client and consultants. A total of ninety-eight (98) questionnaires were returned well filled giving a percentage response of 70% and data collected were analyzed using the SPSS version 20.0. software. The results of the analysis revealed among others that: ‘Mutual trust among party members’ (RII.0.85) is the highest CSF tool in project partnering. This was closely followed by ‘Top Management support’ (RII. 0.81) and ‘Preventive conflict resolution strategy’ (RII. 0.81) identified as effective CSF factors for project partnering. The results also indicated that lack of top management support, and clear definition of partnering objectives, ability to generate ideas, and adequate funds/resources, team work and cooperation hinder project partnering. Thus, from the ongoing, it was recommended that; all stakeholders in the construction industry should work together to engender mutual trust among party members. The study also recommends further research on CSFs on partner selection in project partnering in Nigeria.
Construction Projects are exposed to numerous risks due to their complex and uncertain nature, threatening the realization of the project objectives. However, Risk Management (RM) is a less efficient realm in the industry than other knowledge areas given the manual and time-consuming nature of its processes and reliance on experience-based subjective judgments. This research proposes a Process Mining-based framework for detecting, monitoring, and analyzing risks, improving the RM processes using evidence-based event logs, such as Risk Registers and Change-Logs within previous projects’ documents. Process Mining (PM) is a data-driven methodology, well established in other industries, that benefits from Artificial Intelligence (AI) to identify trends and complex patterns among event logs. It performs well while intaking large amounts of data and predicting future outputs based on historical data. Therefore, this research proposes a Bayesian Network (BN)-based Process Mining framework for graphical representation of the RM processes, intaking the conditional dependence structure between Risk variables, and continuous and automated risk identification and management. A systematic literature review on RM, PM, and AI forms the framework theoretical basis and delineates the integration areas for practical implementation. The proposed framework is applied to a small database of 20 projects as the case study, the scope of which can be tailored to the enterprise requirements. It contributes to creating a holistic theoretical foundation and practical workflow applicable to construction projects and filling the knowledge gap in inefficient and discrete conventional RM methods, which ignore the interdependencies between risk variables and assess each risk isolatedly.
Mould may grow in wood frame wall assemblies when subjected to excessive moisture load over prolonged periods of time. To permit estimating the moisture risk in wood-frame wall assemblies, one approach is to use hygrothermal simulations. This process requires access to relevant climate data and as well, knowledge and experience regarding the use of hygrothermal simulation tools. As well, it may not be practical to undertake such an analysis for each different type of wall application. In this regard, the moisture index is usually considered when designing measures for protection from precipitation as it is a useful indicator that reflects the intensity and duration of moisture loads to which a building envelope may be subjected over time. Hence, in the study described in this paper, consideration was given to determining the correlation between mould growth index and moisture index as this would be beneficial to building practitioners in determining the level of protection to mould growth as may be achieved in different climate regions having a particular value for moisture index. The mould growth indices were generated for Oriented Strand Board (OSB) incorporated within a wood-frame vinyl-clad wall assembly located in selected Canadian cities from which moisture indices were derived. Effects of moisture load and air change rate were also taken into account when assessing the correlation between the two indices. The results indicate that when the air change rate and moisture load are favorable to maintain a humid environment, strong correlations were observed between the two indices, vice versa.
Interstitial condensation is a phenomenon that occurs when, somewhere inside a construction element, a pressure equal to or greater than the saturation pressure is reached. At this time, condensation will occur inside the element, producing interstitial condensation. This phenomenon occurs mainly in the winter. This type of condensation produces various problems, such as the deterioration of materials, humidity, reduced comfort conditions inside the home and health problems. Further, the urban heat island effect means that due to different factors —building materials, green areas, volumes— temperatures are not homogeneous in all areas of the city. This effect makes the same building in different areas behave differently. This research aimed to analyse the influence of the urban heat island effect on interstitial conditions in a temperate oceanic climate. This study was carried out through a case study consisting of a typical house, with three different constructive solutions, located in four representative city points. The city where the experiment was carried out corresponds to Puerto Montt, in the south of Chile. Puerto Montt has a temperate oceanic climate with mild summers and long winters. The research results will be helpful when selecting different constructive solutions for the thermal envelope in cities with temperate oceanic climates.

Keywords: Building, Chile, interstitial condensation, temperate oceanic climate, urban heat island.
The article examines the moisture risk associated with the conversion into flats of cellars in historic (100+ years) multifamily houses in a temperate climate for the case of downtown Vienna/Austria. The goal is to use the thermal losses of the flat above the cellar through the ceiling for heating the new living space (→ project title: „Space4Free”) using the tempering properties of the soil. Further framing conditions are acceptable hygienic conditions and thermal comfort. The cellar’s brick walls are not sealed off the soil for technical and economic reasons during refurbishment. The concept includes the installation of a mechanical ventilation plant. A three dimensional simulation of moisture and heat transport was carried out the coupling building parts to the indoor air. Focus was on designing a moisture based control algorithm for the mechanical (automated) ventilation plant which resulted in a decision tree with 8 states of ventilation operation. The simulation showed that such a cellar refurbishment – from a building physics point of view – is feasible. A main result is that the annual moisture immissions are driven by the moisture loads induced by the inhabitants such as cooking rather than by moisture originating from building components in contact with the soil. This result is corroborated by the fact that such conversion has been successfully practiced by a company represented among the authors since several years. A practical implication that – in the current case – insulating building components against moisture from the soil is less important than controlling user driven moisture loads.
Since the Lattice Boltzmann Method (LBM) showed promising ways in describing fluid flow and convective phenomena, this literature review gives an overview of the application of LBM to date in the realm of hygrothermal simulations (HAM). Furthermore, ways to apply LBM to derive the influence of convection on moisture transport in building components are assessed. This is achieved by a literature review which is carried out for specific fields of application of LBM which are intertwined with topics of hygrothermal simulations (Natural convection, Porous media, Flow through channels). The introduction is accompanied by a condensed theoretical overview of the used LBM-scheme in most of the reviewed literature. It could be seen that, in regard to these topics, the majority of simulations is carried out 2-dimensionally using mostly the D2Q9 model with single relaxation times. The reviewed literature shows LBM as a validated tool, solidifying the choice of LBM for our purposes. No coupling of LBM to HAM-simulations to derive the influence of convection on moisture transport could be found. In conclusion, the deduction of parameters like the permeability is identified as a potent subfield for the coupling of LBM and HAM-simulations for further research.
OFFSITE CONSTRUCTION:
EMPOWERING FUTURE RESILIENCE
AND CAPABILITY
Despite government’s push for the use of prefabrication in Singapore, the problem is that offsite manufacturers of prefabricated building components (hereinafter referred to as manufactures) appear to be unable to harness their inherent strengths, overcome their weaknesses and external threats to take advantage of the available opportunities in the construction market. The aim of this study is to do a SWOT analysis on Singapore’s manufacturers and develop strategies to enable them to thrive. A structured questionnaire was designed based on extant literature of offsite manufacturing. Quantitative data were collected from 46 project stakeholders via an industry wide survey. It was found that manufacturers’ strengths are their high quality prefabricated products and high productivity. Their weaknesses are the high capital and production costs. Their biggest opportunities are the limited supply of manual site labour and tender evaluation criteria that favour productivity and quality. The threats include lack of control over factors of production, shrinking construction demand, stiff competition and complex designs. The implication is that manufacturers should improve and re-examine their internal operations to overcome their weaknesses and the challenges in their external environment. Production should be streamlined, and partnerships with suppliers and transportation firms should be developed to guard against price fluctuations and inaccurate deliveries. Other recommendations are also offered to help manufacturers harness their strengths and opportunities while minimizing their weaknesses and threats.
The construction industry consistently reports higher fatality and injury rates due to its inherent dynamic nature. As an alternative to traditional construction, offsite manufacturing (OSM) has become a construction method that involves the creation of building elements in a controlled factory environment. OSM presents many benefits including optimised schedule, quality control, waste reduction and improved site safety. However, evidence-based research on OSM safety performance remains very limited. Contrastingly, recent statistics on OSM also indicated that in the USA for instance, the number of safety incidents were higher compared to traditional construction. There is a suggestion that OSM organisations simply shift site-based construction activities to a factory environment. Therefore, this study aims to investigate the influence of organisational safety climate factors with respect to the safety performance of OSM. Initially, a comprehensive literature review was conducted to identify organisational safety climate factors by reviewing extant literature pertinent to construction and manufacturing sectors. Following this, 154 questionnaires were collected from OSM practitioners in Australia. Finally, statistical analysis was performed through a correlation analysis to examine the influence of organisational safety climate with respect to OSM safety performance. Findings asserted that safety communication and safety rules and procedures have greater impact on OSM safety performance. Contrary to traditional construction practice, greater influence from managers was identified over supervisors towards safety performance. The novelty of this research lies in its attempt to comprehend the association between organisational safety climate factors and OSM safety performance, which may make contribution to OSM safety knowledge and practice.
Offsite construction (OSC) has been put forward as a solution to many prevailing challenges facing the construction industry, including but not limited to low productivity, housing shortage, lack of innovation, and poor-quality outputs. The uptake of OSC is relatively slow in the New Zealand construction industry. With only 10% of all the new builds making use of OSC approach, it is evident that the potential of this construction approach is under-utilised. Many barriers have been identified as responsible for its low uptake, including cost-related barriers. This study investigates the transaction cost of OSC, which is an extra cost to the project development cost and is generally overlooked in the project planning and development stage. This study aims to identify the factors that contribute to the transaction cost of OSC in New Zealand, alongside investigating the impact of transaction cost on overall project delivery and factors that can minimise the transaction cost. Questionnaire survey was conducted involving OSC practitioners in New Zealand. It was noted that consultation with building consent authority, complexity of interface design, limited capacity of offsite manufacturers, and highly skilled workforce requirements contribute to transition cost during concept design, technical design and procurement, manufacturing, and on-site assembly stages. Consequently, disputes between stakeholders, uncertainty and an overall increase in project cost, and reluctance to use OSC may occur. It is noted that use of innovation like automation, building information modeling, design for manufacturing and assembly, and consenting process to suit OSC hold the potentials to reduce the transaction cost.
The construction industry is a major source of waste generation globally, producing various greenhouse gasses, releasing harmful substances into the environment, and requiring large areas of land for processing, treatment, and landfilling. The emerging field of modular construction is perceived as a viable method to reduce waste and improve sustainability. However, there is a lack of research on the quantified differences between off-site modular and on-site conventional construction for sustainability criteria. This paper develops a methodology to compare waste generation of modular and conventional construction methods. The framework relies on a comprehensive literature review to estimate the waste generation rate of building materials. Real case studies are then used to determine the difference in waste generation between the two construction approaches. It was found that modular construction reduces the overall weight of waste by 83.2% in construction projects, for the cases considered. These results allow construction owners and stakeholders to make more informed decisions when selecting an appropriate construction method.

**Keywords:** Construction methods, waste generation, modular construction, sustainability, building materials
The housing shortage is a prominent issue across the globe. The traditional on-site construction methods seem inefficient to meet the increasing housing demand. As a solution, many countries, including the United States, Germany, Singapore, Japan, Hong Kong and Australia, have introduced off-site manufacturing methods to increase the housing supply. Different from the traditional method of on-site construction, off-site manufacturing is a technique that manufactures building components in a controlled environment. Despite the strong government support and the industry attempting to increase off-site manufacturing, the current building consenting and inspection processes in New Zealand have significant quality-related issues. Therefore, this study aims to identify the gaps in current quality assurance processes used in off-site manufacturing and recommend a framework to gain credibility and acceptance of the housing market.

The study aims to collect qualitative data from industry experts (e.g. developers, architects, engineers, project managers, quantity surveyors, head-contractors and council officers) who have significant experience in current quality assurance regimes in New Zealand prefabrication construction. The key themes for designing the proposed framework will be generated using a content analysis of the primary data collecting from the semi-structured interviews with industry experts.

The findings of this study would contribute to the early engagement of different stakeholders to ensure that overseas manufacturing of building components meet the New Zealand quality standards. It is expected that the new quality assurance framework would help to promote off-site manufacturing for the New Zealand housing sector.
COVID-19 has intensified the need for faster and more efficient construction in Brazil. In this regard, offsite construction methods are important, in particular, modular construction with steel 3D modules. While extensively discussed in the literature, details, such as the inputs of the process related to modular construction, are rarely provided. The purpose of this paper is to map the process involved in modular construction with steel 3D modules, including the operations and inputs. To this end, based on a literature framework, a case study was performed considering six cases of modular construction with steel 3D modules carried out by three different companies. As a result, the process is described in a flowchart, composed by six stages: 1) design and planning; 2) substructure execution; 3) production of the modules; 4) transport of the modules; 5) assembly; and 6) installation. This study shows that the fundamental steps involved in the production of the modules are uniform among the construction projects studied. However, the customization and, consequently, the inputs used to produce the modules vary greatly. Thus, this paper contributes to structuring and documenting the process involved in modular construction with steel 3D modules, including the operations and inputs.
Modular Integrated Construction (MiC) has emerged as an innovative technological approach in the high-rise, high-density city of Hong Kong to address the shortages of housing, skilled labour and to boost productivity and quality in the built environment. The current context of MiC in Hong Kong is mainly driven by the significant government instigation accompanied by policies, regulations, financial incentives, and government-initiated MiC projects. Despite its prolonged benefits and governmental influence, the adoption of MiC is still at the infancy stage of development due to its complex nature in the industry-wide uptake. Consequently, it is vital to boost construction industry participants’ collaboration to accelerate MiC adoption in Hong Kong at the industry level. Therefore, it is required to focus on a consolidated new direction of MiC uptake and adoption. To underpin and justify this new direction, a dialectical system framework is utilised in this paper to review and synthesise the apposite systematic literature to conceptualise the industry uptake of MiC in Hong Kong. Thereby, the focus was widened towards the technical, social, and co-evolved economic and political aspects and geographical boundaries. Subsequently, the system framework was developed to indicate significant components of policy and regulations (regulatory context), technology uptake, stakeholder collaboration and economic and financial inducement, research and development and their inter-relations, providing a complex system.
The urgency of renewing the Architecture, Engineering and Construction related processes to increase quality standards and performances while reducing costs and operations time is widely discussed in literature. In this scenario, increasing the energy renovation rate of the existing European building stock is a key priority to support the EU’s 2050 decarbonisation targets.

The introduction of prefabricated panels for building renovation – incorporating insulation, mechanical systems, and finishing – can provide the existing buildings with improved structural, thermal, acoustic, and architectural features.

Several digital and informative tools have been introduced over the last years to customize and integrate the design of prefabricated panels on existing building envelopes (i.e. panelisation tools). However, the comparison of technological alternatives is left to the intuition of designers and managed thorough the use of several tools that are not interconnected and often downstream the design process.

This paper presents a Panelisation Design Tool, which is a Decision Support System (DSS) to help decision-makers in the choice of technological solutions for retrofitting operations during the Early Design Stage. Thanks to BIM integration, some indicators related to different aspects (n Dimensions) are extracted from the model of the panelised building to compare different technologies in a systematic way.

The Panelisation Design Tool is tested on a case study building located in the city of Monza, in Northern Italy, used as a pilot in the BIM4EEB European Project. The test aimed at demonstrating the effectiveness of the chosen parameters to evaluate multiple technological solutions in an integrated BIM approach.
411. Quantifying safety performance in off-site construction

Nicole Odo  
University of New Brunswick, Fredericton, Canada

Jeff Rankin  
University of New Brunswick, Fredericton, Canada

The construction industry has been identified as one of the most dangerous when examining safety performance and outcomes. The concept of leveraging off-site construction as a safer alternative to execute construction works has been presented by researchers and industry, but support for this premise with quantifiable data is lacking. To investigate differences in off-site construction versus conventional on-site methods, the research has developed a safety evaluation methodology to quantify safety performance and allow for comparisons of construction methods. The methodology is developed in partnership with a jurisdictional occupational health and safety authority and leverages historical safety data to provide inputs for a risk-based process-analysis of construction methods. The methodology is partially validated in collaboration with the project team (owner, general contractor, module manufacturer) and applied to a case study of a mid-rise modular hotel construction project that employed a mix of conventional and off-site construction processes. The evaluation methodology takes a construction product-focused approach (in this a case a hotel room module) with emphasis on defining a complete material supply chain. As such, the approach takes a unique approach to industry level comparison, establishing an evaluation methodology for future comparisons.
430. Offsite construction: reflection is simply not good enough – we need a new Prism!

Volkan Ezcan
Liverpool John Moores University, Liverpool, United Kingdom

Jack Steven Goulding
-, -, United Kingdom

This paper reflects on the recurrent challenges facing Architecture Engineering and Construction (AEC), noting that slow incremental change is still stifling efficiency and product delivery systems underpinning the value proposition. The challenge here is “why have other sectors out-performed AEC in many of these areas?” The work presented here challenges the industry to re-think its position, advocating the use of a new ‘prism’, one which highlights new opportunities for exploitation, rather than re-examining parochial ‘traditional’ approaches. The rationalisation underpinning this treatise rests on the need for AEC to transition towards Industry 4.0. Three case study construction organisations based in Turkey are presented as an exemplar. The foci concentrated on the use and application of Off-Site Construction (OSC) concepts, addressing specific technology-related requirements needed for Industry 4.0 transition; as organisations not only need to unlock their digital potential, but also leverage improved performance, capability and its value proposition. Emphasis was therefore placed on this transformative ‘journey’ using agility as the main prism. Findings highlighted the need to step back from conventional thinking and linear approaches, to ones which help actuate evidenced-based levers for change: from concept through to technology diffusion. This should also embrace macro, meso and micro drivers associated with “people, skills and processes”. In doing so, this paper presents a number of agility-driven innovation and exploitation opportunities, from Additive Manufacturing through to Distributed Ledgers and new data-centric logistic platforms.
The use of prefabrication in building

Dayne Kenny
Nelson Mandela University, Port Elizabeth, South Africa

Emma Ayesu-Koranteng
Nelson Mandela University, Port Elizabeth, South Africa

Christopher Amoah
University of the Free State, Bloemfontein, South Africa

The use of prefabricated construction in the construction industry is a growing technology that is implemented in various developed countries around the world. However, some countries do not implement this new technology. This study sought to identify the barriers hindering the adoption of prefabricated construction in the South African construction industry and open the door for further research into the mitigations of the barriers. The research for this study was conducted using a qualitative approach. The data were collected through semi-structured interviews of 6 prefabrication building firms. The data collected was then analyzed and coded by using the thematic content analysis. The study’s findings indicate the lack of knowledge of the prefabricated construction method as the primary barrier to adopting this construction method in South Africa. The research was focused on South Africa; however, due to time and monetary constraints, the field of focus was the East London region. The study suggests that with the barriers against the adoption of prefabricated construction revealed, further investigation is recommended to mitigate these barriers. The paper has revealed the main factor underpinning the lack of adoption of prefabricated construction and building method in the South African construction industry, especially in the East London region.
Increase of population in large cities of New Zealand, propelled by the massive number of immigrants and many New Zealanders returning to country after COVID-19, has caused deficit in housing supply. Prefabrication has been advocated as a potential solution for this problem. Although it has many benefits, its uptake in New Zealand is relatively low. So, building capacity and more capability of prefabricated housing supply chain by identifying obstacles and proposing methods to tackle them are essential. This research aims to assess and map the supply chain for prefabricated housing projects in New Zealand. The investigations include key industries, trades and skills involved in this construction system. For this purpose, a comprehensive analytical approach is followed integrating bibliometric search and qualitative discussion by objectively investigating: 1) recent prefabricated housing research keywords, pros & cons; to identify factors that are limiting prefabricated sector to deliver New Zealand housing supply requirements 2) study gaps in combining prefabricated housing sector with other new construction concepts, 3) prefabricated construction research directions in the future. Results show lower uptake of prefabrication through supply chain/procurement and knowledge, negative perception, shortage of skills, cost and finance, lack of coordination and communication, site operations, design shortage, lack of ability to alter designs to respond to site context, and lack of government support. Consequently, various effective factors hindering its uptake were discussed, an identification of the industries, parties and trades involved has been performed, and preliminary mapping of the sector is provided.
495. Implementation of a novel data-driven approach to optimise UK offsite housing delivery

Ilnaz Ashayeri  
Research Associate in Wolverhampton university, Wolverhampton, United Kingdom

Jack Goulding  
Director of Unisearchuk, Manchester, United Kingdom

David Heesom  
Reader in Wolverhampton university, Wolverhampton, United Kingdom

Mohammad Arif  
Dean of Architecture, Technology and Engineering, University of Brighton, Brighton, United Kingdom

Nigel Moore  
Lecturer in Wolverhampton university, Wolverhampton, United Kingdom

Lovelin Obi  
Senior Lecturer in Wolverhampton university, Wolverhampton, United Kingdom

Naeem Ahmed  
Research Associate in Wolverhampton university, Wolverhampton, United Kingdom

Mandeep Saini  
Lecturer in Wolverhampton university, Wolverhampton, United Kingdom

The UK is continuing to apply advanced offsite delivery approaches to meet its housing shortage, specifically its social housing provision. Whilst the concepts and benefits of Modern Methods of Construction are well understood, there is a paucity of knowledge on the actual understanding of optimisation per se, ergo, the interrelationships between processes, and the wider understanding of ‘pooling’ [resource management] to promote and maximise synergy, especially to target areas of lag or bottlenecks. In this respect, the research methodological approached adopted in this paper used a single case study to critically evaluate an offsite steel-frame solution for the offsite market. This used applied approaches from Digital Twins, Generative Design, and Discrete Event Simulation. Research findings present a new offsite hub-and-spoke model for discussion. This model allows decision-makers to interact with live data in order to optimise solutions in line with demand and resource requirements.
Generative design (GD) has been heralded in helping transform design practice in three spaces of form definition in design encompassing requirements capture, transformation of design requirements and generation of design options based on defined rules. This study explores the role of GD in improving cost performance and potential for its integration into wider project processes such as supply chain, project implementation, facilities management, commissioning, and post occupancy as well as end of life. A full life cycle approach is adopted for this study looking at how design options can allow for integrated varied configurations of generative and cost models for design performance. The performance of the designs is demonstrated from a case study analysis. The study proposes a new model representing the integrated processes of Cost Modelling and GD. The proposed model can support offsite construction (OSC) design and cost modelling. This improves a key area of wider design performance focused on improved certainty of designs and costing.
Offsite construction (OSC) is increasingly recognised as a viable alternative for conventional in-situ construction. Modular construction (MC) is one of the most advanced and efficient OSC methods in the construction industry. Even with the distinctive benefits offered by MC, it is imperative to investigate the sustainability performance of MC to understand the trade-offs with traditional construction. Life cycle sustainability assessment (LCSA) is a tool that integrates the three pillars of sustainability from a life cycle perspective. At present, the most common method is to consider the LCSA as a sum of life cycle assessment (LCA), life cycle costing (LCC), and social LCA (S-LCA). However, studies that have employed the LCSA methodology in assessing MC are still lacking in the literature. Relevant literature still lacks comprehensive framework guidance to conduct LCSA of MC. Thus, this paper aims to propose a conceptual framework that integrates the triple bottom line (TBL) of sustainability to assess the sustainability performance of MC using LCSA. The publications acquired from the keyword search analysis were reviewed to develop the conceptual framework by identifying the key factors and challenges to the LCSA. The framework integrates the methodological steps, findings, and gaps related to LCSA discovered from the literature survey conducted. The findings show that the LCSA goal and scope should be defined properly to address the complications from the methodological differences of the TBL of sustainability. The proposed framework offers insight to academia and construction industry practitioners about the holistic investigation of the sustainability performance of MC.
Overcoming barriers to wider adoption of off-site construction

Josephine Liale  
University of Pretoria, Pretoria, South Africa

Off-site construction (OSM) has the potential of reducing the 2.6 million housing backlog in South Africa, however, its adoption is slow. Negative perceptions about OSM by communities and high cost are two of the major barriers to wider adoption of OSM in South Africa. The aim of this study is to investigate how these two major barriers can be overcome. A literature review was undertaken. The study is limited to South Africa. To overcome the barrier of negative perception, educating communities on the benefits of OSM is necessary. The findings reveal that pilot projects without education and community involvement are ineffective in changing negative perceptions in communities. Innovative funding structures may alleviate the high cost associated with OSM as financial institutions are reluctant to fund OSM buildings because they cannot have a lien on the title over a structure that is manufactured inside a factory.
731. Exploring the off-site construction and building information modelling integration challenges in New Zealand

Nazanin Kordestani Ghalenoei  
PhD Candidate, School of Built Environment, Massey University, Auckland, New Zealand

Mostafa Babaeian Jelodar  
Senior Lecturer, School of Built Environment, Massey University, Auckland, New Zealand

Daniel Paes  
Lecturer, School of Built Environment, Massey University, Auckland, New Zealand

Monty Sutrisna  
Professor of Construction and Project Management, School of Built Environment, Massey University, Auckland, New-Caledonia

Over the last few years, off-site construction (OSC), in a nutshell manufacturing the components in a controlled environment, has become popular in the construction industry. This method has the advantages of simplicity, speed, reducing project duration, and minimizing construction waste. Therefore, a growing body of literature recognises the importance of OSC to gain better project performance. While OSC has received considerable critical attention, to enhance OSC applications, integrating advanced technologies such as building information modelling (BIM) is essential. There is a lack of research in addressing the integration of BIM and OSC particularly in New Zealand and few studies can be found on the topic. Therefore, this study focuses on finding out the existing OSC and BIM integration challenges within the New Zealand construction sector. The objective of this study has been investigated through literature review and interviews with experts. The common challenges of OSC and BIM integration were identified and classified. Human resources, documentation, managerial, and organisational are the main challenges. This paper is dedicated to exploring OSC and BIM integration in New Zealand, an essential step for the OSC application strategies within the construction sector. This study’s results can help the industry explore the necessary capacities to improve the status quo and optimize OSC applications through advanced technologies.
Governments in advanced countries are implementing construction industry transformation agendas underpinned by driving greater use of modern methods of construction (MMC). In the UK, one such agenda is the Affordable Housing Programme (AHP) targeting the delivery of 130,000 affordable homes by March 2026. This initiative mandates that 25% of all the homes should be built using MMC and achieve a minimum of 55% ‘pre-manufactured value’ (PMV), assuming that higher levels of PMV mean better project performance. PMV is thus presented as a new performance metric for evaluating the use of MMC and a driver for greater MMC adoption. This paper examines whether PMV as a performance metric would drive greater use of MMC and evaluates its usefulness by investigating what it does (not) capture on building projects delivered using MMC. To this end, 14 in-depth interviews were conducted with leading construction industry experts. Findings indicate that the concept of PMV is nascent, even among expert practitioners engaged in the use of MMCs, and challenges around its suitability as an evaluation metric might impede using it to drive widescale MMC adoption. We highlight the need to educate the construction industry on MMCs and PMV, and to create a standardised framework for gathering consistent data. There is a danger in focusing on PVM as a driver of greater MMC use as this might draw policymakers and practitioners’ attention away from other critical project performance indicators. Therefore, it is vital to consider PMV as complementary to existing project performance metrics.
OPEN BUILDING: THE KEY TO A REGENERATIVE HOUSING STOCK
Housing is an important social and economic asset for society. However, increasing costs of living and demand for affordable housing is outpacing supply in Australia. Governments and housing providers, particularly community housing providers, are grappling with these challenges. This paper discusses steps towards building a more rigorous, evidence-based approach for social and affordable housing provision in Australia. It is proposed that housing be considered like other critical social and economic infrastructure such as schools, hospitals and civil infrastructure (i.e., roadways). The paper presents findings of Australian industry-led social and affordable housing research undertaken between 2014 to 2020. The research findings inform the decision-making framework of housing as critical infrastructure, including: (i) a productivity-based conceptual framework; (ii) the establishment of nine impact domains including meaningful and measurable outcomes and indicators; (iii) a composite return on investment approach which addresses the broader benefits of access to safe and secure housing; and (iv) thirteen elements being used to map the complex and integrated social and affordable housing network.
Research on housing complex rehabilitation evaluation criteria focusing on the global environment and sustainability - comparative analysis of environmental assessment indexes in the world -

Satoka Takahashi  
Sugiyama Jogakuen University, Aichi, Japan

Kyoko Kawaguchi  
Sugiyama Jogakuen University, Aichi, Japan

Shin Murakami  
Sugiyama Jogakuen University, Aichi, Japan

Norie Kawano  
Sugiyama Jogakuen University, Aichi, Japan

Mho Akita  
Aichi Sangyo University, Aichi, Japan

Masayuki Ichinose  
Tokyo Metropolitan University, Tokyo, Japan

Shigeru Aoki  
Sugiyama Jogakuen University, Aichi, Japan

In order to realize a sustainable, diverse, and inclusive society, environment-conscious initiatives are expanding on a global scale. Consideration for a sustainable global environment is also important in the field of architecture. In research on rehabilitation of housing complexes, there is a need to establish evaluation criteria and consensus-building methods that include consideration for the earth, health, and welfare. Around the world, many environmental evaluation indexes have been developed for sustainable development. The purpose of this research is to provide a direction for the development of planning and evaluation standards for the revitalization of apartment complexes in the new era. In this paper, we will clarify the characteristics of the evaluation tools developed by 54 Environmental Assessment Indexes in the world. The results of this research will be used as one of the factors when considering the direction of the development of evaluation criteria for rehabilitation of housing complexes in the future. As a result of our analysis, we were able to classify the evaluation tools into six categories according to the categories on which they focus. In addition, there were differences in the categories that the evaluation tools emphasize due to differences in the objects to be evaluated, differences in the development areas, and differences in the target objects set by the indexes.
129. Research on the regeneration procedure for reutilizing vacant housing stock in Japan

Noriyuki Tajima
Chiba Institute of Technology, Chiba, Japan

Since the economic development period in the 1960s and '70s, old buildings were always considered unsuitable because of the risk of earthquakes or due to new social trends. But new construction finally dropped in the '90s, and the birthrate also declined and the aging population grew instead. The number of vacant housing stocks have been more than doubled in Japan last 20 years, with 500,000 residences increased every year, and the issue of regeneration and reutilization of old buildings has become a focus. Yet it has not been easy to achieve successful outcomes because of many and complex impediments, interfere, such as legal, social, structural, economic, or tax-related reasons.

In this study, through unraveling these complex impediments, effective countermeasures are organized and case examples of regenerated buildings that have overcome these barriers are introduced to clarify how each problem can be surmounted, and these regeneration procedures will be drawn in the shape of process planning that visualizes the steps of measures against each problem.

There are five main problems: old housing plans against new social needs; degradation of building structure and materials against new building standards; old technical standards against new technologies; existing legally non-conforming buildings against ever-added new building laws; and old building reliability against possible economic value estimated. These five problems are used to clarify the regeneration procedure in order to propel and increase the fruitful utilization of this stock for the future.
Public housing complexes, built in the period of mass supply as a solution to the shortage of housing after World War II in Japan, have deteriorated. In terms of construction, the buildings have become old and the facilities have become obsolete; in terms of function, the living environment of the housing complex sites can no longer fully satisfy the needs of the residents due to changes in the family structure caused by the decreasing birthrate and aging population. In such circumstances, large-scale architectural renovation of the housing complex sites has been attracting attention to meet the current needs of residents.

In an era when demand for new housings is expanding, efficient standard design and construction systems have been developed. Many papers have also been published in the study of building design and construction processes, but there is currently a lack of research on the design process of housing complex renewal in response to social changes after completion.

In this study, we first clarify the characteristics and structure of information exchange between stakeholders such as the building owners, residents, designers, and builders in the design and construction process. Then, by organizing smooth consensus building between stakeholders in the operation and management phase, we consider how to effectively adapt to social needs in designing future housing complexes.
These days have seen the rise of open building theory through the development of SI housing system in China and Japan, as one of the strategies of long-life housing. In SI housing system, although the concept of levels has been well applied, and the resident decision are being considered before and after occupancy, some of the plans and designs don’t really meet resident requirements and likes, especially in China. As a result, some of the designs are not that effective as expected. There is no doubt that the open building theory is one of the good strategies towards long-life housing though, the realizing methods should be reconsidered, in order to meet the residents’ needs better.

As the local regulation, culture, society, etc. are greatly distinguished in China and Japan, the development histories of long-life housing and open building theory in China and Japan and the differences between them should be firstly investigated. In this article, the development histories of long-life housing and open building theory in China and Japan are introduced and compared, and that different social background influenced their development process and industrial models is confirmed. Besides, the supply method and plan differences of open building housing of two countries are compared and analysed. As a result, it is shown that different social backgrounds have an impact on the development of SI housing, that in Japan the SI structure system has been formed, while China has developed the SI supply system.
Networked methods of cooperation, informatization practices, decentralized systems, «Uberization», emerging today in “common” sectors of the economy, can have an effect in housing/renovation. The 20th century, to solve the problems of large-scale housing creation, formed its own systems (including mass-production, standardization, functionalist vision, typization, etc.)- they all complemented each other and gave a complex effect in synthesis. Today, for new problems of renovation & creating sophisticated environment, we can mark possibility of forming our own complex systems - including uberization, “new” economy, network production, collaboration of participants - creating its own tools, more adapted to solving new problems. Changes of the 21st-century: “new economy”, network cooperation&participation for creating environment (sophisticated distribution design tasks in networks), industry4.0, new management - can form new systems and design techniques that contribute to the individualization & new understanding of housing for 21-stage-society. An experimental platform was created on the basis of these ideas, allowing to synthesize them. 3 cases will be considered: 1-“contrasted”(with the traditional methodology) dwelling design with communities in IT-environment (“what would happen if the residential complex was built not according to the traditional, but according to the network method of collaboration of many specialists together with real inhabitants). 2-Experimental residential complex including a”game” with different forms of individualization. 3-A historical building, renovated into a mixed-use-development with publicpark. All of them demonstrate complicity, usage of AI, big-data & based on the open-building philosophy. The methodology of work includes theoretical models & real community testing, presented systematized information&data of experiments, methods classification, various digital & economic-mathematical modeling.
This research is based on the refinement and diversification demand of housing stock quality improving in China. The paper focuses on the complexity of built environment in old residential areas, which involves numerous responsibilities and rights and multi-role cooperation in the process of regeneration. This paper studies the application of open building theory and its derivative theories in the area of housing regeneration, researches the current situation of policies, mechanisms and design methods for the regeneration of old residential areas in China and discusses the theoretical applicability of open building theory in the design practice of old residential building renewal methods in China. The study investigates the situation of the old residential areas in renovation, divides the responsibility and right relationship between the participants and building components by levels, and establishes a localized theoretical model for the regeneration strategy design of the old residential buildings in China. This study will provide scientific theoretical support for the constructing of a sustainable mechanism involving professional decision-making, long-term management and capital introduction, for the build of a multi-dimensional quality improving regeneration of the old residential areas in China.
After rapid urbanization from last several decades, Pearl River Delta area (PRD) in China gradually steps into an urban regeneration process, especially in the field of housing sector.

However, neighbour and housing reform activities in last few years focused on the inner prat of the cities where are mainly historical districts or chaotic urban villages. While another large proportion of housing in “Dan Wei” has been ignored. It is a typical Chinese working unit combined with living and other activities, but currently faces new challenges of social and functional transformation. Although a new regeneration design strategy: “Micro-upgrading”, was firstly proposed in Guangzhou and specific for this neighborhood typology, it still cannot ideally resolve its core negative issues in last few years.

Therefore, based on an architectural school’s design course, this study will select a region concentrated of “Dan Wei” units in Guangzhou, which is the core city of PRD. By making use of “Open Building” theory and “Level” strategy, some valuable research outcomes and design solutions will be discussed and proposed.
262. Research on the assistance of MySQL database platform to the renewal design of the interior space of urban existing housing

Yu Shao
Harbin Institute of Technology, Harbin, China

Ruihong Yan
Harbin Institute of Technology, Shenzhen, China

Jing Xue
Harbin Institute of Technology, Shen, China

Yuling Chen
Harbin Institute of Technology, Shenzhen, China

Junrui Zhang
Harbin Institute of Technology, Shenzhen, China

In response to the topic of this conference, this paper mainly adopts the strategy of introducing database technology into the renewal and renovation of existing housing. With the advent of the information age, it is urgent to carry out information transformation for the construction industry, especially for the existing housing. Nonetheless, the database is simply used for the storage and visualization of project and product information in the field of architecture. Within such context, this research contends that the database platform shall be applied more deeply. A brand-new online platform is being developed to demonstrate that the database can realize residents’ participation in the renewal design process to a great extent. Therefore, with WAMP as the development platform and database technology as the carrier, this research established a core database concerning the supporting system and auxiliary system of existing housing, so as to provide people with a participatory platform for free renewal design, thereby making people participate in the renewal and renovation process of existing housing in a more convenient manner.

Keywords: MySQL Database, Existing Housing, Renewal Design, User Participation.
Commercial buildings in the residential districts are under rapid redevelopment because retail shopping activities are being replaced by community service, education, eating and dinning and experiential activities in China. This paper revealed three interior refurbishment projects aiming to recreating interior public spaces. Interior fitting has rapidly grown in the building industry. Product suppliers provide strong support for construction quality and intervene in architectural design decisions. Interior design, as independent work, promotes effective dialogue with clients, users and suppliers in the design process. It is a platform for quality by understanding the texture, lighting and atmosphere as the key area of control in design. The interior design of three projects of Baumschlager Eberle Architekten (BEA) Hong Kong Ltd, transforms the common areas of shopping centres in residential areas into interior public spaces. The paper introduces and evaluates the design methods of BEA architects to present and control design quality, especially for interior public spaces. The territory, material, visibility, rhythms and use and overall interior atmosphere are analysed with case studies based on the literature review on outdoor public spaces. The paper concludes that interior refurbishment is an independent level of design in the recreating “publicness” in existing building structure. Only when conceptually free from the constraints of structure and façade can unique atmospheres be achieved through design, opening up further intervention in future.
Responsibility for housing people with a disability has rested with government and the charity-medical model of disability encouraged institutionalized accommodation. However, since the mid-2000s, the introduction of a person-centred approach has seen government’s legislate programs that facilitate people with disabilities living in the community. This shifted supply of appropriate housing to the private-sector, and placed a focus on whether current building regulations are capable of regulating in this space. This paper explores the history of building regulations in Australia, in parallel with the history of treatment of people with a disability. The normalization of institutionalizing people with a disability was reflected in early building codes in Australia, continuing from the 1840s until the 1980s when disability theory began to change – but not building practice in Australia. The decisive break between the approach to disability accommodation (person-centred) and the institutional model in building regulations occurred with the move to the National Construction Code (NCC) in the 1990s. The introduction of the National Disability Insurance Scheme (NDIS) in 2014 highlighted the disconnect when a market-based housing model was proposed that proved difficult to implement with current NCC settings. This study highlighted the complex interaction between existing policy settings, and identified the scope for individual interpretation of the code around key concepts. These include building classification, single-occupancy units, and fire safety. As a consequence of the institutional model enshrined in the NCC, uncertainty and confusion within the private-sector housing industry has impacted the cost and quality of the housing produced.
Study on effective long-term space optimization design regarding existing campus buildings in China

Jinxiu Wu
Southeast University, Nanjing, China

The past century has seen a pronounced development of higher education in China. Notably, the gross enrollment rate has risen from 0.1% in 1970 to 48.4% in 2016. Existing campus buildings in colleges and universities that hold great value because of their historical, cultural and environmental resources, have attracted an increasing amount of attention. Unfortunately, in many cases, campus buildings have to face issues concerning uniformity of spaces and poor adaptability to accommodate changing academic needs. These issues greatly impact not only the comfort of faculty and students but also the effectiveness of teaching & research. This paper focuses on the effective long-term space optimization regarding existing campus buildings in China, inspired by the concepts of Open Building and applying the detailed research of Southwest Building in Nanjing University, Gulou Campus as an example. The process consisting of investigation and space optimization design is introduced. By the design principles of “fixed space” and “variable space”, this paper demonstrates that the application of effective long-term space optimization design can greatly enhance the long-term utility of existing buildings. Numerical simulations of natural daylighting and ventilation by Ecotect and CFD also show an enhancement in building performance after the space optimization design. This research is beneficial to realizing the effective long-term utilization of campus buildings in universities and colleges. It can also be referred to for the renovation design of other kinds of existing buildings in developing countries.
477. A study on the process of design changes that deviate from “standard specifications” in housing production of Japanese house builders - focusing on communication in design meetings

Nobuhiro Hasegawa  
Meiji University, Kanagawa, Japan

Kozo Kadowaki  
Meiji University, Kanagawa, Japan

Background
The system of industrialized housing production by house builders in Japan limits the parts that users can freely change as “standard specifications” to “infill” parts such as interior finishes and water facilities. On the other hand, design changes that deviate from the standard specifications, such as “skeleton” parts, cannot be easily made due to the existence of each manufacturer’s own internal rules. This has been pointed out as a factor that makes it difficult for house builders to respond to today’s diversifying user needs.

Purpose and Methodology
The purpose of this study is to clarify the actual situation and issues with design changes that deviate from the standard specifications. For this purpose, we conducted a survey of case studies in which various design changes that deviated from the standard specifications were realized through collaboration between house builders and architects. Specifically, we recorded the conversations with regular design meetings and analyzed the relationships between the contents of each change, such as construction conditions and legal restrictions, and the issues that were mentioned.

Results
As a result, it became clear that the in-house rules of house builders are a major obstacle to design changes that deviate from standard specifications. Furthermore, it was found that the presence of an “architect” with specialized knowledge was effective in facilitating communication between meetings and increasing the possibility of user participation in the design process.
In order to alleviate the housing shortage problem, in the 20 years after economic reform and open up in China (1978), a large number of multifamily housing had been built with brick concrete structure. Restricted by economic and technical conditions, the quality of these kind of existing housing is relatively poor. After 30-40 years of use, existing housing has been degraded in varying degrees and needs to be renewed. Many cities have carried out diversified renovation exploration for the maintenance and renewal of existing housing, including external wall painting, flat roof to sloping roof, seismic reinforcement, energy-saving renovation, adding elevators, pipeline renewal, etc. The purpose of existing housing renewal is diversified, including the improvement of urban landscape, the improvement of building performance, and the renovation suitable for aging. The practice and effect of housing renewal are lack of systematic analysis.

Based on the “hierarchy” theory of open building, the study divides the skeleton system of existing housing in China into three parts: structural and maintenance system, public equipment pipeline system, common corridor and elevator system. Combined with specific cases, this paper makes a comparative analysis on the purpose, mode and specific practices of existing housing skeleton system regeneration in Beijing, Shanghai, Dalian, Shenzhen and other Chinese major cities. The problems in the maintenance and renewal of existing housing are also summarized. This study provides a new perspective for sorting out regeneration mode of Existing Housing in China.
Phnom Penh, Cambodia, has planned to be one of the liveable and sustainable cities. A city’s vision is to create a clean, green, and competitive city where social safety and living quality are promoted (Global Green Growth Institute 2019). The study also shows that new generations prefer a good quality home design responding to needs and lifestyles. Moreover, the rooms in housing stocks are spacious, but it is ineffectively used (Urbanland 2020). These address opportunities for pursuing living design solutions according to the policies, people’s preferences, and pain points of existing housing designs. A typical urban residential type in Phnom Penh is Apartment Shophouses. In the past, they were a row of two-story buildings located in city areas. The ground units were for business purposes, while the upper floors were for multi-family living access from a courtyard in the middle. Presently, the Apartment Shophouses have changed into a row of 5-6 story, diversified-use, and lively buildings. Nevertheless, they lack maintenance, poor daylight, and ventilation. However, they positively respond to Jacobs’ favours; diversity, lively neighbourhood, and mix-used building (Jacobs 1961). According to the policies and residents’ preferences, these challenges for the Apartment Shophouses revitalization into an adaptable, lively neighbourhood and good lifestyle building for the new generations. The study investigates the living and adaptive conditions of the Apartment Shophouses from the 40 residents via online questionnaires and 10 residents via interviews. The results show weak conditions and opportunities for building with quality improvement based on the Open Building approach.
ORGANISATION AND MANAGEMENT OF CONSTRUCTION: NEW CHALLENGES AND OPPORTUNITIES
Ramin Asadi
Massey University, Auckland, New Zealand

Suzanne Wilkinson
Massey University, Auckland, New Zealand

James Rotimi
Massey University, Auckland, New Zealand

Rework is one of the leading causes of cost and time overruns that primarily affect project performance. The performance of construction projects can be elevated with the implementation of rework moderation strategies. Identifying rework root causes is the first step of rework management followed by a mitigation approach, reducing or preventing strategy. As the contract is the core connection between clients and contractors, using a rework management approach in the contracting process allows participants to be aware of rework impacts before the project’s commencement. Selecting the best approach for rework mitigation depends highly on the causes of rework and their classified factors. Thus, the paper classifies rework root causes in the design stage of projects to provide a platform for contract documents assessment. The method used to classify the identified rework root causes into five categories is based on the literature. Results from collecting secondary data indicated that all categories of rework causes consisting of technical, human resources, process, material/equipment, and general/external factors are appeared in the design stage of the project. Assessment of contract documents through a questionnaire survey based on these classified factors in search of a connection between rework, contractual claims, and clauses of the contract is the next step of the study. The paper recommends that assessing contract documents can be used as a new approach for rework management.
This study investigates the motives of clients, contractors and subcontractors and underlying conditions favoring strategic partnering formation in the Dutch retrofit market. In-depth interviews were conducted with six clients, six contractors, and two subcontractors concerning four cases in the Netherlands. To identify motives, the data from the 14 interviews were coded with Atlas Ti based on a theoretical framework. The thematic analysis revealed the main motives. The main finding of this study was that clients and contractors form strategic partnerships for different reasons: clients unite to exploit the knowledge and capabilities of their supplying partners, while contractors and subcontractors unite to improve their market position. Both motives may be exchanged when clients offer contractors and subcontractors a long-term perspective. This finding shows managers in the construction industry that, to maintain a strategic partnership, it is important to understand and discuss the motives of each partner and how they can be exchanged.
36. Improving safety compliance of construction workers: a theory of trait activation perspective

Diya Yan
Central Queensland University, Sydney, Australia

Xianbo Zhao
Central Queensland University, Sydney, Australia

Pushpitha Kalutara
Central Queensland University, Rockhampton, Australia

Construction workers’ safety compliance plays a decisive role in improving safety performance on site, however, there are limited studies investigate the relationship between individuals’ trait and their safety compliance in the construction industry in a theory of trait activation perspective. Drawing upon trait activation theory, this paper applies the concept of differentiating safety compliance into deep compliance and surface compliance based on workers’ safety compliance behavior and aims at identifying the influential factors and their effects on construction workers’ deep and surface compliance, respectively. The key factors from trait activation theory are identified, including conscientiousness, agreeableness, emotional stability, openness to experience, extraversion, emotional intelligence, and situational awareness. As a result, a conceptual framework is developed by summarizing the proposed relationships among those key factors and two dimensions of safety compliance (i.e., deep and surface compliance). This study will gain theoretical contributions by shedding light on investigating the antecedents of deep and surface safety compliance in the construction industry and will provide practical implications as understanding this framework can help construction workers achieve improved safety performance by enhancing deep compliance or reducing surface compliance.
Construction incentivization (CI) is used as a collective term to describe the range of incentive schemes that are commonly used in construction projects. Most reported studies of CI mainly focused on its effects on project performance. Moreover, recent case studies show that the effectiveness of CI in enhancing performance has not been as promising as intended. Providing singular financial reward may not guarantee improved performance. Instead, CI can also be used to manage the relationship between the contracting parties. This study aims to offer guidelines for the planning and implementation of CI approaches and includes 1) identifying the key components of effective CI; 2) investigating the key contributors of CI in terms of relational management; and 3) developing planning principles of CI for construction projects. The key components of CI are goal commitment, information exchangeability, expectation alignment, risk efficiency and relationship investment. The study also proposes that CI can be used to balance equity gap (EG) and maintain inter-organizational relationships (IOR). Accordingly, the following CI planning guidelines are proposed: 1) Balancing EG should be an integrated part of every CI; 2) The key targets of CI should be established through consensus negotiation to improve the recognition of CI; and 3) For projects seeking outstanding performance, continued development of IORs to evoke cooperation for project performance is necessary. Generally, this study focuses on the relational impacts of CI. Key principles are also provided for the planning use. Further empirical studies are suggested to support these research findings.
This paper summarizes the results of a comprehensive case study on the application of the performance measurement tool, CII 10-10, developed by Construction Industry Institute, in three Norwegian construction project organizations. The aim of the paper is to examine the extent to which the benefits of the application of performance measurement in construction project organizations, is realized in practice. Overall, 176 participants among the three organizations responded to a survey which was designed to assess the benefits of application of performance measurement in the case firms. The findings from the survey have had practical value for the three case firms. They all got an assessment of how well they managed to utilize the tool, what value it provided and where they need to put in extra effort to fully realize all the benefits of the tool. Although not all the expected benefits have been realized in the case firms, the process has proved to create value for the firms through boosting the synergy among the teams and raising awareness on the potential improvement areas. The practical implications of this research relate to the benefits of performance measurement as a tool which improves the processes alongside the project product. It emphasizes the potential applicability of performance measurement as a tool for enhancing teamwork, dialogue and communication among project team.
The popularity of projects being undertaken using Integrated Project Delivery (IPD) forms continues. Delivery platforms include the Integrated Form of Agreement (IFOA) in North America, Alliancing in Australia and New Zealand, Finland, and the Netherlands, and the New Engineering Contract (NEC3/4) in the United Kingdom. Findings from numerous surveys and case studies suggest that this form of delivery is more frequently successful in providing value to the project owner and enabling a range of ancillary benefits to project teams that are collaborative and unified. However, simply forming an IPD team is insufficient. What appears to be the essential ingredient is the effective collaboration that shapes the quality of cross-team and cross-disciplinary dialogue. This raises interesting questions about providing value through project delivery. Aside from the intrinsic value of the project infrastructure developed, other forms of value that escape attention may be created through effective IPD. Accepting the premise that effective dialogue is the key to positive and value generating integrated team collaboration, this paper explores the value that effective dialogue brings to the Alliance delivery platform, across the development phase to implications for the facility operation and its eventual disposal/reuse.
The Nigerian Construction Industry faces a lot of problem that leads to, among other things, materials waste, poor quality of work, poor materials flow, project delay and cost overrun. Overcoming these challenges, requires knowledge of modern management philosophies, techniques and tools. One of the new revolutionary practices which was adapted from the car manufacturing industry is “lean production”. This article aimed at deciphering the lean approach to production management with a view of extracting its utility in restructuring the Nigerian construction industry. A qualitative research approach was adopted in the study which included collective case study investigation. The research activities included a comprehensive review of the related literature and study of selected cases. Abuja, the Federal capital territory of Nigeria was the selected geographical scope of the research. Ten case studies were purposefully selected for the study. The population for the study was ongoing building project sites (ten case studies purposefully selected) in Abuja. The study found that most lean approach were not applied during the production. The research has increased the understanding of the lean production approach in the construction industry. The study recommends that a framework of lean production approach in the construction industry should be developed to guide the professionals.

Keywords: Concurrent engineering, continuous improvement, lean construction, re-engineering, total quality management
There is a common understanding that megaprojects are important drivers of society changes. Their impact is an important phenomenon because of the influence on both society and economy. Despite the best practices all around the globe, numerous challenges can move a megaproject from a programmed success to a failure scenario. It can create an uncertainty impact over the result and justification of the enormous amount of resources spent. Despite much research done so far, it is still not clear what are the causes of megaproject success. However, there seems to be no clear understanding as to what are the major success factors on which a project is judged in developing nation. Hence, this study aims to analyse the most vital success factors that would label a megaproject as being a complete accomplishment.

The research was conducted using quantitative survey. The questionnaires was distributed to different stakeholders who have participated in previous megaproject. The questions were based on a Likert’s scale rating and analysed using relative important index (RII). The result from the analysis was used in establishing the main success factors in megaproject whilst focusing on the most important success factors as projects are unique. The key finding from the study is the Project Manager experience and coexistence with other stakeholders was found which is vital factor for the successful delivery of MIPs. Therefore, the research demonstrates the implication of the role of the project managers in terms of coordination of other parties in achieving stakeholders goal.

**Keywords:** Mega Infrastructure, Success Factor, Project Management, Project Performance, Stakeholder
Globally, the dynamic change such as Covid-19, which has presented a rapid shift in human livelihood appears not to disappear soon. Businesses scramble to adapt and are shaken by this unprecedented shift amidst this unknown pandemic known as coronavirus. This virus outbreak has highly disrupted almost every country in the world and is even more devastating in developing African countries like South Africa. The nature of the disruptions and their effect has placed industries like construction at the forefront of their contribution as well as the corporate social responsibility to the economy where it exists. This article sought to understand the contribution of the built environment to support the economy towards recovery amid coronavirus pandemics. A quantitative method was adopted where 210 questionnaires were distributed, however only 150 were returned which gave a response rate of 71%. SPSS version 27 was used for the study and descriptive and inferential statistics were carried out. The study showed the construction industry contributed significantly to the South African economy during the coronavirus pandemic. The study contributes to the body of knowledge concerning the support of the construction industry in times of disruptions in South Africa.

Keywords: Contractors, Construction industry, Economic growth, Infrastructure, Pandemic
A comparison study between guideline for pure CM Method in local governments of Japan and pure CM contracts in other countries

Atsushi Tamura
Building Research Institute, Tsukuba, Japan

In Japan, government buildings constructed by local governments during the period of rapid economic growth are aging, and there has been an increase in the rebuilding of them since the 2011 Japan Earthquake. However, with the exception of government ordinance cities there are only a small number of technical staff in local governments, and their experience and capabilities are insufficient. In 2020, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) published the “Guidelines for the Pure CM Method in Local Governments,” which established the conditions of Pure CM contracts in public projects to support local governments. However, this Pure CM method specified in this guideline is unique and different from Pure CM methods in the USA and the UK.

This study aims to clarify the characteristics of CM in Japan and its problems by comparing the CM contract in public projects in Japan, the USA and the UK through a literature survey.

Our survey showed that the scope of services of CMRs in “Guidelines for the Pure CM Method in Local Governments” are limited compared to the USA and the UK. The scope of services of CMRs in Japan are stipulated not to overlap with existing roles such as architectural service, supervision service, or construction work. The CMR can provide support and advice to the Owner, but cannot give instructions or directions to the Architect, Contractor, or Subcontractor. CMRs can participate in the project in the early phase but are not encouraged to develop the master plan.
183. Visualization of blockchain-based smart contracts for delivery, acceptance, and payment process using BIM

Xuling Ye  
Ruhr-University Bochum, Bochum, Germany

Ningshuang Zeng  
Ruhr-University Bochum, Bochum, Germany

Markus König  
Ruhr-University Bochum, Bochum, Germany

Building Information Modeling (BIM) provides an excellent opportunity to digitally document and visually display construction projects’ information throughout their whole lifecycle. Another recent technology that is fostering the digital transformation of the construction sector is blockchain-based smart contracts. In combination with BIM models, such smart contracts can be used for the automation of delivery, acceptance, and payment (DAP) processes in the construction industry. The DAP process can be modelled by using smart contracts and securely stored via a blockchain. Since smart contracts are programming codes, for stakeholders it is difficult to understand what is exactly written in the smart contracts. Therefore, it is necessary to visualize the status of the deployed smart contracts and the executed transactions. In this paper, a framework is highlighted to record and visualize the status of the DAP processes by combining BIM with smart contracts using the Business Process Model and Notation (BPMN) to develop a smart contract system. With the help of suitable visualization concepts, the individual transactions of the blockchain can be displayed in a comprehensible way. The feasibility of the framework is presented through an illustrative implementation of the smart contract system. The proposed framework can help project participants better understand the current state of a smart contract.
186. Stakeholder engagement and collaboration in overcoming the constraints to delivering low carbon buildings in high-rise high-density cities: Insights from a social network analysis

Nandun Madhusanka Hewa Welege
Department of Civil Engineering, The University of Hong Kong, Pok Fu Lam, Hong Kong

Wei Pan
Department of Civil Engineering, The University of Hong Kong, Pok Fu Lam, Hong Kong

Mohan Kumaraswamy
Department of Civil Engineering, The University of Hong Kong, Pok Fu Lam, Hong Kong

The building stock in high-rise high-density cities is a principal contributor to global anthropogenic carbon emissions. Even though there are many commitments and action plans, an effective uptake in the delivery of low carbon buildings (LCBs) is not evident in high-rise high-density contexts due to several prevailing constraints. Despite many studies in the arena of LCBs, only a few have focused on analysing stakeholder ‘engagement’ and ‘collaboration’ towards identifying and addressing constraints to delivering LCBs. This paper addresses this gap by employing a Social Network Analysis (SNA) based methodology to explore the required engagement and collaboration of stakeholders in addressing constraints to delivering LCBs in high-rise high-density cities. In total 21 constraints to delivering LCBs were identified through a systematic literature review followed by a questionnaire survey covering Hong Kong, Singapore, Australia (Sydney and Melbourne), UAE (Dubai and Abu Dhabi) and Qatar. Furthermore, 15 influential stakeholder categories were identified from the literature. Subsequently, a two-round Delphi survey was conducted to map the engagement of stakeholders over the constraints and to develop the input dataset for SNA. The SNA results revealed the stakeholders’ influencing ability over each of the identified constraints and their significance in terms of their position in the developed social network structures. The findings should benefit industry practitioners by providing useful insights into potential engagement and collaboration channels for smoothly addressing the constraints to delivering LCBs.
The importance of building repair and maintenance sector has become more significant in recent years as universally construction activity continues to expand the volume of building stock globally. With this growth in building stock coupled with repair and maintenance complexity unforeseen risks has become an increasing problem to solve. The increased prevalence of unforeseen safety risks increases the likelihood of accidents for workers. In such complex working environment a type of organisation known as high reliability organisation is known to operate successfully. The concept of mindfulness from high reliability organisation theory has been identified as a key strategy to address the unforeseen risks derived from the complexity in socio-technical systems. However, the concept of mindfulness has not been investigated in improving the safety performance of building repair and maintenance. Therefore, this study aims to examine the relationship between mindfulness and safety performance of building repair and maintenance companies.

Initially, a comprehensive literature review was conducted on high reliability organisations and the concept of mindfulness to develop the research hypothesis. A questionnaire survey was utilised to collect the data from building repair and maintenance professionals in Australia. A Pearson correlation analysis was conducted to examine the relationship between mindfulness and safety performance. This study found that mindfulness has a significant impact on accident prevention in building repair and maintenance companies through discovering and managing the unexpected events occurred due to the complexity. The findings have implications for organisations in the way they train and implement professional development programs for their staff.
The transformation of the construction industry to incorporate modern methods of construction is proceeding in a patchy but seemingly inexorable manner. This drive towards achieving certainty of outcomes and eliminating workmanship of risk overlooks the human-centred act of building. Even in a technologically equipped society such as the UK, much construction work remains predominantly human powered and non-digital. This is particularly the case for extant buildings. With the focus on a building refurbishment project, the aim is to explore how building workers solve emergent problems without recourse to digital forms of information, but instead utilise experience and knowledge of the existing structure and materials, and skill in practice. Participant observation is used to gather rich data on one such site. The resultant ethnographic account explores the practice of building workers illustrating how skill remains central to the day-to-day realisation of projects and that much of construction continues to be an overwhelmingly analogue work world. It is timely to emphasise that the reification of designs and project ambitions is dependent upon workers undertaking physical acts as free and thinking agents. The absence of explicit digital information is compensated for by these workers who generate solutions in a manner that combines both ad hoc and long-practiced techniques springing from a deep well of tacit knowledge. While not diminishing the advantages offered by a modernised construction industry, there is a need to emphasise the ingenuity, pleasure and pride gained from building things in a human way.
As the population in Victoria continues to grow, there has been a corresponding increase in building approvals across the State. Houses characterised as low-rise residential buildings often take the largest share of these approvals, with incessant residential building activities being driven by record low interest rates. Low-rise residential buildings comprise of various building forms that use several construction materials specified to construct the building envelope and other structural and non-structural elements. As materials used for constructing residential building envelopes continue to evolve, these materials must be fit for purpose, satisfy design criteria and performance requirements, while being aesthetically pleasing. This research analyses the trend in construction materials used in building envelopes of low-rise residential buildings using data from building permits issued between 1996 to 2019. The trend analysis shows that traditional double brick wall systems and suspended timber floors have reduced in popularity for houses built in the 21st century. The analysis also shows that brick veneer wall cladding systems built over slab-on-ground footings is the dominant construction form while the roof cladding material is influenced by the geographical location. Insights from the data analysis indicates very little innovation has emerged on materials for residential building envelopes despite its crucial role in providing thermal comfort for inhabitants. Results from this research will serve as a basis to provide quantitative assessment of the trend in materials resource; provide insights about impact of new building envelope products on existing industries; and perceptions on materials for future building envelopes.
Agile Project Management (APM) is traceable as a concept for software development and IT projects. It represents one of the basic competitive advantages of contemporary organizations that can be applied to almost any large-scale project in any industry. Construction projects have high uncertainties and high rates of change, complexity, and risk. However, the adaptive approach of APM is yet to be seen in the construction industry. A questionnaire consisting of four core agile values and 70 agile practices was used to study the inclination of project management practices in the Malaysian construction industry. The survey, which garnered 210 responses from construction personnel, revealed the inclination of four core agile values between 6.38 and 7.34 on the scale of 0-10, while agile practices scored between 3.4 to 4.0 on 0-5. The agile oriented group is found to apply 25 project agile practices more than the non-agile oriented group. Smaller organizations have adopted more agile project practices, especially those related to the continuous improvement domain. The study concluded that the Malaysian construction participants are leaning towards the core value of project management, and most of the project management tasks practiced currently are agile orientated.
Purpose: Emerging construction companies often liquidate due to the stiff competition among their rank in the construction market. This study investigated the skills and strategies adopted by emerging contractors to make their businesses sustainable within the highly competitive construction markets.

Methodology: A qualitative research approach was to achieve the project’s objectives by making use of semi-structured interview questions to solicit information from emerging contractors within the Construction Industry Development Board (CIDB) Grade one (1) to four (4) in the Gauteng Province of South Africa. The data gathered was analysed using qualitative content analysis to identify the main themes.

Findings: The study’s findings indicate that emerging contractors adopt different skills and strategies to remain competitive and sustainable in the construction industry, including; improving the quality of work, delivering projects on time, willingness to adapt, keeping updated on the happenings in the construction industry, building good relationships with bigger companies, reducing waste in the value chain to minimise cost, improving business cash flow, exploring joint ventures strategies, better investment decisions, among others.

Value of the study: The construction industry is highly volatile and competitive, yet some construction firms are able to strive through strategic business decisions. This study gives insight to emerging contractors on the strategies to adopt for business sustenance in the highly competitive construction market.

Keywords: Business sustenance, emerging contractors, management skills, strategies
The Sri Lankan construction sector continued to boom in the last decade reporting a 6.78 percent growth of GDP in 2019. Nonetheless, construction recorded 40 fatal and 59 non-fatal accidents in 2019. There is a serious lack of safety management in construction companies in Sri Lanka. The reason is largely attributable to the lack of an institutional mechanism to ensure accountability, planning, prioritising, reviewing, learning, and training for continuous improvement of safety. Therefore, it is necessary to explore the system of laws, regulations, procedures, stakeholders with their roles and norms that shape construction safety in Sri Lanka. The study explored how national and industry level institutions are linked to construction safety management systems in Sri Lanka through document review and interviews with personnel from the Department of Labour, Construction Industry Development Authority, construction companies, professional bodies, and academic institutes. The Factories Ordinance, No. 45 of 1942 is the main legislation applied on construction safety enacted in the colonial period, thus, no improvements are made to industry-specific requirements and technological advancements. Neither, the Construction Industry Development Authority has any standards, guidelines, codes of practices to conform with safety. Major construction companies align with international standards (ISO 9000, 14000; OHSAS 18000) to win major construction projects. It indirectly affects maintaining a safe work environment. Therefore, Sri Lanka needs to focus on an industry-level institutional mechanism to improve the safety management system. Further, support from educational and training institutes, trade associations, and professional bodies is necessary to push forward the importance of safety.
Digital technologies are becoming increasingly wide-spread not just in our personal but also in our professional lives. This change has been evident also in the construction industry, although the industry has been identified as one of the least digitalised industry sectors. Construction professionals use a wide range of digital technologies when performing their responsibilities. These range from basic office applications, which have existed for a long time, to more advanced and modern applications such as laser scanners and Building Information Modelling. This research looks how various digital technologies have become and are becoming part of construction management responsibilities. Construction management responsibilities have been identified through a document analysis as eight responsibility groups including management of time, cost, quality, health and safety, environmental factors, resources, and contracts, and development of human resources and processes. Construction management related digital technologies on the other hand have been identified through a document analysis and a systematic literature review and categorised under communication and other enabling technologies, technologies combining hardware and software in intelligent systems, and data technologies. The way how the construction management responsibilities and the digital technologies interlink forms a description of the modern way of performing construction management responsibilities. Some of the technologies are in everyday use across construction management professionals, however, many are at their pilot stage and used only by few offering a perspective not just to present but to the near future for the whole discipline.
The studies show that risks occur during the construction of projects and affect performance in terms of cost, time, and quality. However, with the growing evidence of cost and time overruns associated with public tertiary education building projects, this paper assessed factors predisposing these building projects to risks. Using the survey method, 452 questionnaires were administered to consultants, contractors, and client representatives across five tertiary education institutions. The research instrument had a reliability value of 0.763 via the Cronbach alpha test. Of 452 questionnaires administered to the respondents, 279 were retrieved, representing 61.73% return rate, and analysed. Furthermore, the top three factors include financial constraints, location of the project, and project type. In contrast, economic requirements, special and legal conditions, and building use are the minor predisposing factors. The respondents had convergent views on eight out of eleven factors except for project duration (time limit), economic requirements, and building use. Besides, the eleven factors presented in the study were significant and recorded high mean scores, implying good parameters for measuring factors predisposing public tertiary education building projects to risks. Based on the preceding, the study provided information on the factors that could enhance the performance of public tertiary education building projects.
Construction and demolition (C&D) waste has been a significant issue around the world. Although Australia has achieved a C&D waste recycling rate of 67%, some states and territories have set an even higher target. Thus, effective C&D waste management (WM) has been well studied by Australian researchers. This study aims to perform a systematic review of the barriers to C&D WM in Australia. Using Scopus to search relevant literatures, a total of 14 journal articles were targeted for analysis. Through content analysis, 31 hindrances to C&D WM were identified and their frequency of occurrence in literatures was checked. “Lack of economic incentives for practitioners to implement WM” received the most attention from Australian researchers. These barriers were categorized into five groups: government-related factors, industry-related factors, project-related factors, stakeholder-related factors, as well as methods and technologies. The findings will provide researchers with a general picture of C&D WM practice in Australia.
The construction industry is labor-intensive, applying effective human resource management plays a crucial role in influencing the performance of the workforce. Approximately around 40% of the overall project’s expenses will be dedicated to the workforce. While there has been plenty of research on labor productivity, there has always been a void in understanding the financial aspects of management. Considering the budget overrun in the majority of projects, providing a different perspective to reduce the cost implications in the fields of management to increase workforce productivity is the crux of this research. This study is qualitative in nature sourcing the secondary data, involves linking the concepts of personnel management and worker motivation. Bridging Epistemology is used as the research tool to strengthen the tacit knowledge existing among the people. The findings of this research show that intrinsic motivation factors have a prominent positive effect on the workers. Identification of management practices that brings out intrinsic motivation reveals a new kind of system called a non-financial management system which has minimum or zero cost implications. Intrinsic motivating factors such as providing positive feedback, assigning challenging work, worker recognition, responsibility delegation, maintaining social reputation, relationship management, performance management, and non-monetary management practices. The results of this study will also highlight the possibility of multiple solution channels that can be adopted by the practitioners to reap better worker productivity. This research concludes that adopting certain non-financial management practices intentionally will trigger intrinsic motivation among workers which will ultimately enhance their productivity.
In construction projects, bid packaging involves dividing the project scope into work packages that are assigned to trade contractors. The division of the work determines the scope and complexity of each bid package, as well as the dependencies with other bid packages and consequently the need for coordination between project participants. Improper division of bid packages can create coordination difficulties and breakdowns, with potential delays, added costs, and contractual friction between project participants. The construction literature, however, provides limited information on the topic both descriptive (how managers make the bid packaging decisions) and normative (methods to perform effective bid packaging). The objective of this paper is to increase understanding of the factors affecting bid packaging decisions, and the project implications of bid packaging. The investigation consists of three exploratory case studies on educational building projects. The findings show that the Construction Managers (CM) on these projects had multiple goals, which created trade-offs between the goals. The findings identify three basic configurations for organizing scope elements and discuss their project implications for bid price, and performance risks. The study develops new insights into the complexity, challenges and implications of bid packaging decisions.
Analysis of sustainable procurement in supplying recycled content: a case study in Western Australia

Salman Shooshtarian  
RMIT University, Melbourne, Australia

Tiendung Le  
RMIT University, Melbourne, Australia

Yingbin Feng  
University of Western Sydney, Sydney, Australia

Louis Bettini  
Western Australia Main Roads, Perth, Australia

Extensive construction activities across Australia have resulted in an unprecedented rate of construction and demolition (C&D) waste generation. A fraction of this waste is currently being recycled and supplied to the market. However, the reports indicate that the Australian market is not prepared to uptake such a quantity of recycled content (RC). A successful policy approach in increasing RC uptake in the construction industry is sustainable government procurement. However, the benefits of this policy instrument have not been fully realised in Australia. Therefore, this study aims to understand the dynamics of sustainable procurement using Roads to Reuse Program managed by Western Australia Main Roads as a case study. This public organisation is responsible for managing road networks across Western Australia. The study employs an interview with a senior sustainability advisor of this organisation. The interview is guided by a framework for enabling sustainable procurement seeking transformation in behaviour, culture, context and processes in the government and industry sectors. The results of the study shed light on sustainable procurement opportunities and challenges in the Australian context. Furthermore, a series of recommendations proposed to improve the status quo towards a more sustainable future. The findings can be used by policymakers, government procurement experts, and industry practitioners to drive sustainable procurement planning and practices changes.

Keywords: Sustainable procurement, construction and demolition waste, waste management, architecture, engineering, and construction sector, Australia
Brazilian housing needs are high. Even with important technological advancements taking place in recent decades, the degree of industrialization of housing construction remains relatively low in Brazil. The perception of the sector is that housing needs can only be equated by a significant increase in the industrialization of construction, and that the technologies available can support such increase. Currently, the existence of barriers and difficulties for industrialization are out of the production area, concentrated in the production chain, and in the macroeconomic, and political-institutional environments. The purpose of this paper is to provide an overview on the subject. For that, the following items were developed: technological base of housing construction, the main industrialization technologies available, and the barriers and difficulties to be faced in order to support the increase in industrialization. Finally, scenarios of the future trends of evolution in the sector are discussed. This research is exploratory, based on literature review, and the results may support actions in the sector aimed at overcoming the barriers and difficulties for industrialization. It may also contribute to increasing knowledge, and furthering studies on the subject.
Complexity is the property of a project that makes it difficult to understand, foresee and control its behavior due to interrelatedness between various project attributes such as tasks, parties, disciplines, and interfaces. Project complexity is an inherent part of mega construction projects due to their large scale, long period, the multiplicity of disciplines, the high number of stakeholders, multi-nationality, and high level of public attention, as well as political interest. This paper depicts findings of a research project that aims to identify characteristics of and factors that contribute to project complexity by referring to the experiences of professionals involved in mega construction projects. For this purpose, data has been collected by interviewing 18 participants from 11 mega construction projects. Communication complexity, which reflects the amount of distributed communication channels between various stakeholders, has been identified as one of the major drivers of project complexity in megaprojects. Based on literature and semi-structured interview findings, a causal structure to represent communication complexity comprising of three components, which are; project, stakeholders, and communication management, was developed. The causal map, which represents the opinions of a limited number of experts, can not be generalised; however, it can provide useful insights about drivers of communication complexity that can be used to develop strategies to manage complexity.
721. Construction industry classification systems: Defining the construction sector in New Zealand

An Thi Hoai Le  
Massey University, Auckland, New Zealand

Niluka Domingo  
Massey University, Auckland, New Zealand

Monty Sutrisna  
Massey University, Auckland, New Zealand

CanConstrucNZ is a partnership programme between New Zealand universities, government agencies, and professional bodies to develop a smart system that enables mapping future pipeline projects with the industry capacity and capability to advise the stakeholders whether the sector will be capable of delivering the proposed construction projects. Defining the scope of the construction sector itself is the first step of the programme that helps measure the construction sector capacity. This paper compares different definitions and approaches of the construction sector boundaries and discusses similarities and differences in the selected classification systems, usually used to define, collect and generate data for measuring the construction sector. The findings highlight the need for a more comprehensive classification to help generate the correct level of data for measuring the construction sector’s true scope and size, resulting in better policy initiatives and informing changes in the industry. The findings of this study recommend future research to develop a customised classification system to represent the value of the New Zealand construction sector in a holistic manner.
PUBLIC PRIVATE PARTNERSHIPS: PAST, PRESENT AND FUTURE
8. Criticality analysis of financial risks of public-private partnership projects in a Sub-Saharan African country

Isaac Akomea-Frimpong
Western Sydney University, Sydney, Australia

Xiaohua Jin
Western Sydney University, Sydney, Australia

Robert Osei-Kyei
Western Sydney University, Sydney, Australia

Integrating sustainable and complex financial performance models into Public-Private Partnership (PPP) project management is a challenging task due to the sheer number of inherent financial risks. Financial risks disrupt the financial success of PPP projects and act as one of the topmost impediments in the development of public infrastructure projects in Ghana. Studies on PPP projects in the country have concentrated on critical success factors, conflict management of PPP stakeholders and performance among others with little attention on financial risks. This study aims to develop and analyse the critical financial risks of PPP infrastructure projects in Ghana, a sub-Saharan African country. The research methodology is set as follows. First, the identification of twenty-eight financial risks related to PPP projects from institutional and project reports as well as peer-reviewed articles. Second, surveys of 126 participants who are experts (academic), risk managers and practitioners related to PPPs are undertaken. Third, the development and testing of a novel quantitative matrix to determine the criticality of financial risks of PPP projects against existing risk criticality models. The findings show high interest charges, excess operating expenses and huge construction material costs as some of the most critical financial risks that project managers must tackle in the country. The outcomes of this study broaden the understanding of financial risks of PPP projects, and it sets the stage for further research.
History shows that one successful method of addressing poverty and inequality is by providing social housing. In England during its post war peak, local authorities, such as borough, urban and rural district councils, built thousands of “council” houses. The common perception of the “council” estate is of huge developments such as in Beacontree built by the London County Council, but construction took place on a smaller scale in rural districts and much can be learned from studying how social housing was provided in these areas. Princes Risborough in Buckinghamshire is an excellent example of council housing provision before and after WW2. Archival data was used to analyze and evaluate the council house-building program from 1919 to 1953. Beginning in 1919 with 10 workers cottages built under the powers of the Housing and Town Planning Act 1919 and ending in 1953 with the erection of 164 “Wimpey” no-fines concrete houses, the Wycombe Rural District Council built 790 dwellings. By the time of the 1961 Census after the WRDC postwar building program effectively ended in 1953 council houses accoutered for about 40% of the homes in the town and the population doubled since 1921. Records show construction of the dwellings helped develop a thriving local construction economy fueled by procurement with local builders, constructing as few as two units. Only toward the end of the building period were contracts let in large quantities when non-traditional construction methods were adopted.
The global COVID-19 pandemic has led to diverse lock-down measures in many countries to arrest virus spread, thereby also creating a ‘work-from-home’ culture, which triggered a ‘pause’ in the previously rapid migration to urban centres worldwide. However, most rural settings do not provide cutting-edge ICT-based and advanced infrastructure along with reliable and efficient community services such as health, education, and transportation, on par with those in urban regions. These shortfalls pose significant barriers towards residents of non-urban areas to living well and working efficiently. Such barriers inspired the aim of this research to explore and evaluate the development of Smart Infrastructure (SI) in non-urban areas; i.e., not for ‘Smart Cities’ alone, but also for rural infrastructure. However, developing SI in non-urban areas must overcome resource constraints of governments, hence pointing to the potential for Public-Private Partnership (PPP) to complement public sector resources where appropriate. This paper presents the outcomes of a literature survey, as well as of 5 subsequent expert interviews and AHP-based questionnaire responses of 2 experts on exploring and evaluating barriers to deploying PPPs to develop SI in suitable projects in non-urban areas. The findings were derived through content analysis and the Analytic Hierarchy Process (AHP) techniques. These reveal the importance of overcoming community culture and ‘values’ related barriers impeding the success of these projects. The findings and outcomes of this paper also establish a solid base to boost the development of SI in non-urban settings, thereby also facilitating more well-balanced sustainable development in the post-COVID world-order.
Critical infrastructure resilience requires disintegrating the traditional silos of stakeholders to form collaborative network such as a public-private partnership. Critical infrastructure resilience is mostly influenced by the relationship between public (government institutions/agencies) and private sector (private institutions/agencies). Public-private partnership is recognized as a medium to build the resilience of critical infrastructure. In this study, a scientometric review was conducted using i.e. VOSviewer and Gephi to identify the publication trend and gaps in the public-private partnership in critical infrastructure resilience research domain. A total of 87 publications were retrieved from the literature search on Scopus. It was identified that more studies have indeed acknowledged the use of public-private partnership to build critical infrastructure resilience. However, majority of the public-private partnership in critical infrastructure resilience research papers were on cyber security. Some of the gaps identified included, limited studies on the responsibilities of the public sectors and private sectors in CIR, risks in using public-private partnership to build critical infrastructure resilience, the structure of PPP in CIR in different infrastructure sectors, and critical resilience strategies applicable to a public-private partnership in building critical infrastructure resilience. The outcome of this research will be beneficial to researchers where the gaps identified can be explored for further studies.
The impact of transparency on large Public-Private Partnership (PPP) projects has been a topic of interest for both scholars and policymakers. However, empirical evidence of its impact has been limited. Governments from more than 100 countries across the globe have enacted transparency laws in the recent past. The development phase of PPP projects is critical for the success of the subsequent two phases—construction and operation. The objective of this study was to determine influencing characteristics of projects and the environment in which they operate, as well as the impact of transparency laws on the duration of the development phase. Regression analysis using data of 469 PPP highway projects implemented in India revealed that concession period, length of the road, nodal authority implementing the project, duration of the construction phase, and road density in the region have a significant impact on the duration of the development phase. Mean comparison and regression analysis showed that the projects implemented after the enactment of transparency law had a longer development phase. However, the projects with a longer development phase had a shorter construction phase. Understanding the factors affecting the duration of the development phase will help the nodal authority and the concessionaire to develop strategies to complete the project in a reasonably time-bound manner. The fact that transparency law has an impact on the development phase has strong policy implications and a shot in the arm for those advocating transparency in PPP projects.

**Keywords:** Development Phase, Financial Closure, PPP, RTI Act, Transparency
COVID-19 crisis has simultaneously triggered a global economic crisis whose consequences will lead to a dichotomy where several governments’ debt has grown to unprecedented levels and simultaneously is required to promote new infrastructure supply. This global economic crisis scenario endangers current Public-Private Partnership (PPP) programs given their dependence on payment from the user and/or government subsidies in long-term lifecycles. This study aims for unravelling the PPP research agenda derived from the last global economic crisis in 2008 and the current one for understanding the trends developed as a tool for building a post-pandemic PPP research agenda. For understanding the last global financial crisis PPP literature review and its time and geographic evolution since 2008, this study developed a literature review employing Network Analysis. Therefore, crisis- and PPP-related keywords were combined for establishing used for the search in Scopus and Web of Science. After removing duplicate papers, 67 peer-reviewed articles were identified for recognizing underpinning topics, potential gaps, and time evolution. This paper contributes to the PPP body of knowledge by unraveling the post-global economic crisis agenda and its gaps for proposing a new research agenda for overcoming the consequences of the global economic crisis derived from the COVID-19 pandemic.
Towards a sustainable framework for road infrastructure management and maintenance scheme in south East Nigeria

Emeka Luke Okolie
University of Wolverhampton, Wolverhampton, United Kingdom

David Oloke
University of Wolverhampton, Wolverhampton, United Kingdom

Emmanuel Daniel
University of Wolverhampton, Wolverhampton, United Kingdom

Tochukwu Moses
University of Wolverhampton, Wolverhampton, United Kingdom

The construction sector is key in the economic growth of any country. Nigeria is faced with the need to provide adequate road infrastructure. Regardless of Nigeria’s enormous human and natural endowments, the road infrastructure within the country is in a poor state especially in South-East Nigeria. This research is aimed at identifying Public Private Partnership (PPP) as a panacea for inadequate road infrastructure development scheme in South East Nigeria. An in-depth literature review was carried out to explore the benefits of PPPs in the delivery of road infrastructure in South East Nigeria. Findings from the literature review showed that PPP allows the government to concentrate on policy making while the role of infrastructure maintenance and operation is carried out by the private sector. It also allows the private sector to generate income through user levy or contract sum. The review identifies high cost and complexity as challenges facing PPP implementation. It further showed that PPP has been successful in countries like Sri Lanka, South Africa, India, the United Kingdom and even South West Nigeria. The key recommendations of the research is that the existing PPP regulatory framework be reviewed, a transparent procurement process be put in place and that proven PPP models such as Build-Own-Operate-Transfer (BOOT) and Build-Own-Transfer (BOT) be explored for road infrastructure delivery in South East Nigeria.

Keywords: public-private-partnership, Build-own-transfer, build-own-operate-Transfer, infrastructure, framework, Road abandonment.
More than 25 years into democracy, South Africa is still faced with the persistent challenges of inefficient delivery of low-income housing backlog, specifically the subsidized housing. Provision of adequate low-income housing remains one of the national governments towards the realisation of adequate housing as Constitutional right. Although, there has been a number of housing policy interventions, poor delivery of low-income housing remains an area of concern and has a direct impact on the socio-economic lives of ordinary citizens. Current policies have been inefficient for addressing poor delivery of low-income housing. This paper argues that governance is the missing ingredient in the effective delivery of low-income housing. The focus is on governance theories and their relevance in the broader housing development discourse. There is a consensus that the concept governance is used both in the academic discourse and general discussions with reference to how institutions manage their business and how they relate with the broader societal structures. Using review of international literature, this paper establishes the role of governance in the context of low-income housing, as an important factor in addressing inefficiencies that result in poor delivery and makes recommendations for the South African context.
Build-Operate-Transfer (BOT) model of public-private partnerships (PPPs) are among the most popular infrastructure delivery models used by governments across the globe. Yet, concession agreements are criticized for being dispute prone. This study identifies a few areas where BOT projects are often challenged and proposes further interventions. Interviews with the private developers and the transactions advisory provided the necessary evidence for exploring the expectations of revising the BOT Concessions. The study found interventions that the private sector stakeholders suggest. These interventions span over the procurement, construction, and operation phases of the infrastructure delivery and are argued to build a rubber wall that can absorb the impacts of risk events. The suggested interventions would be helpful to policymakers to understand the prevailing challenges and expectations of the private sector developers. Future BOT concessions can be less dispute prone by deliberating and effectuating a mutually beneficial bargaining power. This study did not focus on the public sector perspective and their challenges for not considering these alternatives. Future studies need to expand to make the results more amicable and implementable. BOT concession model is popular but ever-evolving. This study challenges the status quo by identifying a few challenges to be considered for increasing its effectiveness.
Transit-Oriented Development (TOD) has been popular for urban development, especially for cities with transport network expansion. While TOD has been proved effective in facilitating mass transportation and making optimal use of property development, it is hardly a one-stop development strategy for solving issues such as traffic congestion. In this study, the city of Hobart is investigated with reference to the TOD metrics and experiences of public-private partnership (PPP). Hobart authorities have attempted to provide better living and working conditions while facing the problems of economic development and traffic congestion. The TOD metrics are proposed for application at different stages: (1) Travel Behaviour, (2) The Local Economy, (3) The Natural Environment, (4) The Built Environment, (5) The Social Environment, and (6) The Policy Context. Based on a literature review, a set of PPP metrics is proposed for the Hobart’s potential TOD framework. Drawn from on-site observations, key transport issues of Hobart are examined with the application of the PPP and TOD metrics. The results of this study could serve as a reference for regional cities in formulating their TOD strategies via PPP.
REUSING, RECYCLING AND UPCYCLING CONSTRUCTION AND DEMOLITION (C&D) WASTE
The true cost of construction materials wastage for a typical 8-yard mixed skip in the
UK is widely quoted as £1300. This cost is at least 15 years old and needs to reflect
the current practices. This study calculates a preliminary updated cost of construction
materials waste whilst developing a robust methodology that can be applied in more
extensive projects. Three contractors agreed on site selection, relevant risk assessments,
timings, and availability of personnel based on selection criteria. The data collection from
the three sites involved commercial, civil engineering, and residential building projects. The
calculation of cost data included material costs: contractor purchase price per unit from
bills/invoices; industry standard cost book (SPONS) per unit; and builders’ merchants
and trade catalogues whilst the contractors provided labour costs (hourly rate). The
commercial project mostly contained plasterboard, timber and demolition waste resulting
from ‘cutting waste’ and ‘stripping out’ with some of the wastes suitable for recycling. The
civil engineering project mostly contained welfare waste and non-construction source with
the welfare waste recorded as ‘mostly recyclable’ (large quantity of plastic and metal drink
containers). The residential project contained a wide variety of waste, including packaging,
insulation, timber and plastic resulting from ‘cutting waste’, ‘unrecovered packaging’,
and ‘damage’. Therefore, the new cost for an average 8-yard mixed skip is estimated as
£1,618.99. The method developed also identifies the ‘root cause’ for each waste item in
the skip, and allows targeted strategies for reduction to be implemented thereby forming
the basis for further research.
Demolition pathways in academic literature are divided into two main categories: conventional demolition and selective demolition. While conventional demolition is deemed a wasteful approach, selective demolition is considered a sustainable solution moving away from the destruction approach of conventional demolition to one that emphasises materials recovery. Currently, many contradictions are present of how both pathways are described in the academic literature and are used in practice.

This paper therefore, sets out to explore the demolition pathways from the perspectives of demolition engineers in the UK. This was achieved following a phenomenological research approach, whereby 12 in-depth qualitative interviews were conducted with demolition engineers to explore the subject of demolition pathways. Findings show that demolition pathways, from the industry’s point of view, are categorised under three main headings: conventional demolition, sustainable demolition, and circular demolition. While conventional demolition remains perceived as a wasteful approach, findings show it is the most appropriate demolition pathway to implement in times of crisis. Sustainable demolition represents the current best practice in the industry, which is signified by a drive for recycling. And circular demolition is a step beyond sustainable demolition whereby building materials are retrieved to maximise reuse opportunities. This study shows that the demolition industry could contribute to the circularity movement through early engagement with designers, establishing circular objectives in the tender form, disposing waste following the order of the waste hierarchy, and providing a circularity feedback report at the end of each project.
Knowing the imminent risk of a global environmental crisis, it is extremely necessary for the Architecture, Engineering and Construction (AEC) industry to study ways to reduce ecological impacts it causes during the constructions, for being one of the industries that produces the most solid waste. With the rise of Building Information Modelling (BIM), a technology that has increasingly revolutionizing the Civil Construction Market, several possibilities were opened to help decision-making from the design stage. Thus, this paper aims to understand how BIM could be used for a better management and reduction of waste construction. The method adopted was case study, done in the project of the Apodi Campus of Federal Institute of Education, Science and Technology of Rio Grande do Norte, in Brazil. The main steps developed were: a) identification of material loss rates through literature reviews; b) 3D modelling of Campus Apodi; c) analysis of the BIM model for waste construction management. As a result, it was verified which materials generated more waste, as well as their respective classes, according to CONAMA resolution 307/2002. In addition, the ease of extraction of this information from the BIM model was observed, through tables generated in the software itself. Given this scenario, BIM can contribute to design decision-making, regarding the choice of materials more sustainable and considering the reduction of waste construction.
There is a current lack of management tools that guarantee control and traceability of actions taken by the generator of construction and demolition waste (CDW). Furthermore, the reinsertion of recycled CDW into productive cycle is necessary to foster the circular economy in construction sector. To address these challenges, this study builds a novel blockchain-based information management framework for CDW management in construction, which extends the applications of blockchain for improving circular economy in the sector. Using design science research as methodological research strategy, this study presents and analyses a blockchain framework and its development processes. The framework performance was evaluated through quantitative and qualitative indicators. Through a SaaS (Software as a Service) concept, the system allows to strengthen the connection between stakeholders looking for sustainable solutions for CDW management. These solutions are independent of the size or segment of the company and allow the creation of business opportunities within the industry itself that provide expertise to foster the circular economy such as reverse logistics, servitization and industrial symbiosis.
Construction waste needs to be managed to safeguard the environment. Various factors that affect waste management include culture, financial, technical, and political aspects. During the design stage in construction, BIM is usually used to create a digital model, which gives a virtual presentation of the building. The model can predict material that could be wasted during construction activities. Despite the merits of BIM in cutting construction waste in the industry, there is little research towards BIM for waste management. This study, therefore, adopts a systematic literature review using the PRISMA model to evaluate extant studies on BIM for waste management. A systematic literature methodology is used to summarise the results of articles that have been published over the recent years. Furthermore, this article identifies BIM tools and technologies that can be used for addressing the major problem caused by construction (C&D) management. Findings reveal the barriers to the implementation of BIM for waste management, which are; lack of BIM awareness, unavailability of resources, the lack of guarantee in the security of stored information, and uncertainties in legal policies. Three main BIM-based tools, which can be used for planning for effective waste management, have been identified and discussed. The significance of this research is to raise awareness for BIM tools as an aid to effective waste management, which will reduce waste and increase profit in construction projects. The study also points out future research areas that can be investigated to aid the implementation of BIM-based tools for waste management.
The practice of reusing and recycling building materials has the potential to enhance resource use efficiency in the construction industry. Recycling can lead to reduced waste and energy consumption. Use of reclaimed and recycled building materials is considered a pro-environmental behaviour and studying the factors that influence this is a first step towards establishing such behaviour. It is therefore essential to understand how pro-environmental behaviours develop. This article investigates the relationships between the influential factors on behaviours that help reduce waste in the construction industry, focussing on New Zealand architects. The study utilizes an online questionnaire based on the Theory of Planned Behaviour (TPB), which is made up of attitude, subjective norm, intention, and perceived behavioural control. The study reveals that the attitudes, intentions and perceived behavioural control of architects are strong predictors of pro-environmental behaviour while the subjective norm is a weak predictor. Knowledge of architects about regulations and certificates related to recycled materials will influence the pro-environmental practices. One of the obstacles in this way is the attitude of people and government and architects can play an important role in changing it. These findings should encourage and help construction industry stakeholders, especially policymakers, to understand that construction and demolition waste and deconstruction regulations should be compulsory, and architects need to be informed about them. Along with educating architects about different ways of integrating these materials and reducing waste in projects, this will hopefully lead to less waste and improved resource efficiency in the construction industry.
Modern waste management facilities that combust wastes to provide domestic hot water or produce electricity are a more sustainable option compared to landfilling but not necessarily a more viable option. Space limitations and advances on sorting waste before burning it may financially justify the construction of waste combustion facilities. In addition, building small-scale incinerators near demand centers (e.g. homes) can provide a resilient option compared to centralized systems. This study aims to financially assess the use of an incinerator to provide domestic hot water for homes. First, data regarding hot water consumption in homes will be collected through a survey. The collected data will be compiled with national data to generalize the results. Once we know the hot water demand, a cost-production model will be developed to assess the cost of hot water supply for an incinerator that combusts wood, rubber, and plastic wastes. The incinerator used in this study has a water-cooled structure that allows for building the facility in the proximity of the demand center. In addition, this smokeless incinerator is equipped with high-pressure air to attain the highest achievable efficiency in the market. The cost per gallon of supplying hot water will be compared to the cost of using traditional power options such as gas and electricity and the cost of disposing of waste in a landfill combined. The results of the study will determine the required amounts of wastes per household and the financial viability of using waste management facilities to provide domestic hot water.
As a best practice for sustainable construction, Construction Waste Prevention (CWP) is poorly practiced, and may be largely associated with the knowledge, attitude, and behaviour of construction practitioners. With a focus on the Knowledge, Attitude, and Practice (KAP) of CWP, this study was purposed to provide an in-depth analysis of the implementation of CWP within the construction industry, using a meta-synthesis of purposively sampled literature. An analysis of responses from construction industry professionals, derived from extant literature, was used to gain deeper understanding of the linkages of KAP to current CWP practice, if any. Findings show limited knowledge of waste prevention measures, and a negative attitude, which translates to practice for many. The study contributes to the unique area of construction waste prevention by shedding light on gaps between existing norms and what should be CWP practice among construction professionals.
Launching new waste policies by developing nations that ban waste imports from other countries has put pressure on Australia’s waste management and recovery sector. Hence, the Australian state and territory governments have started to find solutions to mitigate its impact. However, obtaining such solutions needs to be informed and backed by the industry key stakeholders’ outlook. Therefore, this study aims to determine how various stakeholders perceive the impact of new waste policies and corresponding solutions. A cross-sectional (online) survey of a purposive sample of C&D waste management stakeholders in different Australian jurisdictions was conducted from June to September 2019. The results based on 132 collected responses showed that a majority of participants opined that the new policies have a positive impact on the Australian industry in the long run. The participants indicated that developing a domestic market for C&D waste is the best response to the new changes. Besides, the study presents open-ended responses on the nature of new policies impact on the Australian waste management and resource recovery sector. Lastly, the study provides a set of mitigating strategies extracted from academic sources to resolve the issues arising from implementing these policies. It is expected that the findings of this study assist policymakers and authorities in local agencies and government departments with providing the best solutions to the potential issues. Such findings would contribute to developing sound policies that do not negatively affect the key stakeholders.
The use of recycled products largely depends on the existence of viable end markets. In Australia, state regulations have a pivotal role in creating and stimulating the market for recycled construction and demolition (C&D) waste products. Hence, this study aims to identify regulatory barriers and enablers affecting C&D waste end markets. This study employed a qualitative research approach to understand the effectiveness of the current C&D waste regulations. The data collection concerned a series of interviews with C&D waste experts across five Australian states (i.e., Victoria, New South Wales, Western Australia, Queensland and South Australia). Overall, 27 interviewees were recruited from various stakeholder groups (e.g., recycling, government, construction, consultation & manufacturing). The findings provide an insight into the primary factors affecting market development for recycled C&D waste materials. A series of reforms are proposed to improve the current regulatory framework. They aim to address issues around recycled C&D waste uptake in construction projects. The research contributes to the body of knowledge in the field of built environment and design by providing first-hand information about regulatory mechanisms involved in utilising recycled products. Policymakers and authorities can use the results to devise advanced regulations that provide a level playing field for all parties involved in C&D waste management in Australia and other countries with similar contextual conditions.

**Keywords:** Circular economy, construction and demolition waste, market development, regulations, Australia
SMART AND SUSTAINABLE BUILDINGS AND CITIES
17. Barriers to the implementation of green buildings in Palestine

Adnan Enshassi
Islamic University of Gaza, Gaza, Palestine

Ehsan Risqa
Islamic University of Gaza, Gaza, Palestine

Suhair Alkilani
The University of Sydney, Sydney, Australia

Like other countries in the Middle East, Palestine is still lacking the initial steps towards achieving sustainable development. The objective of this study is to identify and evaluate critical barriers to the implementation of sustainable green buildings in Palestine. A self-administrated questionnaire was used for data collection. The results revealed that financial barriers are the most critical barriers to implement sustainable buildings. The main reason of this result is that construction participants are not convinced of the value added nature of sustainability. Findings also show that cultural barriers are the second most critical barriers to implement sustainable buildings. This study provides insights into a less investigated area regarding green buildings in the Middle East. It is recommended to enhance the awareness of construction practitioners regarding sustainable green building and its important role in conserving energy, water, land, and resources and in improving the quality of life. Government in Palestine should issue laws and regulations and provide incentives to promote sustainable buildings to improve quality of working life, education, training as well as knowledge management for all stakeholders in sustainable construction.
Various sustainable energy technologies are evolving around the world to reduce the carbon footprints in buildings. Building integrated photovoltaics (BIPV) is one of the emerging sustainable technologies and it refers to a technology where the elements of the building envelope such as façade and roof are replaced with solar cells. However, the adoptability of BIPV technology in buildings is limited as its costs and benefits are unknown to the public. This study aims to review the BIPV literature qualitatively, to explore the beneficial-related and cost-related factors of adopting BIPV technology. A thematic analysis was undertaken among journal papers published between 2011 to 2019 that focused their investigation on integrated solar renewable systems. The identified cost and benefit-related factors were classified into environmental, health, design and social themes. It is recommended that further research can be undertaken to explore the importance of cost and beneficial factors identified in this study quantitatively. Finally, these factors will assist in quantitatively measuring the societal impacts of BIPV technology.
People generally spend 90% of their time indoors. Owing to the increasing proportion of the elderly, how to develop healthy residential buildings, especially for the elderly, has raised more concerns. Even though many researches have studied the healthy performance within the home environment of the elderly, there are few researches focusing on their safety of indoor public spaces in mid-rise or high-rise residential buildings that are quite common in high-density cities. Dissimilar to other ordinary residents, the elderly would take changing and greater dangers during the egression under normal and urgent circumstances. Therefore, this study aims to explore building egression safety for the elderly under diverse circumstances. The agent-based egression models (ABEMs) are developed to simulate the egression process, and absolute values and relative values of simulation results are proposed to explore the egression safety for the elderly. One ten-story residential building is adopted as the case of simulation. The findings reveal how building egression safety for the elderly changes with different circumstances. This study offers an effective tool to ensure building egression safety. In practice, the ABEM-based simulation and indicators of building egression safety would benefit several stakeholders, by helping the designers and developers to improve their design schemes for better egression safety in the design stage, assisting the developers and property managers in updating egression plans and facilities based on the new occupancy status in the operation stage, helping potential old home buyers to make decisions, and finally facilitating the development of healthy residential buildings.
Energy plays a crucial role in smart and sustainable cities as buildings and construction account for 36% of energy consumption, and cities account for 75% of GHG emissions. The electrification of heating and transportation could significantly increase buildings’ electricity consumption. Previous literature has focused on on-site energy, especially in the energy community context, to encourage the cities to participate in the energy transition. However, on-site electricity can only produce one-fifth of the total demand.

When pooled together, households could contribute to off-site electricity production to bring negotiation power and subsequent economic and environmental benefits. This paper examines households’ opportunities in contributing to off-site electricity production and electricity prices by utilizing the energy community concept. It quantifies the economic benefits for the households to participate in a community power purchase agreement in the context of Helsinki, Finland. It presents a blockchain-based platform to facilitate the establishment of community power purchase agreements.
Construction schedules are the timetables showing the planned start and finish dates for activities within projects, and thus serve critical roles to instruct construction execution and monitor project progress. However, the construction industry has been suffering from delay and cost overrun for decades. It’s becoming important to produce quality schedules with accurate contingency allocation and risk mitigation plans. Experienced schedulers produce quality schedules based on personal experiences and knowledge. However, such tacit knowledge hasn’t been captured, stored and shared with inexperienced schedulers. This paper proposed a hybrid method (G method) to capture, store and reuse the tacit knowledge in the construction schedules. The G method consists of three stages: feature generation, data annotation, and classification. The G method is implemented on a bridge project to automatically generate construction schedules from a conceptual stage Building Information Modelling (BIM) model, and then compare with the original schedule regarding the time- and cost-efficient. The results indicated that the automatically generated construction schedules are 57.1% more time-efficient than the original schedule. Different from existing automatic scheduling methods, the proposed G method relies little on the availability and data richness of BIM models. Hence, the proposed G method helps schedulers initiate new schedules more efficient at the early construction stages.
92. Forecasting green building growth in different regions of China

Linyan Chen  
The Hong Kong Polytechnic University, Hong Kong, China  
Tongji University, Shanghai, China

Albert Chan  
The Hong Kong Polytechnic University, Hong Kong, China

Qiang Yang  
The Hong Kong Polytechnic University, Hong Kong, China

Amos Darko  
The Hong Kong Polytechnic University, Hong Kong, China

Xin Gao  
Tongji University, Shanghai, China

Green building has significant merits in energy conservation and resource efficiency, making it prevalent in many countries. Forecasting green building growth helps governments develop relevant policies and benefits researchers to solve the problem of lack of data. Although there were various studies on green building development, few forecasted growth to inform green building policy. To fill the gap, this study aims to develop an innovative approach to predict green building growth in different regions of China. A long short-term memory (LSTM) model with an attention mechanism was put forward in this study. Results show that the innovative model performed well in forecasting green building growth. The green building development in China keeps an increasing trend and will continue the growth at a higher speed in the following years. Moreover, geographical clustering patterns of green buildings were investigated, and a three-step distribution pattern was observed. Although this research was conducted in the Chinese context, it provides references to other countries by proposing an innovative model, which helps them better understand the patterns of green building growth. This study developed an innovative approach to forecasting green buildings, contributing to the existing green building knowledge body. Furthermore, it benefits governments and practitioners in decision-making.
93. The contribution of smart buildings to low carbon built environment

Eerika Janhunen
Aalto University, Espoo, Finland

Seppo Junnila
Aalto University, Espoo, Finland

Decarbonizing the energy sector is one of the most significant challenges of our time. Accordingly, the electrification of the energy system, deployment of renewables, and implementation of smart electricity control in the built environment is at the core of the in-force EU policy actions. Recently, the European Commission released the Smart Readiness Indicator (SRI) for buildings framework. The SRI intends to raise awareness of the benefits of demand-based smart electricity control in energy- and carbon-intensive buildings. However, whether the implementation of SRI compatible smart electricity control technologies truly leads to carbon emission reductions in the built environment has remained unclear. This study modelled an SRI compatible smart electricity control (i.e., 2-hour peak shaving) to every ground source heat pump heated building in the Helsinki Metropolitan area. The study evaluated the climate mitigation implications before and after the smart electricity control using hourly-level energy consumption data. The study revealed how the climate mitigation potential of smart electricity control was only 0.02% annually. The reason for such a slight decrease in emissions appeared to be Finland’s relatively clean electricity network. Nevertheless, the results questioned whether the SRI delivers its primary objective – decarbonizing the electricity grid – in northern European countries. Furthermore, the opportunity to broaden the SRI’s scope from the property to the city level should be further considered due to a single building’s limited capacity to participate in the electricity market.
Social sustainability indicators for road infrastructure projects: a systematic literature review

Ankitha Vijayakumar  
Deakin University, Geelong, Australia

Muhammad Nateque Mahmood  
Deakin University, Geelong, Australia

Argaw Gurmu  
Deakin University, Geelong, Australia

Imriyas Kamardeen  
Deakin University, Geelong, Australia

Shafiq Alam  
Department of Transport and Main Roads Queensland, Toowoomba, Australia

Australia’s population is predicted to grow to 31.4 million by 2034 according to Infrastructure Australia Audit 2019, resulting in additional demand on road infrastructure. Although road infrastructure projects promote economic development and have a significant positive impact at the regional level regarding reduced travel time, improved accessibility, and amenities; they may also have negative social impacts at the local level. Study shows that the existing road project assessment models provide relatively lesser consideration to the social aspect of sustainability comparing with the economic and environmental aspects over the project lifecycle. In order to bridge the gap, this paper aims to examine the existing literature on social sustainability in the construction industry and identify the social criteria and relevant indicators to be considered in assessing the social sustainability performance of road infrastructure projects. Through systematic literature review, using Scopus, Web of Science, EBSCHO and google search databases from an initial set of 1178 journals, conference papers, books, book chapters and other relevant industry reports, 80 articles were selected for the study. Based on the analysis nine social sustainability criteria such as quality of life, equity, employment, health and safety, stakeholder participation, culture and heritage, compensation strategies, governance, macro-social activities and 78 respective indicators were identified.

The findings of this study may assist the policy makers and industry practitioners pave the way to develop comprehensive assessment models for benchmarking social sustainability in Australian road infrastructure projects.

Keywords: Social sustainability, social criteria, social performance, road infrastructure, life cycle, Australia
Wood, as a building construction material, has two types of climate benefits: 1) the lower life cycle emissions compared to non-wooden options and 2) the carbon storage potential of wooden materials. This study aims to estimate the climate implication of gradually replacing concrete buildings with wooden ones for a period of 30 years in Helsinki metropolitan area, Finland. The study has three main steps. First, the greenhouse gas (GHG) emissions difference between concrete and wooden buildings is estimated based on literature and case studies. Next, we select the most accurate carbon storage potential of wooden buildings based on existing studies. Finally, we compare future wooden and concrete building scenarios regarding GHG emissions and carbon storage for the metropolitan area. We use data provided by the regional authority of the study area on predicted future building construction including multifamily and single-family developments. According to our findings, switching to wooden construction in urban areas can have a significant climate benefit for the studied region. By increasing the share of wood in future housing developments, the studied region can cut carbon emissions by 0.56 Mt and increase the carbon storage potential by 1.83 Mt, an amount that is four times bigger than the yearly emissions from traffic in the same urban area. The findings are not only useful for the city of Helsinki but also to other European and global cities which have committed to carbon neutral strategies and have sustainable forestry practices and modern wooden products available.
Sustainability indicators have been developed since late 1990s to be utilized in construction projects as tools and instruments for achieving higher level sustainability. Achieving sustainability goals in construction projects can be affected by the delivery model in place in a positive or negative manner, as it accounts for accomplishing project definition, design, planning, and execution phases. With any construction project we can recognize three main delivery elements which are project organization, contractual relationships, and operational system. This study aims to address the role of these project delivery elements in the application of sustainability indicators in building construction projects. To do so, a literature study was carried out and qualitative analysis of the relevant studies led to the identification of sustainability indicators, barriers and enablers in building construction. Then, these indicators, barriers, and enablers were analyzed and structured within a model based on their relation to the elements of construction project delivery. The findings present a sustainability model for building construction, revealing the connection between the project delivery elements and the identified barriers and enablers for the application of the sustainability indicators. The findings of this study contribute toward facilitating sustainable construction through project delivery and provide a frame of reference for the future studies.
Poor indoor environmental quality (IEQ) has been found to contribute significantly to productivity losses, with the extent of the contribution differing according to the type of office work in which workers are engaged. However, few studies focus specifically on the occupants of university office buildings where the work being undertaken involves a significant amount of academic research that is expected to require high levels of concentration, insight, creativity, and consistency than is needed in many other types of work. To develop a preliminary understanding of the IEQ factors affecting the productivity of people working in university office buildings, a pilot questionnaire was administered to postgraduate students to validate the IEQ factors that have been found to impact on productivity. To date, twelve postgraduate students from 3 different office buildings in the University of Auckland completed the questionnaire. The results showed that noise, temperature, air quality, and lighting were the factors most reported on affecting work productivity. The perceived effects of these factors also varied among age and gender. The findings from this study will help advance understanding of the IEQ factors affecting the productivity of workers in university office buildings, and provide insights for architects, building owners, office managers, and office users to help prevent or mitigate negative impacts on productivity by managing the IEQ conditions in workplaces. Future research will involve the analysis of data from staff as well as students to identify any possible differences that might exist between the two groups of workers engaged in academic research.
121. Explaining the changes in the greenhouse gas emissions of New York City buildings

Mohamadali Morshed
Purdue University, West Lafayette, IN, USA

Arkaprabha Bhattacharyya
Purdue University, West Lafayette, IN, USA

Makarand Hastak
Purdue University, West Lafayette, IN, USA

Greenhouse Gas (GHG) emissions are among the major causes of global warming. Previous research shows that New York City emits a high amount of GHG across the US and the globe. According to the United States Environmental Protection Agency, US commercial and residential buildings contributed to 12% of the total U.S. GHG emissions in 2018. Using big data will facilitate the identification of key predictors and increasing the accuracy of predicting building GHG emissions. Several past studies have introduced prediction models for the GHG emission of buildings. However, the factors that contribute to the changes in GHG emission patterns over time are less explored. In this paper, the New York Local Law 84 datasets for 4 consecutive years from 2017 to 2020 are used to explore which changes in building attributes would increase/decrease GHG emission over time. A Random Forest prediction model in combination with a variable importance analysis is used to identify the most important factors contributing to the observed increasing or decreasing GHG emission patterns. The results show that Energy Star Score (ESS) is a significant factor in explaining the increase in the GHG emission per square foot of the largest occupancy area of the evaluated buildings. Similarly, the reduction in the GHG emission levels can be explained by the success in maintaining the ESS and significant reduction in the electricity and gas consumption of the buildings. The findings of the study can be used to prioritize actions and policies to reduce the GHG emission of buildings.
123. Integrating the sustainable development goals into green and sustainable neighborhood rating tools

Jeremy Gibberd
CSIR, Pretoria, South Africa

The Sustainable Development Goals (SDGs) represent international consensus on targets and the type of development that should be achieved by 2030. However, the extent to which SDGs have been integrated into national strategies and policy appears limited and current projections indicate that a significant proportion of the SDGs will not be achieved in many countries. Slow progress in achieving the SDGs therefore may be partly attributed to these goals not informing and being integrated into, development processes. This appears to be the case in the building and construction industry where the focus on green buildings and rating tools has not extended to the SDGs. This paper, therefore, investigates the extent to which green and sustainable neighbourhood rating and assessment tools address the Sustainable Development Goals. It finds that existing tools address some SDGs effectively, while other SDGs are not accounted for. Through analysis of the SDGs and the tools, the paper makes recommendations on how the Sustainable Development Goals can be more effectively integrated into neighbourhood rating tools.
124. Integrating the sustainable development goals into green and sustainable building rating tools

Jeremy Gibberd
CSIR, Pretoria, South Africa

The Sustainable Development Goals (SDGs) represent international consensus on development targets that should be achieved by 2030. However, current projections indicate that a significant number of SDGs will not be achieved in many countries. Slow progress in achieving the SDGs maybe be partly attributed to the Goals not being integrated effectively into development processes. This appears to be the case in the building and construction industry where the SDGs are not addressed explicitly. This could be partly remedied through green and sustainable building rating tools which have a focus on improving building performance and could help include SDGs in built environment processes. This paper investigates the extent to which existing green and sustainable building rating tools address the Sustainable Development Goals. The analysis indicates that tools address some SDGs, while other SDGs are addressed indirectly, and some SDGs are not addressed at all. The findings are used to make recommendations on how the Sustainable Development Goals can be more effectively integrated into green and sustainable building rating tools.
134. Smart retrofitting of buildings: a bibliometric study

Sanduni Peiris
The Hong Kong Polytechnic University, Kowloon, Hong Kong

Joseph Lai
The Hong Kong Polytechnic University, Kowloon, Hong Kong

Mohan Kumaraswamy
The University of Hong Kong, Pokfulam, Hong Kong
University of Moratuwa, Moratuwa, Sri Lanka

SMART BUILDING (SB)s have gained significant attention over the past decade. This is mainly because of the performance and efficiency enhancements that smart features can enable a building system to achieve, for example, net-zero energy consumption, operational savings, state-of-the-science user-friendliness, safety and security. Nowadays, many new buildings are being designed with smart features. The ‘grand challenge’, however, is converting the existing, ordinary buildings into SBs, through a process called “smart retrofitting (SR)”. This process, while affecting the existing building components and the end-users, is challenging to the relevant facilities managers. As strengthening the SR knowledge base will enable better-informed, hence more effective decisions, the focus of this research is to undertake a bibliometric analysis of SR research to assess its development in terms of prominent authors, countries and organisations. The bibliometric searches were conducted on the ‘Scopus’ and ‘Web of Science’ databases. A total of 107 journal articles were identified and analysed using the “VOSviewer” software. The findings revealed: the co-authorship patterns; the connections among the most influential authors, countries, and organisations; and the weak collaboration among the authors and organisations. This study is the first bibliometric analysis on SR, the results of which not only serve as a useful reference for both researchers and practitioners but also signpost further works to be undertaken for complementing the current results.

Keywords: Bibliometric; buildings; retrofitting; review; smart; VOSviewer.
Amongst the great global environmental challenges of our time few are as pronounced as climate change and biodiversity loss. The two are closely connected, as feedback mechanisms associated with warming climate could also lead to large-scale biodiversity losses worldwide. It would therefore be logical to seek mitigation methods beneficial for both impact categories yet research on the issue, especially in the urban setting, remains relatively scarce. Our study focuses on two key aspects of environmental sustainability, carbon sink potential and species biodiversity to determine whether these correlate at different levels of urban density in the capital Helsinki Metropolitan Area of Finland. GIS-datasets from Helsinki Regional Environmental Services and Finnish Biodiversity Information Facility are utilized to estimate the carbon storage potential and species diversity across the urban landscape as well as their association at different levels of urban land use intensity. The results highlight the importance of small green spaces at dense urban cores, indicating that in environments where green infrastructure is limited species diversity and carbon storage are more likely to correlate, whereas in high green environments at urban fringe the observed relationship is weaker and divergence of the two impact categories becomes more probable. The study draws attention to the role fragmented, limited green spaces play at establishing functioning ecosystems at local scale and provides new information to support the development of sustainable planning and management practices across the urban land use gradient.
The energy landscape in Australian built environment is becoming more complex, with traditional utility consumption declines and the rise of renewable energy sources, meaning buildings are able to generate, monitor and store their own energy. These energy transitions are impacting upon the stability of traditional business models. Energy-as-a-service (EaaS) as an emerging business model has shown potential under this complex energy transition. However, with limited studies into this business model, there is a research gap in understanding of how EaaS can facilitate a successful energy transition. In addressing such research gap, this study investigates about potential pathways to establish EaaS from an industry perspective. A generic qualitative research design within a constructivist paradigm was adopted in this exploratory study with twenty-nine semi-structured interviews. The study revealed four recommended directions EaaS could be practically established for improving energy transition within the built environment. This study contributes by providing research-based evidence into new, emerging, and innovative business models within the built environment.
Towards a theoretical understanding of BIM innovation success in facilities management: a comparison of actor-network theory and diffusion of innovation theory

Zelinna Pablo
Torrens University Australia, Sydney, Australia

Ruwini Edirisinghe
RMIT University, Melbourne, Australia

Research on BIM adoption has been linked to different theories of innovation underpinned by diverging assumptions. Diffusion of Innovations theory (DIT), for example, assumes the innovation adoption process is linear, while Actor-Network Theory (ANT) assumes innovation is dynamic and non-linear. Different theoretical lenses can thus lead to conflicting conclusions about what the BIM adoption should look like, and what makes it successful. However, limited work has been done to compare the often hidden assumptions of different innovation theories, and to explore how well they suit the BIM process. This study has two objectives: (1) to conduct a comparative analysis of the contrasting conceptual foundations of DIT and ANT and (2) to build and test two early-stage analytical toolkits using the conceptual apparatus of each theory, allowing users to examine the experiences of adopter organisations using two lenses. The toolkits this study offers were developed by moving iteratively between key theoretical concepts and qualitative interview data from a single US-based owner organisation, a case study of an early adopter of BIM. The study has two contributions. The first, a theoretical finding, is that DIT is better suited for analysing innovations that are material, stabilised and thus significantly “closed” in their early stages, while ANT is better suited for innovations that are dynamic and iteratively (re)created. The second is a set of preliminary insights for practice that help account for the success and failure of BIM adoption in an owner organisation. Future work can focus on developing/validating the toolkits further.
Embedded within its culture and accepted for decades, the UK construction industry continues to be perceived as a sector of poor productivity, low profit margins and tarnished reputation. Whilst many sources believe that these issues are the result of fierce competition within the sector, other factors, such as poor planning and project management are deemed to be the root causes of the dysfunctional strategy construction organisations follow. In an attempt to overcome historical issues, the construction industry must evolve from traditional 2D, separated disciplinary inputs, to a more holistic integrated delivery model. Digital transformation has the potential to rapidly transform construction sites by improving visibility on projects; providing safer operations with higher accuracy and enabling more accessible and clearer communication. Failure to adapt could marginalise the sector and diminish its allurements to attract a younger, more diverse generation of workers who consider the digital world, the “norm”. The aim of this research was to establish if and how digital technology could resolve the critical failings of the construction industry. A mixed research method approach was undertaken through interviews with six industry professionals and seven digital experts. The data collected resonated with findings from the literature which reinforces the difficulties construction organisations endure. The primary issues were found to be; a disconnect of communication between internal departments and key stakeholders resulting in poor efficiency; ineffective and time-consuming manual processes resulting in poor productivity; and a consensus of confusion about digital transformation.
The reputation of the UK construction sector has been tainted due to a variety of high profile incidents. The Oxgangs Primary School masonry wall collapse in 2016 and the Grenfell Tower fire in 2017 both led to public enquiries, identifying industry-wide systemic failings. Principle contractors hold significant quality responsibilities in the overall project delivery, which requires culture and management reform for improvements to be made. This research presents the findings of a single case study of a UK based principle contractor using qualitative research methods. Seven Project Managers contributed to the research study to evaluate the strategies available to improve quality on their projects. The data collected highlights a need for cultural improvements and additional development of management systems and operational practices. Some of the key recommendations are as follows: creation of a company-wide definition of quality; continue to develop quality benchmarking through auditing processes; focus on selecting sub-contractors with developed quality management systems (QMS); create better lines of communication within the projects; continue to develop how technology is implemented to aid managerial tasks; and provide quality training opportunities and guidance documents to inform inspection test plans (ITP).
204. ISO standards or global indices: who decides if a city is smart?

Katerina Prevelianaki
Anglia Ruskin University, Chelmsford, United Kingdom

Fred Sherratt
Nemesis V, Chelmsford, United Kingdom

Christian Henjewele
Anglia Ruskin University, Chelmsford, United Kingdom

The Smart City status has become much sought after and desired as cities across the world continue to develop through smart initiatives. The International Organisation for Standardisation (ISO) Smart City Indicators “…specifies and establishes definitions and methodologies for a set of indicators for smart cities”. As a highly recognised standards organisation with international impact the definitions and criteria used therein will inevitably influence wider understandings of smartness and smart cities. However, although the standards give extensive guidance on how to become smart, their benchmarks and assessment process arguably remain unclear. International Smart City Indices use various criteria to evaluate smartness and publish annual rankings. Yet the lack of consistency among them, as well as with the ISO Standards, suggests a disconnect between what regulators propose for the development of smart cities and what the Indices perceive and measure as smartness. This paper presents the current challenges of smart city standards adoption, particularly how these lead to vague and unmeasurable city changes, further contributing to an already chaotic state in defining smartness of cities. Through critical content and comparative analysis of the ISO standards and selected Smart City Indices, different conceptualisations of smart in both its evaluation and measurement are illuminated, revealing areas of complexity, ambiguity, dissonance and even conflict between them. This indicates a disparity between regulators and the wider smart city industry community, and thus potentially further problems in the progress of smart in reality. This paper forms part of an ongoing PhD study, more detailed findings are forthcoming.
268. Code checking using BIM for digital building permit: a case study in a Brazilian municipality

Douglas Brito  
Federal University of Bahia, Salvador, Brazil

Dayana Costa  
Federal University of Bahia, Salvador, Brazil

Emerson Ferreira  
Federal University of Bahia, Salvador, Brazil

There is a growing interest from municipalities around the world in digitizing the building permit process using building information modeling (BIM) and geographic information system (GIS) for automated code checking. However, technical, political, and commercial barriers still prevent digitization from becoming a reality and being widely implemented and locally adapted. The main objective of this research is to analyze best practices and lessons learned by a Brazilian municipality for BIM-based electronic system implementation. The adopted methodology included a comprehensive literature review of existing international initiatives in America, Europe, and Asia. Data collection occurred in a case study in a Brazilian municipality implementing BIM to digitize the different types of existing permits. The results indicate the leading practices and lessons learned by the municipality in their internal stage for developing the automated code checking system and promoting changes in processes, policies, and organizational culture. The findings also highlight best practices and promising international experiences, a comparative analysis with the Brazilian municipal context. The main contribution of this study is to provide a greater understanding of the required practices and the BIM/GIS role in the digital building permit process. As a practical contribution, the experiences in the Brazilian context provide valuable inputs for the journey of smart cities.

Keywords: Digital Building Permit. BIM. Code Checking. GIS. Case Study.
Unmanned Aerial Vehicle (UAV) and photogrammetry have been widely used to reconstruct a photorealistic 3D model of physical bridges for documentation of cultural bridges or remote bridge inspection. However, the optimal image overlap for photogrammetric bridge reconstruction that can trade off the model quality and overall mission time has not yet been studied. In this paper, a comparative experiment was conducted on a real girder bridge with three typical overlap configurations being implemented to capture corresponding UAV image sets and then generate bridge models using a commercial photogrammetry software package. The time consumption and the quality of reconstructed bridge models for these three experimental cases were compared and analysed. The results showed that the configuration of 66.7% forward overlap and 50% side overlap is the optimal overlap configuration for the reconstruction of a variety of bridge components, which can result in the minimum number of images while saving the overall mission time for image acquisition and processing. The overlap recommendation may also be applicable to the 3D reconstruction of other types of bridges and buildings with similar structural components.
320. Trends in residential sustainability measures in the state of Victoria

Robert H. Crawford
The University of Melbourne, Parkville, Australia

Vidal Paton-Cole
The University of Melbourne, Parkville, Australia

Robert Turnbull
The University of Melbourne, Parkville, Australia

Emily Fitzgerald
The University of Melbourne, Parkville, Australia

Aleks Michalewicz
The University of Melbourne, Parkville, Australia

Jonathon Garber
The University of Melbourne, Parkville, Australia

Buildings require a significant quantity of energy and water during their operation. Solar water heaters and rainwater tanks are two examples of systems that have become increasingly common to reduce the demand for fossil-fuel based energy and mains water within buildings. Since 2006, the Victorian Building Authority has required either a rainwater tank or solar water heater to be installed in any new house built in Victoria, Australia as part of their Residential Sustainability Measures. This research analyses the trend in adoption of these two systems using data from building permits issued from 2006 to 2019. This shows that despite an initial preference for rainwater tanks, most likely due to the overlap with the Millennium Drought, solar water heaters have been the preferred choice. This preference was found to be greatest for projects costing from $200k-$600k and for allotment areas smaller than 500 m2, most likely due to the reduced space available for rainwater tanks. Preference for rainwater tanks tended to increase in line with an increase in project cost and allotment area, and this preference was found to be most common in metropolitan areas, supported by a small correlation with socio-economic data. This study provides insight into the opportunities for further adoption of solar water heaters and rainwater tanks, including using information at the LGA level to develop specific business opportunities or to inform policy, such as alternative water efficiency solutions for households where allotment area may limit adoption of rainwater tanks.
Majority of people live in cities, which use immense amounts of resources and emit significant amount of greenhouse gasses. As urbanisation is growing in the future, this outsourcing of negative impacts of larger cities will increase.

One solution for mitigating emissions is power to gas where fuels are made with electricity, water, and carbon dioxide. Often power to gas technologies have been planned for locations where there is a direct use for the gas, such as industrial sites. Regardless electrolysis and methanation have suffered from poor profitability. Cities have multiple networks such as electricity, heat, water, logistics and information networks, but also municipal solid waste and energy production from waste and biomass. If the power to gas process could be joined with all these networks and resources in a way that production and side streams of the process would always be utilised effectively where the value is largest, smart cities could become more efficient and resilient.

This paper analyses the increase of profitability of power to gas process with waste heat recovery compared to a traditional process. In addition, the maximum potential for waste heat utilisation in European cities is analysed based on energy consumption.

The preliminary results show that the profitability of synthetic gas production can be improved significantly by waste heat recovery and that there is a large potential for European gas production in connection with cities heating networks. Local gas production with renewable electricity could increase self reliance of EU and reduce emissions of the built environment.
352. Reducing embodied carbon emissions of concrete modules in high-rise buildings through structural design optimisation

Yang Zhang
The University of Hong Kong, Hong Kong, China

Wei Pan
The University of Hong Kong, Hong Kong, China

Yue Teng
The University of Hong Kong, Hong Kong, China

Modular buildings have been widely recognised as a solution for improving the sustainability of the construction industry. However, the implications of modular buildings for reducing embodied carbon (EC) have seldom been examined previously. This paper aims to quantify the EC reduction potentials of different structural designs of concrete modules in high-rise buildings. The study was conducted via a real case study with a high-rise modular building in Hong Kong. The EC of the concrete modules during the cradle-to-end-of-construction stage was assessed using process-based LCA method. Three critical structural and one material design variables were considered to optimise the structural design of modules in order to achieve the lowest possible EC, including concrete grades, rebar ratios in modules’ structural components, dimensions of modules’ structural components and low carbon concrete mix alternatives. Material quantities were extracted from the parametrically established BIM model of the modules using Dynamo software, followed by structural safety check according to Hong Kong’s codes. Results indicated that the feasible reduction potential of the modules with fixed external size could reach up to 27% compared to the design with highest EC emissions. Reducing components’ dimensions could reduce up to 20% EC of the modules with the same concrete grade. Adopting low carbon concrete could reduce 10%-13% EC of the modules on average for different concrete grades. The findings revealed a significant potential of EC reduction in concrete modules through structural design optimisation, providing a new direction for achieving low carbon modular buildings.
Buildings contribute significantly to carbon emissions over their life cycle. Recently, embodied carbon (EC) accounts for an increasing share of life cycle carbon emissions of new buildings as their energy efficiency is improving. However, traditional methods of data collection and communication from diverse carbon sources such as manual recording lead to low-efficient and prone-to-error estimation of embodied carbon emissions. Therefore, this paper aims to propose an Internet of Things (IoT)-integrated embodied carbon assessment and monitoring system (ECAMS) for prefabricated buildings. This system involves three layers, i.e. of data collection, data communication, and data analysis. To provide a theoretical foundation, the EC assessment model is firstly modified to distribute carbon emissions into twelve construction statuses and at five levels of analysis of prefabricated buildings. IoT sensors including radio frequency identification (RFID), acceleration transducer, and global positioning system (GPS) are employed for automated real-time data collection. RFID readers are installed at the twelve locations to identify specific element and input dynamic process data. Acceleration transducers are attached to construction equipment for estimating the operation time and GPS modules are embedded in the driving system to record transportation distance. IoT data will be communicated with building information modeling (BIM) model and carbon assessment software through application programming interfaces (APIs). Laboratory tests were conducted to demonstrate the feasibility of sensor-based data collection and communication. The proposed system facilitates more efficient and accurate estimations of prefabricated buildings’ embodied carbon, which should help practitioners to explore effective carbon reduction strategies.
370. An occupant-centric approach in BIM environments to improve comfort and renovation planning

Andrea Giovanni Mainini  
Politecnico di Milano, Milan, Italy

Martina Signorini  
Politecnico di Milano, Milan, Italy

Sonia Lupica Spagnolo  
Politecnico di Milano, Milan, Italy

Simone Ciuffreda  
Politecnico di Milano, Milan, Italy

Markku Kiviniemi  
VTT, Espoo, Finland

Kostas Tsatsakis  
Suite5, Limassol, Cyprus

Bruno Daniotti  
Politecnico di Milano, Milan, Italy

The construction sector is among the main responsible for energy consumption and greenhouse gases emissions. Hence, buildings retrofitting shall be encouraged and supported by targeted actions to achieve a European climate-neutrality by 2050, as pointed out by EU Agenda objectives. In this context, the European Commission is promoting an action plan for the renovation wave. One step towards the renovation action is the exploitation of digital tools such as Building Information Model (BIM) and Internet of Things (IoT). This paper is related to the outcomes of an ongoing EU funded project –BIM4EEB- and it illustrates how the application of two BIM-based tools, namely BIMPlanner and BIM4Occupants, developed within the project. The two tools have respectively the purpose of sharing current information about the progress of construction site works among renovation stakeholders and giving inhabitants tailored information about their indoor home conditions, comfort preferences and energy consumption. In this regard, IoT devices installed in a demonstration building permitted the real-time evaluation and control of several parameters. Therefore, a pilot building, namely the Italian demonstration application of the project, is described for testing the proposed tools. Benefits connected to the BIM framework and IoT devices result in an improvement of data sharing and communication between renovation stakeholders, then in an enhanced building process.
Urban green spaces are a critical component of cities, providing environmental, social, cultural, and economic benefits. To support smart(er) decisions by city planners and managers, this study aims to investigate how open data sources could be integrated into urban green space management. Specifically, it proposes a novel GIS-based method to prioritise urban green space in a resource-constraint scenario so that social benefits are maximised. To quantify the social benefits, the methodology is based on the WHO indicator, which recommends access to at least 0.5-1 ha of green space within 300 metres’ linear distance to all the city residents. The approach assigns each urban green space an ‘accessibility score’ based on its significance in the city, and a ‘quality score’ based on its performance on different quality parameters (size, greenness, quietness, and safety). Urban green spaces are ranked with respect to these two scores, enabling to prioritise spaces under resource constraints such as water shortage, limited staff, or budget. This approach is demonstrated through a case study on a mid-size German city and is transferable to other cities worldwide with varying weightage factors.
403. Evaluating the impact of building material selection on the life cycle carbon emissions of South African affordable housing

Alireza Moghayedi
University of Cape Town, Cape Town, South Africa

Mark Massyn
University of Cape Town, Cape Town, South Africa

Karen Le Jeune
University of Cape Town, Cape Town, South Africa

Kathy Michell
University of Cape Town, Cape Town, South Africa

This study evaluated the life cycle carbon emissions of the two most common affordable housing designs primarily used in South Africa. The study examined the impact of conventional, alternative and green building materials on life cycle carbon emissions of five main building components: building envelope, internal walls, flooring, window frames, and roof. The life cycle carbon emissions of the various building materials and the overall house are estimated using the EDGE application modelling software. The comparison between the resulting carbon emissions of the three scenarios proved that modifying the building materials from conventional to alternative and green materials is able to reduce ~55% and ~75% of carbon emission of the construction phase respectively and overall ~10% of life cycle carbon emission of the house. However, the findings correlated that a change in building material has a more significant impact on the carbon emission in the construction phase compared to the operational phase. Thus, the results confirmed the important role of material selection in affordable houses as the main contributor to the life cycle carbon emissions, given the absence of heating and cooling systems in these types of housing. Finally, the finding led to the conclusion that a change in material used for affordable housing will alter the method of construction for the proposed materials, in turn lowering lifecycle carbon emissions produced by the construction industry and improving the sustainability of houses and housing sectors.
Sustainable buildings were introduced to lessen the negative impact of buildings on their users, occupants, communities, and the environment, and to increase contractors’ productivity and profit margins. However, despite the prospects and benefits of sustainable buildings, instances of reworking in buildings have been recorded by construction companies. This research developed a questionnaire instrument that included 20 determinants of rework in sustainable buildings, measured on a 5-point Likert scale. An artificial neural network model was used to predict the determinants of rework in sustainable buildings. The data revealed that sustainable buildings are delayed by more than 15% and cost overrun by more than 20%. Rework in sustainable buildings is about 15%. The correlation results revealed that rework will increase project costs by up to 29% and completion time by about 27%. The model revealed that lack of performance specification; lack of skilled workers with green materials and components; poor application of industrialised building systems; lack of project governance; absence of sustainable construction managers; poor welfare; and poor adoption of building information modelling are the main predictors of reworks. The research will provide references for all stakeholders involved in the procurement of sustainable buildings. This study is foremost to examine reworks in sustainable buildings, as its findings hold critical theoretical and practical implications for future research on the sustainable building market.

Keywords: Claims, productivity, contractors, maintenance-span, building pathology, site operatives, Malaysia
A review of sustainable technologies for energy efficient upgrade of existing buildings and structures

John Dadzie
Kumasi Technical University, Kumasi, Ghana

Isaac Pratt
Kumasi Technical University, Kumasi, Ghana

James Frimpong-Asante
Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Sustainable upgrades include actual case studies with before and after retrofit results, case studies with simulated results and use of computer systems to predict energy savings based on exiting building parameters. In the latter no actual renovations are done thus technologies and systems are assumed. The review used real cases including simulations and adopts a mix of systematic and content analysis approaches. Thus, over 288 articles were gathered from all the major scientific journals using Scopus, ProQuest, Web of Science etc. The sample was reduced to 230 articles based on the search themes; thereafter, a detailed focus on the methods used provided basis to trim the articles to 47. Sustainable technologies identified cover those installed to the external façade, indoor areas, air filtration, insulation systems, building elements, heating, ventilation and cooling (HVAC) systems, sensors, lighting, hot and cold water systems such as boilers, chillers, pumps, motors and renewable energy technologies. The results show sustainable technologies have been used to improve various existing buildings. Also, the results indicate high rate of adoption of insulation systems for external and internal walls, roofing and ceiling elements. This paper provides evidence to support the drive towards environmental sustainability through the adoption and installation of sustainable technologies. Policies to trigger demand and installation could further improve actions towards greenhouse gas reduction.
Photovoltaic (PV) is recognised as the most promising technology to generate green electricity in the built environment. Unlike other PV applications, Building Integrated PV (BIPV) that can be applied to various parts of the building envelope such as walls, roofs, windows, and balustrades provides untapped opportunities to produce green energy to meet even the total building energy demand. Although, there are buildings with successful applications, the growth of the BIPV among both PV and building industries is still limited due to various reasons particularly the technical complexities. However, currently, many technological advancements have been emerged meeting market expectations while eliminating the current obstacles. Hence, system performances that always lead to the decision of BIPV adoption are continuously varied. This paper aims to investigate the impact of technology developments on the multiple performances: economic; structural substitutable; environmental of 46 BIPV projects in non-domestic buildings in western countries using levelised cost of energy, Net present value, material offset and greenhouse gas emission savings. Sensitivity analysis enables to identify the effect of technology development using four scenarios i) capital cost, 2) electricity conversion efficiency, 3) share of grid supply and 4) lifetime. The results revealed that capital cost has substantial influence than others to uplift the performances. It is significant to optimise the share of grid supply and share of onsite consumption for favourable performances. The longer lifespan of BIPV can always attract building professionals owing to enhancing the multiple performances. The outcome empowers stakeholders to explore the significance of technology deployment.
Cities across South Africa are predominantly characterised by multiple forms of poverty, growing inequality, environmental degradation, slums and informal settlements, social and economic exclusion, and spatial segregation. These challenges present significant hurdles in planning for and coping with rapid population growth, urbanisation and protecting communities against natural and human-made disasters. This project aims to address the lack of local neighbourhood sustainability assessment (NSA) frameworks to improve the inclusivity, sustainability and connectivity of communities in South Africa. The existing NSA tools promote a specific type of urban development that effectively excludes marginalised communities and is not entirely suited to South African communities’ economic, socio-cultural, and environmental context. To achieve this, seven major assessment tools across the global North and South are selected and scrutinised using content analysis to identify and catalogue the critical success factors (CSFs) for enabling inclusive, smart, sustainable communities in South Africa using existing knowledge on neighbourhood assessment tools and relevant literature. The result is a proposed structure of four categories and 86 CSFs for the Afro-centric NSA framework that can address the challenges encountered in South African marginalised communities.
Climate change plays a significant role in the landscape architecture discipline dealing with climate adaption while seeking efficiently and effectively solve the problems related to floods and heatwaves caused by climate change. Climate adaptation deals with a high level of uncertainty while precipitating future climate events to prepare adaptable landscape designs. However, digital technologies such as BIM are rarely implemented into landscape design projects with deep environmental concerns. Meanwhile, digital tools have the potential to improve climate adaptation planning while calculating and simulating the adaptive capacity of design improving decision making. Therefore, this research investigates the capabilities and implementation possibilities of software tools simulating landscape design adaptability defining the roadmap on software selection. The software tools are evaluated using ISO 25010 framework and the capabilities are compared considering the requirements on sustainability certifications including DGNB, BREEAM and LEED. The main method used for this research is based on objective experiments while implementing different software tools to conceptual landscape design on the case study project. The experiment revealed that the implementation process deals with many limitations including interoperability and data loss. Moreover, the comparison on DGNB, BREEAM and LEED requirements revealed that climate adaptation planning currently deals with high variation on climate adaptation measures as well as software tools have different capabilities and functionalities. The roadmap on software selection resulted from this research can help the implementation process of software tools to climate adaptation projects improving the planning process and ensuring the effective use of natural resources in the future.
The synergies of the Building Information Modelling (BIM) process and green building assessment tools (GBATs) such as the Malaysian Carbon Reduction and Environmental Sustainability Tool (MyCREST) ensure that information is accurately exchanged during the green building design (GBD) practices. However, the issue of poor Information Exchange (IE) synthesis persists due to the lack of a standard model for implementing the BIM process in GBD. Therefore, the aim of this study is to develop the BIM-MyCREST Process Model (BMPM) for the concept design of green buildings. To actualize the research aim, an in-depth interview was conducted with 10 construction experts. Using the narrative analysis technique, the interview data were analyzed to identify the incidents that take place during the BIM process execution in GBD practices. With reference to MyCREST Guide, and BIM standards BS1192 and PAS 1192; Utilizing the Integrated DEFinition (IDEF) structured diagramming techniques (IDEF0 and IDEF3), the BMPM was explicitly coordinated following the narratives of the interviewees. The developed BMPM will enable the multi-disciplinary GBD team to use the diverse domain BIM software to exchange accurate information and make critical decisions during the design of green buildings; thereby developing a building with high sustainability performance and accomplishing the business and commercial objectives of the MyCREST rating.
In terms of the 2030 Agenda for Sustainable Development and the United Nations (UN) Sustainable Development Goals (SDGs), sustainable cities and communities (SDG 11), combined with good health and wellbeing (SDG 3), are vital. This is even more so following the COVID-19 pandemic. The world is not making adequate progress in meeting the UN’s targets to address food security (SDG 2). In South Africa, the growing population, rapid urbanization, poverty and unemployment exacerbate the issue of food security; even more so in the light of climate change (SDG 13). The built environment needs to respond to these demands and incorporate green initiatives that can provide ecosystem services. Novel approaches are required to enhance ecosystem services, optimize land use and promote sustainable, smart built environments through food production. This paper summarizes and consolidates literature on local vertical urban food production with vegetable crops to enhance ecosystem services and lower the carbon footprint of buildings in the Global South. The literature review points to the potential of small-scale edible living walls that utilize local materials and traditional African vegetable (TAV) species to enhance system sustainability and resilience. The TAV species offer advantages opposed to exotic food crops as they are tolerant to extreme heat and drought, have a high nutritional value, and have low irrigation and agrochemical maintenance requirements. This is the premise of a research project to determine the potential of modular living wall systems with TAV species to enhance built environments in the Global South.

Keywords: Ecosystem services, living wall systems, sustainable cities, traditional African vegetables, vertical urban food production.
Environmental sustainability has become a priority for an increasing number of Australian cities in recent years. As a smart distribution platform, Virtual power plant (VPP) is a promising approach to achieving urban sustainability. Understanding local conditions, such as user electricity demand profile, is one of the most important aspects to modelling a VPP platform. However, due to data privacy and confidentiality, in many cases, energy demand profile has limitations. This study demonstrates how clustering techniques can support the development of electricity patterns from high-dimensional data, thereby inform VPP modelling. This study analysed historical electricity consumption data from an Australian city by using two clustering algorithms, K-Means and DBSCAN. According to the experiment results, both algorithms have their advantages and disadvantages, and the optimal algorithm choice is highly dependent on the clustering purpose. As a result, the electricity patterns generated by clustering analyses can be used as input data to train Reinforcement Learning agents to learn human behaviours and rationality in VPP modelling.
For predicting pedestrians’ flow patterns it is necessary to have strategically located sensors throughout the city, so that useful information could be obtained. Knowing the average activity of those throughout different days of the week we could match the typology of the buildings neighboring those sensors. Two clusterings are made to classify the sensors depending on the typology of buildings surrounding them and the mean activity for different time intervals. Next, applying different supervised machine learning algorithms are validated these clusterings. Finally, an approach to identify the correlation between both clustering is done. This study reveals that there is a close connection between the activity pattern of the sensors and the type of environment they are located. Furthermore, we could tackle different security and energy efficiency tasks by knowing only the building types of an urban zone, not needing any further information. By this way institutions could alleviate a great amount of effort needed to ensure safe and energy efficient urban areas.
Defect digital twinning: A technical framework to integrate robotics, AI and BIM for facility management and renovation

Junjie Chen
Department of Real Estate and Construction, The University of Hong Kong, Hong Kong, China

Weisheng Lu
Department of Real Estate and Construction, The University of Hong Kong, Hong Kong, China

Frank Ato Ghansah
Department of Real Estate and Construction, The University of Hong Kong, Hong Kong, China

Ziyu Peng
Department of Real Estate and Construction, The University of Hong Kong, Hong Kong, China

The aging buildings and infrastructure call for proper facility management, maintenance and renovation. Awareness of defects and damages occurred to the facilities is a prerequisite to make informed decisions. Despite extensive research in defect detection, it remains unclear how to timely update the dynamically changing defect condition at scale and with ease, so as to support facility management and renovation. This study aims to develop a technical framework that integrates robotics, artificial intelligence (AI), and building information modeling (BIM) to enable defect digital twining. The framework establishes a mechanism to bridge defects in the physical world with their digital representations in the virtual world. It extends existing defect information modeling with a means to capture accurate and up-to-date as-damaged information in a timely manner, which is deemed indispensable for the concept of digital twin. The proposed framework was evaluated with a 10-story residential building in Hong Kong. The case study demonstrates the effectiveness of the framework in twinning defects concerning their positions, geometry and dimensions. The research opens new possibilities to twin facility defects at street block or even city level to support urban renewal.
The involvement of many stakeholders from diverse sectors throughout the distributed solar energy (DSE) project lifecycle and their discrete commitments to the project have lessen the stakeholder understanding in each other’s contribution. Communication between stakeholders is not continuous and systematic; thus, the project information is not well-communicated for accurate decision making. Therefore, DSE projects have not yet won the complete stakeholder trust and its adoption in the building industry is not yet fully accepted. This study aims at exploring the opportunities for using blockchain technology to reduce/eliminate the trust issues and communication gaps along the DSE lifecycle. The study conducted 50 semi-structured interviews with building and energy stakeholders to identify the issues/limitations which (1) reduce the stakeholder trust on DSE technologies and applications and (2) generate communication gaps along the DSE project lifecycle. Findings revealed that most of the issues/limitations were occurred due to the unavailability of a common platform for communication and information sharing, unavailability of information, improper record keeping and limited information security. The unique features of blockchain technology such as (1) distributed leger technology (DLT), (2) smart contracts, (3) token-based access control, and (4) automated consensus and forking could effectively eliminate the identified issues/limitations by providing (1) information accuracy and reliability, (2) information security, (3) open access to project information, (4) systematic record keeping and (5) proper governance of the system. The outcome of this study provides a systematic approach to increase the quality of communication in DSE projects design and management.
Coastal areas have emerged to be the most significant and dynamic regions worldwide. Therefore, automating shoreline recognition will aid non-profit conservation authorities to reduce public budget expenditures, relieve erosion damage, and increase the climate resilience of the natural environment. In this paper, advanced ML boosting algorithms including XGBoost, and LGBM are firstly applied into shoreline recognition with aerial images (of Lake Ontario in this study). This paper first discussed the significance and a literature review of recent progress in shoreline detection. Then, this paper adopted semantic segmentation instead of detecting shoreline directly, which enables the (Machine Learning) ML model to achieve relatively high accuracy with a small amount of data. 5 high-resolution images are used for training the model in which shorelines are detected.

The work was carried out in four steps: 1) labeling the contents of shoreline images as areas of water and banks; 2) training ML algorithms; 3) using the trained algorithms to classify the image content as either water or land objects; 4) post-processing by de-noising image pixels (applying a Fourier transform algorithm) to obtain a defined shoreline.

The averaged training time per image for Random Forest, XGBoost, and LGBM algorithms are 195.2 sec, 71.0 sec, and 8.6 sec, respectively. The averaged accuracy is 95.6%, 96.0%, and 94.8%, respectively; the XGBoost algorithm has slightly higher accuracy, while LGBM has a significantly shorter runtime. Cross-validation of the LGBM algorithm reduced the training time by around 23% (7.0 sec) and increased the accuracy by only 1.1% (to 95.9%).
The construction industry is responsible for 40% of global energy demand as buildings increase heating, cooling, and lighting demand. In the last decade, building energy performance has become one of the most significant subjects for the architecture, engineering, and construction (AEC) industry. The envelope of a building has an essential role in optimizing energy performance and consumption. The research objective of this study is to analyze and compare the impact of different envelope materials on building energy performance for a high-rise residential building (10 stories). The research methodology includes a literature review and case study. The literature review analyzed studies published between 2015 and 2021 (84 publications were extracted from Web of Science and Scopus databases). The Web of Science and Scopus databases were used, and the following sources were included: articles published in prominent journals, conference proceedings, thesis, scientific reports, and books. In the case study, a high-rise residential building based in Istanbul, Turkey, is designed and analysed via DesignBuilder regarding passive strategies like shape, orientation, insulation, window-wall ratio, and shelter as the individual scenario. Design-Builder 7.0.0.116 and EnergyPlus 9.4.0.001 are used for analyzing and comparing the energy performance of the different wall, insulation, and glass materials used in the building. The result of the current study demonstrates the impact of each parameter and material of interest on the energy performance of buildings. This study would contribute to the A.E.C. literature and industry by comparing different envelope materials’ energy performance and the proper scenario according to Istanbul’s climate.
SUSTAINABLE FACILITY MANAGEMENT AND MAINTENANCE
In the Netherlands, the development of student housing has been increasing with the significant growth of the student recruitment in recent years. As such, there is a pressing need for a retrospective reflection of the performance of student housing built in previous years. However, a user-centric building performance evaluation framework (BPEF) for student housing is not available. From the user perspective, this study aims to develop a BPEF to support student housing management. Based on a thorough literature review, 14 building performance attributes (BPAs) applicable to student housing were identified, structured and incorporated into a preliminary three-level hierarchy of BPEF. A focus group discussion and expert interviews, which were conducted to verify the preliminary BPEF, established an improved, four-level hierarchy of BPEF that comprises 15 BPAs. A Dutch student housing case was selected to test the established BPEF using the data collected through a survey. Included in the survey are pairwise comparison questions designed based on the Analytic Hierarchy Process (AHP) method. The qualitative (narratives from focus group discussion and interviews) and quantitative data (survey results) complement with each other to provide in-depth examination of the student housing’s performance, and the survey results prove the validity of the BPEF. This study serves as a pilot case in establishing the BPEF from the user perspective, and the validated BPEF can be used in future research or practical evaluation on other student housing developments.
Heritage building maintenance management (HBMM), which has been recognized as a tool to enhance sustainability, enables the preservation of past legacies for future generations. HBMM is also known for reducing the intensity of climate change and preserving embodied energy through adaptive reuse and conservation. To this end, facility management (FM) – a multidisciplinary approach towards achieving the functionality of the built environment – has been increasingly applied. However, the absence of clearly identified critical success factors (CSFs) and a systematic framework for identifying the CSFs for effective performance measurement of HBMM remains a salient problem.

Intended to bridge this gap, this study aims at developing a framework for identifying the CSFs for HBMM. Conducted at the beginning of the study was a review of relevant literature in the domains of HBMM and FM. Afterward, a conceptual framework was developed by integrating different levels (strategic, tactical, and operational) of FM concepts and useful building performance measurement tools, thus resulting in a guide for identifying CSFs to meet the objectives of HBMM stakeholders. This study’s outcome helps practitioners identify relevant CSFs for achieving organizational maintenance goals and contributes to the existing knowledge about the management of heritage buildings. It can also serve as a basis for future studies that assess the significance of the identified CSFs in HBMM.

**Keywords:** critical success factors; facility management; heritage building; maintenance; sustainability
Buildings represent a major source of energy use and significantly contribute to carbon emissions and hence, the global warming problem. Towards the goal of sustainable and smart buildings, worldwide a variety of voluntary and mandatory tools have been introduced to enhance buildings’ operational performance. Among these tools is retro-commissioning (RCx) - a knowledge-based systematic process to periodically check and improve existing buildings’ performance. However, the uptake of RCx in the building sector remains limited. This paper reports on the emergence and development of RCx, a comparison between RCx programmes in places including the United States, the United Kingdom, Singapore and Hong Kong, the characteristics of RCx, and the concerns over the implementation of RCx in existing buildings. In addition, a review of the relevant literature was conducted, from which the barriers to RCx and policy measures or mechanisms that can help foster wider adoption of RCx, were identified. The way forward for tackling the problems with RCx for buildings, including a research methodology by which appropriate policies can be identified to enable RCx implementation, is also illustrated.
Sustainable refurbishment is an important approach toward reaching the EU’s climate goals. The challenges of rehabilitation of existing housing areas are high quality standards and lack of funding or residential interest for that. The objective of this paper is to present the results of the Sustainable Accounting Standard (SAS) project, led by Housing Federation of Norway representing 41 co-operative housing associations with 1,350,000 members. A triangulating combination of literature review, survey and interview is chosen. The literature review forms a theoretical basis within the field. Experiences with SAS tool are retrieved through semi-structured in-depth interviews with project participants from the co-operative housing associations and a survey for the residential board members from selected pilot projects. The project presents the findings from the development of the SAS tool, different stakeholders’ perspectives and information from the testing period on 12 pilots. The SAS tool forms an improved process for sustainable development in housing companies, addressing all aspects of sustainability, early involvement of stakeholders and importance of resident’s participation. The project shows that ‘residents’, ‘residential board’ and ‘co-operative housing associations’ are equally important to reach the goal, and for that commitment, trust, communication and knowledge sharing are the basis. The established KPIs are good indicators for condition analysis and ambition plans of the main stakeholders. The SAS tool can contribute to a smoother refurbishment process with right prioritization of improving measures. The investments in sustainable refurbishments are high, so it is important to spend enough time to instruct end-users and gain trust.
Standards for products, processes and management systems are important tools for the much needed sustainable transformation of the built environment. With standards we refer to documents coming from standardisations bodies such as ASTM/ANSI (USA), BSI (UK), CEN (Europe), and ISO (global). The purpose of this paper is to investigate the role standards play in current research and in particular in building research to exemplify various ways CIB and standardisation bodies can combine efforts for a sustainable transformation of the built environment. Through a review of literature, we identify scientific journal articles which address standards and the built environment. The paper focuses on the building’s use and operation phase and especially the new Facility Management standards (ISO 41000 series) developed by the technical committee ISO TC267. Our findings are based on a core of 10 journal articles from 2010-2021, these were selected for closer analysis after 198 relevant articles were identified. The articles refer to a broad range of standards which proves the relevance of standards in building research. However, there are no proves of how research has influenced standards, only examples of various ways building research aim to enhance standards. Improving and implementing international standards for facility management (FM) is a driver to improve the sustainability of built environment. CIB and the standardisation bodies have an important role to accelerate the societal transition processes and contributing to society’s demands of sustainability and resilience. This research provides examples for inspiration and stronger relations between people and processes in research and standardisation.
Building Information Modelling (BIM), as one of the key elements of digitised construction, is becoming increasingly popular amongst facilities management (FM) organisations. The advantages of BIM in the in-use phase of a facility will only develop with a mature implementation of BIM within all stakeholders’ organisations, and in particular, within FM, who are the main stakeholders in this phase. As with any new technology, there are people, processes, and technology-related challenges and shortfalls associated with the adoption and implementation of BIM in FM; challenges that can result in cybersecurity threats to both FM organisations and the facilities they manage. Thus, BIM maturity models are developed to provide guidance to organisations who wish to overcome the obstacles of adoption and improve on their BIM-enablement, positively affecting their cybersecurity capabilities in strategies, procedures, and employee performance. However, the competencies set out in the existing maturity models have a limited indication towards cybersecurity considerations and lack a holistic view of the problem. Through a comprehensive review of the existing BIM maturity models and cybersecurity best-practice guidelines, this study sheds some light on the socio-technical determinants that contribute towards a more cybersecure BIM implementation in FM organisations. The findings present assimilation of socio-technical cybersecurity and BIM determinants that would guide FM organisations towards a unified management of cybersecurity and BIM in facilities’ management organisations. This study also creates a new stream of thought for the development of future BIM maturity models, to include cybersecurity considerations within their assessment benchmarks.
As water and energy costs rise in South Africa due to the limited water and energy supply, green methods and technologies implemented in buildings will help alleviate the burden of this crisis. Many literatures studied green building technology; however, there is limited research on the barriers and drivers of using green methods and technology in supportive educational buildings at universities. It is essential to note the distinction between the different types of university buildings. Although the focus will be primarily based on supportive educational buildings, the overall study deals with the university as a system in a holistic view. This study makes use of a mixed-method approach, using an over-arching case study of supportive educational buildings at the University of Cape Town. A field survey of a supportive education building at UCT and semi-structured interviews were conducted with executive management at UCT. Findings reveal that across UCT's various buildings, numerous green methods and technologies have been installed to help monitor and manage water and energy usage. Furthermore, it was indicated that the university had employed various strategies since the early 2000s to increase environmental sustainability to achieve sustainability. Additionally, there has been a shift to positively influence student behaviour through the phasing in of water and energy-saving campaigns around campus. The findings also reveal that UCT has recently prioritised green methods and technologies implementation, which inherently improves the resource efficiency and environmental sustainability of the supportive education buildings and, consequently, the overall university.
Dylan Hübner  
University of Cape Town, Cape Town, South Africa

Alireza Moghayedi  
University of Cape Town, Cape Town, South Africa

Kathy Michell  
University of Cape Town, Cape Town, South Africa

This research examined the concept of industry 4.0 technologies (IT4) and identified the effects that they have on the environmental sustainability of commercial properties in South African. The extensive literature review revealed that IT4 used to reduce the energy consumption of commercial properties is not widely adopted in South Africa. This could be attributed to South Africa’s energy building regulation, SANS 204, which provides the minimum energy saving specifications for local building requirements. It was discovered that only green buildings implemented industry 4.0 energy-saving technologies to reduce their energy consumption above the SANS 204 standards. Furthermore, it was found that buildings waste large amounts of energy which can be prevented through the use of industry 4.0 energy-saving technologies. The researchers attempted to evaluate the impact of IT4 on the energy consumption of South African commercial properties through an overarching constructivist paradigm. The research was conducted using a multi-case study approach, utilising qualitative and quantitative data on green buildings which have IT4 installed. Descriptive statistics was used to analyse the quantitative data (energy consumption), while qualitative data was collected through semi-structured interviews for an in-depth analysis. The research findings revealed that IT4 could reduce a commercial building’s energy consumption by as much as 23%. The study also found that IT4 reduced a building’s carbon footprint and improved employee productivity. This paper would provide value to developers and landlords who have limited information regarding the factors around the implementation of IT4.
406. Investigating the safety and security of the open campus using community-based facilities management and technological innovation principles: University of Cape Town

Alireza Moghayedi  
University of Cape Town, Cape Town, South Africa

Karen Le Jeune  
University of Cape Town, Cape Town, South Africa

Mark Massyn  
University of Cape Town, Cape Town, South Africa

Kathy Michell  
University of Cape Town, Cape Town, South Africa

Safety and security is significant issue affecting South Africa, especially within the context of Cape Town as it is one of South Africa’s most crime-ridden metropoles. The University of Cape Town (UCT) as a large open campus has also fallen victim to increasing levels of crime. The provision of safety and security is largely the responsibility of an organisation’s facilities management services. Therefore, the study was undertaken to determine whether the University of Cape Town has implemented the Community-based Facilities Management (CbFM) principle of community participation to better understand and manage the needs of the community regarding issues of safety and security. The study was initiated with an investigation into the literature relevant to the research which includes safety and security and CbFM. The research employed a mixed-method approach and utilised both surveys of the university community and semi-structured interviews with university executive management to obtain data from the single case study. The findings are then presented and establish an overall view of the provision of safety and security at UCT, the unique challenges management faces in doing so and the main safety and security issues affecting the community. Lastly, the findings revealed that UCT has implemented community participation processes in the past with limited success. The processes implemented constitute a narrow perspective of community participation and a much smarter and inclusive perspective by using technological innovation is required for successful community participation to occur and to be successfully utilised in the provision of safety and security.
The significance of occupants satisfaction on the maintenance planning process

Morolake Ayo-Adejuyigbe  
University of Huddersfield, Huddersfield, United Kingdom

Milan Gyanwali  
De Montfort University, Leicester, United Kingdom

In general standardisation and maintenance of a building, numerous plans, procedures, and guidelines are essential for the appropriate management of such structure to meet expectations and withstand any form of problems that may erupt from its usage. In situations of employing inadequate and improper maintenance architecture in the management of the building services, the outcome leads to the compromise of the purpose of design of such building, thereby causing dissatisfaction to the users(occupants). The result of dissatisfied occupants often leads to complaints which increase the cost of maintenance. The main focus of this paper suggests the appropriate use of the maintenance planning process to avoid accruing extra costs on maintenance both from the housing provider and user. This paper further highlights the effectiveness of the maintenance planning process and the significance of occupants’ satisfaction with maintenance provided in their homes. In achieving the objective, a survey was conducted and data gathered were analysed using different analytical tools such as frequencies, ANOVA, and correlation. The study reveals the level of satisfaction of occupants with maintenance issues in the property and satisfaction with the safety measures put in place within the building. Finally, the result generated from the survey recommends the proper use of the maintenance planning process to avoid accruing extra costs on maintenance while prioritising maximum customer satisfaction.

Keywords: Maintenance Planning Process, Occupants Satisfaction, Extra Cost, Building services
The built environment is in a digital revolution, requiring a new knowledge generation on information management platforms that go across the lifecycle. The development of digitalization has focused on the project stages (design/construction), with an assumption that facility management (FM) will catch up. The reality is that this is not the case. For real value and sustainable use of the data and data platforms coming from projects, there needs to be a focus on FM that bridges back to the project. In a recent research project, we examined current challenges and opportunities of creating value through information delivery from projects to FM. Seven interviews were conducted with FM, project management and construction management involved in renovation projects along with one workshop of 12 built environment representatives. The results show the ongoing emphasis of developing systems and documenting of processes for coordination of information flow between projects and FM. However, there is less understanding on how this information is used and integrated into FM practices. The outcome is that a framework that breaks down the barriers between building lifecycle phases is needed for better interaction and communication between FM and projects. Both coordination processes and clear communication interactions is required to build meaning into data that can be adapted to different knowledge discipline bases working in different times and contexts across the building lifecycle. The research is relevant to practitioners and educators on illustrating how FM need to evolve and engage further in the digital revolution.
Reducing the vulnerability and improving the resilience of the existing built environment to disaster events is a complex multidisciplinary challenge in which facilities managers (FMs) need to contribute an understanding of the impact that a disaster event could have on both their hard and soft facilities. FMs also need to identify potential operational, physical and corporate adaptations and mitigations that can support continued business functioning during, and immediately after, a disaster event. This paper describes work in progress to develop a holistic model of business vulnerability and resilience to earthquakes and establish a disaster risk reduction adaptation/mitigation framework that can be integrated into short, medium and long-term facilities and built asset management plans. Focusing on theory and methods, the paper will consider the different aspects of resilience (engineering resilience, ecological and socio-ecological resilience) from a facilities management perspective (hard and soft attributes) and present early findings from a participatory action research programme that mapped the business case for an earthquake forecasting, early warning and rapid response system (TURNkey) against business organisational disaster risk reduction metrics derived from literature.
609. How Sustainable Facilities Management can add value to organisations and the environment

Per Anker Jensen  
The Technical University of Denmark, Lyngby, Denmark

Susanne Balslev Nielsen  
NIRAS A/S, Allerød, Denmark

Helle Lohmann Rasmussen  
Danish Facilities Management, Copenhagen, Denmark

Purpose: To investigate and give guidance on how Sustainable Facilities Management (SFM) can add value to organisations and the environment.

Methodology: A conceptual framework has been developed for investigating the opportunities for Facilities Management (FM) to add value in relation to six selected value parameters: Branding, Economy, Flexibility, Productivity, Risk and Sustainability and the five FM scopes: Portfolio management, Project management, Space and workplace management, Property management, and Service management. The main focus of the paper is on environmental sustainability and in particularly materials and energy. For each scope a value tree with interventions as value enablers and a list of key performance indicators were developed. The paper is based on literature reviews, discussions and verifications in a group of researchers and experts with comprehensive practical experience from FM organisations and consulting companies.

Findings: The paper concludes that SFM can contribute to organisational and environmental value within all five scopes. Synergies and trade-offs between Sustainability and the other five value parameters are discussed.

Implications: The results can be used to obtain a deeper understanding of how SFM can add value to organisations and the environment. The conceptual framework can give inspiration to further research on the added value of FM. Practitioners can find and guidance on how to contribute to added value by SFM within each of the five FM scopes.

Originality: The paper adds new insights to the growing body of knowledge about the added value of FM, in particular how SFM can contribute to organisational and environmental value.
Purpose: The purpose of this paper is to demonstrate how Urban FM both as a consideration and practical application can contribute to the positive development of human centered Smart Cities.

Methodology: Through a combination of desk research and data from ongoing research project in Norway, this paper will use literature to provide a theoretical link between these concepts whilst also showing how this link can be demonstrated in real work projects in the Norwegian Municipalities of Lier and Oslo.

Findings: The findings illustrate that FM focused urban planning processes don’t just allow for citizen optimized communities but allow for well planned and easy to implement maintenance to ensure the long term viability of Smart and Sustainable Cities.

Further Implementation: The results of this paper can be important for the development of Urban FM as a field, the reorientation of FM as not just a building level concept, but community level and has applicability to the fields of FM, architecture, urban planning and smart cities.
Purpose: The purpose of this paper is to demonstrate possibilities for the blockchain to impact Facilities Management and the challenges that its implantation would present.

Methodology: This paper mostly takes the form of a theoretical study involving desk research and limited case study examples.

Findings: The paper shows that the growth of blockchain technology is becoming more and more embedded in various industries and that the building and FM sectors may be potential candidates for its future implementation under certain circumstances. Blockchains are not a fully established technology in FM yet so its potential value is yet to be established. Smart contracts and documentation recording in blockchains such as Ethereum can schedule maintenance better, ensure supplier, landlord and tenant contracts are more robust and easier to action. This paper also shows that blockchain technology is not without its challenges such as a lack of privacy and the fact that it is still an emerging technology. However, new competencies and understandings are essential in preparing for what is increasingly likely to be an inevitable future for the industry. This leads to the question of whether blockchains to shape their infrastructure to FM, or whether FM should be the medium to change.

Further Implementation: The results of this paper can be of benefit to facilities and buildings managers, property developers, blockchain experts and the developers of the technology needed to support these concepts.
It is evident in the literature that building design is a prominent factor in determining occupant satisfaction in office buildings. The main goal of this study is to provide insight to the professionals working in the design and management of office buildings by presenting empirical data on the office occupants’ perspectives on building design. To achieve this goal, a detailed literature analysis was conducted to determine the main factors that can be used to evaluate the effect of building design on the satisfaction of office workers. In order to get the industry’s opinion, interviews were performed with 12 facility managers and building design related work orders were analysed to determine the possible complaint types. Based on the results, a hierarchical structure of building design factors was established along with the related complaint types. Finally, 308 office workers were surveyed to determine (1) the number of respondents with complaints related to each building design factor, (2) the level of importance of the design related factors, and (3) office worker’s satisfaction levels for each building design factor. The findings reveal that the noteworthy root causes of dissatisfaction with the building design are amount of space, layout and indoor design in the office buildings. On the other hand, occupants are more satisfied with the furniture, outdoor design and vibration. The largest gap between the perceived importance and satisfaction appears in the ‘amount of space’. Most common complaints include insufficient social areas, poor layout of the work environment and indoor aesthetics.
Sustainable management practices such as lean and visual management can be directly linked successfully to facilities management practices. This was acknowledged during an exploratory case study that assessed the leanness of a university’s transformation, evaluating their lean and value-added approach to enhancing workflow efficiencies. The research study was limited to one UK university estates and property services lean journey. Design science research methodology with an action research approach was applied. In conjunction with qualitative methods such as interviews, questionnaires, and participatory observations in action that included a workshop. The literature review surmised that there is a lack of data demonstrating the correlation between lean visual management and sustainable management practices especially in facilities management services. Additionally, combining sustainable management and change management methods is also not widely researched. When sustainable management practices that include lean and visual management are implemented in facilities practices customer expectations are improved, waste eliminated, color coding and labelling implemented, and known sustainable practices such as recycling of furniture, fixtures and equipment occur adding value and reallocating financial resources. It is recommended that change management be introduced to better understand workplace culture when executing transformation directives. Subsequently, management will become better equipped at contending with employee’s attitudes, work ethics, and behaviors. The originality of this research exploration illustrates that facilities management departments should embrace sustainable management practices that include lean visual management methods combined with change management. Consequently, improving employee experience, return on investment and acknowledgment from customers, senior leadership, and the C-suite.
As buildings have various subsystems and numerous components, managing them is challenging. The management of buildings should be efficient during their life cycle, with a sustainable way of considering the new challenges of the Europe Union (EU): resilience and digital transition. Facility Management (FM) contributes to achieving these goals, involving multidisciplinary activities and relying on different technologies. The recent concern about an effective digital transition in FM offers an excellent opportunity to improve facility information management in existing buildings through powerful tools for data analysis, machine learning, and simulation, such as interoperable Building Information Modeling (BIM) platforms. Within this scenario, gathering and structuring in-service information for FM is crucial to boost digital transition in buildings management. This paper discusses the approaches with potential and higher impact in FM and the related steps that we should consider in terms of product data template, data collection, and optimisation models.
635. It’s not only hygienic: identifying problems in Thai community hospital outpatient clinic during the first COVID-19 outbreak

Supuck Prugsiganont
Faculty of Architecture Chiang Mai University, Chiang Mai, Thailand

Tanut Waroonkun
Faculty of Architecture Chiang Mai University, Chiang Mai, Thailand

Background: due to the unprecedented outbreak of COVID-19 (Corona Virus Disease - 2019) healthcare facilities, including Thailand community hospitals are mandatory to adjust their facilities both medical and non-clinical areas.

Aim: the study aimed to identify problems focusing on physical settings of community hospitals out-patient-department (OPD) during the first Thailand COVID-19 outbreak in March 2020. The study was conducted through the interviews comparing between opinions and needs between healthcare employees of the two community hospitals.

Methods: the study was conducted employing two-steps of data collection. First, physical setting observations of OPD areas of the two hospitals. Second, semi-structure interviews with 23 healthcare employee; 12 participants from the first hospital and 11 participants from the second hospital. Interviews were transcribed verbatim and analyzed using content analysis.

Results: five main themes were identified (1) factors leading to accumulation of pathogens (2) preventive measurement for respiratory diseases (3) current services and physical settings of outpatient clinics (4) guideline for improving the physical setting of outpatient clinics (5) prevention of accumulation of pathogens in OPD areas. Results indicate that not only improving physical setting of the OPD areas is required, but strict patient screening process and organized building management should also be considered.

Conclusions: Strict screening process with organized building and work flow management play important role in preventing the spread of respiratory diseases during the first outbreak of COVID-10 outbreak.

Keyword: community hospitals, COVID-19, healthcare staff, space management, problems
Unmanned Aerial Vehicle (UAV) has gained popularity in visual building inspection due to its unique advantages of high mobility and low cost. However, it has been a challenge to efficiently manage the large number of images collected by the camera-equipped UAV for analysis and support building condition assessment. One potential solution is to manage the UAV data and building data through the platform of Building Information Modelling (BIM). However, little research has been found that successfully combined UAV and BIM for the visual inspection of buildings. This research explores the state-of-the-art UAV and BIM for visual building inspection through a systematic literature review. A mixed quantitative-qualitative analysis is conducted to provide insights into the application of UAV and BIM in visual building inspection based on identified academic publications (i.e., 48 articles on UAV, 31 articles on BIM, and 4 articles on integrating UAV and BIM). Furthermore, challenges and possible research opportunities are highlighted to guide future research: (1) integrating UAV and BIM to automate the visual building inspection process, including the data collection and data management; (2) considering the safety concern induced by the complex surrounding environment for the BIM-based UAV flight path planning; (3) developing an efficient way for managing UAV images in BIM. In addition, a conceptual framework for integrating UAV and BIM towards automated visual building inspection is proposed to serve as a roadmap.
THE COMMON GOOD
(W099 & W123)
Construction management is often blamed for the poor application and enforcement of safety policies and regulations on worksites. The concept of management safety empowerment (MSE) involves conferring some level of authority on workers, which enable them to communicate safety concerns on their worksites and even stop work when they confirm that their health and safety (H&S) is at risk. This study assesses the level of MSE among construction professionals in Nigeria and South Africa. Data were collected using an explanatory-sequential mixed methods approach. The quantitative data were collected using the MSE dimension on the Nordic occupational safety questionnaire (NOSACQ-50), while questions for the qualitative data were developed from survey findings. A total of 280 responses were subjected to analysis, which reveals low perception levels in both countries, implying that factors such as error reporting, safety voice, H&S knowledge and job satisfaction levels are either non-existent or require improvement. The study concludes that there is a major potential for management to promote H&S compliance through MSE in favour of improved performance. It is recommended that management ensures that the work environment enables error reporting and H&S voice by improving required knowledge among workers.
Within the sustainable construction philosophical worldview, the construction industry is transiting towards the adoption of offsite construction (OSC) as a sine qua non for resolving ill-performances of the construction industry. However, its various definitions have the potential to obtuse its industry-wide benefits and challenges. The aim of this paper is to give a concise description of OSC and its benefits for improving occupational health and safety (OHS). With a framework for conducting a scoping study, this paper highlights various appellations of OSC using scholarly articles by various researchers and practitioners from 2000 to 2020, collected from multiple sources, i.e., Google Scholar, ResearchGate and ScienceDirect. The scholarly articles are reviewed regarding research contribution, methodology used, and the distribution of papers according to the type of journal or conferences and year of publication. A plethora of OSC studies with divergent scopes and objectives highlight its benefits to environmental sustainability indicators of energy, waste and carbon gas emissions, with only an implied link to OHS. A new OSC focus that is explicit on OHS benefits and challenges is suggested for future research. The papers contribute to the body of offsite literature by providing a broader OSC definition and reviewing the benefits of OSC to OHS based on their production systems.
Designers’ Risk Assessments (DRA)s are essential to the successful implementation of projects and contractor’s work methods. The Construction Design and Management (CDM) Regulations 2015 in the UK demands that all parties who specify or recommend a component or elements on a building project. As more buildings are moving from traditional forms of construction to various forms of hybrid construction, designers contributing to the project will need to provide DRAs that are associated with their designs and specifications. Traditionally, the input of the architect, structural and services engineers would suffice for this process. However as projects are incorporate more off site production and on-site assembly, design responsibilities are getting more fragmented and designers will need to will need to propose risk assessments that manage the safe implementation of their designs at the points of production (off or on-site). Furthermore, Principal Designers who have the duty to coordinate all DRAs will need incorporate these into a wholistic document that will ensure that all risks (off site, in transit and on-site) are properly assessed for elimination, reduction, information and control at the final point of project implementation on site. An illustrative case study approach based on a project being delivered a hybrid of insulated concrete formwork, beam and block suspended ground flooring, precast concrete first and second floors/ staircases and timber truss roofing was used to study and proposed a conceptual framework that seeks to inform research/practice and engender wider debate relevant to integrated DRA formulation.
64. Improving the built environment for manual wheelchair users: A review

Claire Flemmer
SBE, Massey University, Palmerston North, New Zealand

The aim of Universal Design is to make the built environment accessible to all people regardless of disability. This is a laudable aim, but most people are unaware of the many barriers manual wheelchair users actually face when accessing the built environment. The main challenges for manual wheelchair users arise from three areas. Firstly, there are intrinsic limitations arising from the manual wheelchair user’s condition and capability. Secondly, there are features such as ramps and cross slopes in the built environment that fail to comply with building codes relating to wheelchair access. Thirdly, there are cosmetic features such as cracked paths, obstructions and poorly placed signage that place an additional burden on manual wheelchair navigation. Each of these three areas is discussed in this article.

The intrinsic limitations of user condition and capability include a wide range of physical impairments and an inherently inefficient manual wheelchair propulsion mechanism. The typical code compliance requirements for wheelchair access in the built environment range from limitations on minimum path widths to maximum permissible ramp slopes. However, even when these features comply with code requirements they may be compromised by temporary obstructions or by poor maintenance so that they become insurmountable challenges to manual wheelchair users. An understanding of these challenges is necessary to improve the built environment so that it is more accessible to manual wheelchair users in the future.
It is estimated that over 2.7 million workers are employed in the UK construction and cases of mental health and wellbeing of workers have not been adequately addressed compared to the strides made regarding worker safety and accident prevention. There has been an upsurge in the number of workers experiencing anxiety, stress and depression and these are the precursors to suicides in construction. It is believed that larger UK construction companies have strategies or interventions in place to address mental health and wellbeing in the workplace but the SMEs and self-employed still face uphill task in initiating and implementing any of such strategies. It is estimated that 60% of workers in the UK private sector work for an SME and one in 10 SMEs have OSH support mechanisms in place compared to eight in 10 large organisations. This study adopted a purposive sampling strategy with self-selecting respondents. A self-administered questionnaire benchmarked against the mental health core and enhanced standards tools adopted by the ‘Stevenson/Farmer review of mental health and employers’ served as the basis for the study. The study focused mainly on 37 construction workers using content analysis to assess the levels of supportive environment available to manage the risks to worker’s mental health and findings indicate that the role of leadership in the implantation and communication of mental health work plan, raising the level of mental health awareness among employees and encouraging open conversations reduces stigma and discrimination within the workplace.
Blue-collar workers are in general more susceptible to certain health conditions such as musculoskeletal disorders. Previous studies have shown that one of the major problems among older workers is back pain, and as much as 72% of all sick leave over a 4-weeks duration in the Swedish construction industry can be traced to some form of back injury. This study presents the design of a smart insole system developed as a part of the project, and the practicality of its use in the construction industry, including evaluation of its benefits and limitations. Pressure sensors in the soles generate heatmaps that allow us to identify incorrect posture using an adaptable artificial intelligence lifting engine. This data is used to evaluate the lifting actions in real-time and preemptively warn the individuals. Using the principles of participatory design as a starting point, the pilot phase and real environment testing of the solution was conducted among construction workers to understand the users’ experience while interacting with the solution. The user testing period was followed by the feedback and evaluation period, which included informal feedback from the user. While it has shown the promise of a new solution, we realize that it still needs improved robustness, simpler instructions, and also lacked some other technical functionalities that must be addressed before we can move to the next stage. The results will be used to further evaluate and improve the system and to make decisions in the product design, that could contribute to offering a better product.
Thousands of lives and dwellings are lost every year in residential fires around the world. While the threat of building fires has been an ongoing issue, within more recent times there have been notable contemporary challenges that governments have had to consider in greater detail. The flammable cladding crisis and an increased risk of bushfire events (manifesting from climate change) in both urban and regional areas, respectively, are two high-profile examples. Within this paper, the government response to both façade-fire threats on buildings and bushfire threats to buildings are critically reviewed in the State of Victoria (Australia). To investigate this, a desktop study was undertaken to identify significant façade-fires and bushfires over the last 20 years in Australia. Drawing on key case study events, the paper analyses available government documentation on their response to these fire events. These documents were examined through a content analysis. The results of this study highlight the government responses to both large-scale bushfires and façade-fires, and in particular, where and when certain fires or fire types resulted in changes to policy. The review contributes to knowledge by providing an overview of government responses to contemporary fire risks, and highlighting where further government action and future research should be focused both in Australia and elsewhere.
179. Developing client leadership to drive BIM adoption for WHS management

Kerry London
Torrens University Australia, Sydney, Australia

Zelinna Pablo
Torrens University Australia, Sydney, Australia

Yingbin Feng
Western Sydney University, Sydney, Australia

Angelica Vårhammar
Centre for Work Health and Safety, Sydney, Australia

The construction sector is one of the most dangerous in Australia and consistently reports high numbers of incidents of fatalities and injuries. Many of these incidents can be avoided through better planning, design and construction practices. Such practices can be supported by technologies such as Building Information Modelling (BIM). BIM adoption has been increasing in Australia over the last 20 years, however the adoption of BIM specifically to support work health and safety (WHS) goals remains limited. Excellent practices are emerging, but these remain the exception rather than the norm.

This paper presents findings from Phase 1 of a four-phase government-funded research project that explores how a large-scale industry-wide shift to this norm can be achieved. In Phase 1, the research team conducted a targeted literature review and nine-semi structured interviews of expert stakeholders to explore drivers and barriers to the adoption of BIM for WHS management. Using a two-stage qualitative analysis involving thematic and axial coding, the research team found four areas that were fundamental to achieving this shift: (1) client leadership, where clients with large infrastructure project portfolios created an environment prioritising the structured, collaborative creation and use of information requirements across supply chains; (2) tendering proficiency where BIM for WHS information requirements were specified during procurement, regardless of the procurement model; (3) best practice, showing use of BIM across six WHS areas and (4) supply chain monitoring. The paper concludes with a description of subsequent project phases, including the development of a Decision Framework for client leaders.
With the frequent occurrence of construction safety accidents, improving safety management performance in the construction industry is imperative. To scientifically predict safety management performance, the number of construction accident deaths is selected as an indicator of safety management performance. This study integrates the analytic hierarchy process (AHP) and grey relational analysis (GRA) to identify labor productivity, construction area of the house and number of construction enterprises and employees of the construction enterprises as the main factors affecting the number of construction accident deaths. Then this study uses the grey prediction theory to build a GM(1,5) model to predict the number of deaths from safety accidents in 2013-2019. The results show that the model has good prediction accuracy and it can be used to predict future construction safety management performance. Through the prediction of safety management performance, managers can evaluate the development trends of construction projects and thereby take timely measures to reduce the occurrence of safety accidents. Meanwhile, the study provides a new optimization method for the development of the GM(1,N) model and the application of real data.
Although an overabundance of research exists on gentrification, little is known about ‘green gentrification’, especially in a South African context. ‘Green gentrification’ is the process in which providing green amenities and cleaning up pollution attracts wealthier residents or tenants to a previously disenfranchised or polluted neighborhood, which in turn increases property values. This paper investigates the phenomenon of ‘green gentrification’ and its effects in a South African context. Using the Silo District in the V&A Waterfront, Cape Town as a backdrop, the study investigates the occurrence of ‘green gentrification’ in the area, and whether the Silo District affects the perception of ‘green gentrification’ therein. The study investigates whether the characteristics of ‘green gentrification’ are identified in the Silo District’s transformation. A qualitative research was adopted with a review of the literature on ‘green gentrification’, obtaining primary data through semi-structured interviews of relevant actors in the study area, supplemented by photographic and documentary evidence. The findings show that transforming the Silo District and implementing green and environmental amenities attracted wealthy individuals to the area. The study establishes that the transformation of the Silo District has encouraged a perception of ‘green gentrification’ in the area, and contributes to the general discourse, and a better understanding of this phenomenon. Furthermore, given the advantages of providing green amenities on an urban scale, the study highlights the potential challenges that may also be inadvertently introduced therein. This research was based on a single node and therefore the findings may not necessarily be generalizable.
Due to the dynamic and complex nature of the construction industry, construction workers are often exposed to a range of stressors which are causative factors for mental health problems. Simultaneously, intercultural contact between workers in a multicultural working environment may aggravate mental health issues. A better understanding of stressors can contribute to the development of targeted measures for mental health prevention and promotion. Therefore, this study aims to investigate the correlation between stressors and mental health for construction workers in a culturally diverse working environment. Data were collected using questionnaires from 252 construction workers in Australia. The Pearson correlation analysis was used to analyze the collected data. The results revealed the significant correlations between stressors and mental health outcomes and indicated the most significant stressors from work, personal and cultural domains. The findings provide valuable insights for practitioners and policymakers on the development of mental health interventions for construction workforce in a multicultural context. Researchers could also benefit from an in-depth comprehension on the causative factors of psychological issues in the construction industry.
Nanotechnology is a recent development within construction, however, exposure to nanomaterials entails exposure to emerging hazards and risk, which is exacerbated by the limited knowledge pertaining thereto. A quantitative survey was conducted among medium to large sized general contractors, and architects in the Eastern Cape. The salient findings include: the responding architects and contractors specify and use nanomaterials during the construction process; the responding architects follow ‘designing for safety’ practice to a limited extent; the responding contractors conduct the necessary training, inform their employees of the potential hazards related to the use of nanomaterials, implement safe application techniques when working with nanomaterials, issue employees with the necessary PPE to carry out the work safely, and generally do not analyse the characteristics of materials to a major extent, but do analyse the material safety data sheets (MSDSs) when received. Conclusions include: there is a low level of awareness and knowledge with respect to nanomaterials; the responding architects are hardly committed to construction H&S; responding contractors are committed to H&S, and there is a need for research to determine the healthiest and safest methods of using nanomaterials. Recommendations include: designers and contractors should enhance their awareness of and knowledge pertaining to nanomaterials, including the hazards and risks; tertiary built environment education should address nanomaterials in various modules; professional associations and statutory councils should present nanomaterials-related continuing professional development, and employer associations should raise the level of awareness relative to nanomaterials.

Keywords: Chemical, Construction, Hazardous, Nanomaterials, Substances.
The impact of various safety leadership styles on construction safety climate: A case of South India

Senthamizh Sankar S
Department of Civil Engineering, College of Engineering and Technology, SRM Institute of Science and Technology, SRM Nagar, Kattankulathur, India

Anandh K S
Department of Civil Engineering, College of Engineering and Technology, SRM Institute of Science and Technology, SRM Nagar, Kattankulathur, India

Sathyanarayanan Rajendran
Engineering Technologies, Safety and Construction Department, Central Washington University, Ellensburg, USA

Krishna Nirmalya Sen
Larsen and Toubro Limited, Kolkata, India

The Indian construction industry is the second-largest job-providing sector in the country, which comprises many investments. According to the International Labour Organization (ILO) report, India is a significant contributor to construction site accidents and fatalities among world nations. The poor safety leadership (SL) style and the diminished leader's commitment towards the quality safety outcome have caused several construction site misfortunes. This paper aims to identify the impact of various safety leadership styles over the predictors of organizational safety climate (OSC) and propose a conceptual model that explains the relation between SL styles and OSC. The study identifies six leadership styles from the works of literature: Leader-member exchange (LMX), Distributed leadership, Contingent reward, Laissez-faire leadership, Management-by-exception, and Superior's empowerment leadership. Structured questionnaires were circulated for data collection among construction professionals working in metropolitan cities in South India. The collected data was analyzed using the stepwise regression analysis and structural equation model (SEM) analysis to identify the SL styles influencing OSC predictors. The findings revealed that four out of six SL styles are optimistic. Two of them are pessimistic, namely laissez-faire leadership and management-by-exception leadership style, which leads to an increase in construction site misfortunes. The outcome of this study helps the top-level management personnel to build and develop a positive safety leadership trait to achieve quality safety outcomes of the construction organization.
The construction sector is India’s second-largest industry, contributing to the country’s economy and providing many job opportunities. However, construction has been described as a hazardous industry with a high rate of injuries, accidents, and fatalities compared to other sectors worldwide. The “psychological contract of safety (PCS)” is one of the safety climate (SC) variables which influence worker safety behavior (WSB) actions on construction sites to improve safety. This research investigates the influence of SC factors on PCS and PCS on WSB in construction site safety. A quantitative method of research has been adopted in this study, and the data is collected from the construction professionals working in South India. Statistical analyses were performed for the collected data; consisted of stepwise regression analysis and structural equation modeling (SEM) analysis to determine the significance of PCS. The findings disclose that in direct effect, four out of six SC factors contribute to enhancing PCS, namely supervisor safety behavior, co-worker safety behavior, worker involvement, and safety system and it shows that PCS influences WSB. In in-direct effect of SC factor on WSB two factors positively influences namely supervisor safety behavior, co-worker safety behavior and remaining two negatively influences. The outcome of this study helps the construction professionals to improve safety performance by fulfilling their obligations and improving WSB in construction sites.
With the increase of mechanization in the construction industry, more and more construction machines appear on construction sites. This improves construction efficiency but leads to the high risk of human-machine collision. At present, human-machine collision risks are usually monitored and warned manually. It is difficult to identify relevant risks in time due to the lack of sufficient safety supervisors. This paper proposes an efficient human-machine collision warning system based on computer vision and deep learning. The designed system and relevant devices are installed on construction machinery. It can quickly identify workers and measure the distance between workers and machinery in the complex and dynamic environment so as to quickly warn the risk of human-machine collision based on a threshold. Power supply restriction and harsh environment such as dust and vibration are also considered to ensure the stable and effective operation of the system. The system was tested on a construction site for 6 weeks. The result shows that the system has a significant positive effect on the early warning of human-machine collision risk, thus benefiting the improvement of safety performance of workers in human-machine collaboration scenes.

**Keywords:** Construction safety, Human-machine collision, Warning system, Computer vision
The demanding work environment of the construction industry has led to many studies on construction professionals’ experiences of work-to-family conflict. Relatively less attention has been placed on family-to-work conflict. Many employees in modern organizations play a role in both work and family domains, juggling between work and family responsibilities and underscoring the need to holistically understand work-family experiences of construction professionals. This study considered the bi-directional nature of work-family conflict and proposed an integrated research model to examine the work-family interface among South African construction professionals. Data were collected through an online survey administered to construction professionals registered with their respective statutory councils. Structural equation modelling (SEM) was employed to test the research model. Within the work domain, work demands (i.e., work pressure and work hours) affect work-to-family conflict both directly and indirectly through the boundary-spanning activity of role blurring. Within the family domain, the number of young children living at home and household task demands are positively associated with family-to-work conflict while partner support is negatively associated with family-to-work conflict. Work demands and role blurring experienced by professionals are likely to be affected by their job position and level of work authority. The findings also suggest that construction organisations should protect their employees from experiencing excessive work-family conflict through creating a socially-supportive workplace environment, providing work-family programmes that foster greater boundary flexibility, and implementing effective work design characterised by reasonable workloads and hours.
A comparative study of occupational safety and health (OS&H) regulations in United States, United Kingdom, Australia, South Africa, and Oman

Tariq Umar
University of the West of England, Bristol, United Kingdom

Nnedinma Umeokafor
Liverpool John Moores University, Liverpool, United Kingdom

Mohamed shaik Honnur Vali
A’Sharqiyah University, Ibra, Oman

Considering the importance of the OS&H regulations in curtailing the number of occupational accidents and injuries, this article identifies the gaps in OS&H regulations in Omani construction using a critical review and analysis of relevant literature. Four countries United States of America (USA), United Kingdom (UK), Australia (AUS), and South Africa (SA) were then compared to Oman in relation to selected OS&H regulations. The study reveals fall from a height is one of the main causes of accidents in different sectors in Oman however there are no specific regulations that cover this cause of accidents in detail. The only regulation which applies to the “fall from a height” is the regulation of OS&H, issued by the Ministry of Manpower in 2008. Overall, the whole regulations applicable in Oman shows that although the term fall, appear several times in the regulation, the full spectrum of the fall protection is not covered in detail. The provision of chemical hazards in Omani regulations is not of the standards as adopted in the USA, UK, AUS, and SA in that there is limited information for the regulated to support adequate compliance. While the term “scaffolding” was not found in the current regulations enforced in Oman, the term “ladder” was, however, used at five different instances in the regulations which obviously cannot substitute the scaffolding. The development and implementation of separate regulations for different industries and hazards will help Oman to raise its profile in OS&H performance.
UK Construction industry employs 2.7m employees and can lead the economic recovery by adapting to the current crisis. It embodies 6.02% share of the GDP and was hit strongly by the COVID-19 pandemic. Government and organisations will need to work strategically, providing much needed safety environments for the workers. While the industry protects staff from visible risks, taking precautions to maintain the physical well-being of its workers, the big risk that isn’t visible is employee mental health. Data shows that male construction workers are three times more likely to commit suicide than the average male in the UK. Job insecurity, long hours, time away from families, lack of support from organisations and late payments are all known to contribute to this crisis. This paper will explore how construction industry can improve the mental health of the work force in the post pandemic era and what measures organisations can take to tackle the mental health crisis that the industry is facing, and which has been exacerbated by the pandemic. The research will mainly adopt a qualitative methodology, relying on recently published literature, behavioural data and case studies complemented by quantitative data collected by organisations and research agencies. It will identify specific actions that stakeholders can take to minimise the risk of widespread and long-term mental health problems. It is assumed that the findings will give an insight to how organisations can improve the conditions of workers in the construction industry and in turn improve the resilience of their organisations.
Why are early career professionals leaving the construction industry? It’s all about the culture

Jessica Borg
School of Management, RMIT University, Melbourne, Australia

Christina Scott-Young
School of Property, Construction & Project Management, RMIT University, Melbourne, Australia

The construction industry is central to most national economies, but many countries are facing construction skills shortages. This qualitative study investigated the turnover intentions of early-career project management professionals working in construction. Semi-structured interviews were conducted with 38 early career professionals and employers to explore their perspectives on the prevalence of turnover intentions and identify the contributing factors. A high incidence of turnover intentions was reported by the young project management professionals, who identified bad workplace behaviour, high levels of work-related stress and poor work-life balance as the main drivers. Employers concurred that bullying, and long working hours contributed to early career project managers’ intentions to leave but believed that a desire for higher salaries was the strongest driver. However financial considerations were not mentioned by the early-career employees themselves. Recommendations are made for managers to improve construction workplace culture to increase the retention of early career professionals.
Construction projects involve significant tasks that can be mentally and physically challenging. Previous research has investigated the perceptions and understanding of construction workers regarding safety hazards and the safety information to obtain before working on a construction site. However, further research is needed to investigate how the conditions of a construction site, work operation, and work task influence construction worker safety, especially with respect to worker mental workload, while performing tasks. The present study aims to clarify and confirm the level of impact of task-related characteristics, referred to as constituents, on the mental workload that a worker feels when conducting carpentry work. The concept of mental energy is used as a means to quantify mental workload. The research also aims to determine the extent to which the amount of physical energy present on the site impacts the mental workload felt by workers when performing the tasks. Insights collected from 34 construction professionals in the US using a survey questionnaire are presented. The study revealed that task constituents such as interruptions and distractions have a high impact on a carpenter’s mental workload. Similarly, physical energy types (motion, temperature, etc.) have a high impact on mental workload. The contributions of this study to knowledge are the determination and confirmation of the level of impact of task constituents and physical energy on mental workload for carpenters performing construction work. The results of the study can be used to assist and improve the understanding of safety behaviors among construction workers.
Beyond compliance in the construction sector: mapping the modern slavery statements through content analysis

Emiliya Suprun
School of Engineering and Built Environment, Griffith University, Gold Coast, Australia
Cities Research Institute, Griffith University, Gold Coast, Australia

Ranoufa Almeshari
School of Engineering and Built Environment, Griffith University, Gold Coast, Australia

Tingting Liu
School of Engineering and Built Environment, Griffith University, Gold Coast, Australia
Cities Research Institute, Griffith University, Gold Coast, Australia

Rodney Stewart
School of Engineering and Built Environment, Griffith University, Gold Coast, Australia
Cities Research Institute, Griffith University, Gold Coast, Australia

Shane Duran
School of Engineering and Built Environment, Griffith University, Gold Coast, Australia

Modern slavery is considered a widely recognized issue within labour-intensive markets of the construction industry. The recent introduction of the Modern Slavery Act 2018 (Cth) in Australia, has pragmatically pressured construction companies into publishing modern slavery statements that explore the methods in how they have managed to tackle and address the presence of modern slavery within their business and supply chains. This paper, as a part of an ongoing research project, conducts a content analysis to examine Australian modern slavery statements to identify common practices among Australian construction firms. For this purpose, we collected 62 modern slavery statements from construction companies that had issued such statements after the introduction of the regulatory requirement in Australia. The analysis uncovers diverse reporting practices in relation to the corporate commitment and governance, traceability and risk assessment, recruitment, purchasing practices, worker voice, remediation, and monitoring. The paper provides a baseline of understanding about the content and substance of modern slavery statements as a foundation for future research into developing an integrated framework for evaluating the performance on addressing modern slavery.
Worker safety is of the utmost importance; consequently, construction project sites use alert systems to notify project team members of emergencies on the job site. Various emergency alert systems are available in the construction industry, from the simple air horn to the more complex remote and app-based systems. This research aims to improve construction safety by investigating emergency alert systems that notify workers of widespread emergencies on the project site. The objectives are to identify the types of emergency alert systems available in the construction industry, explore the industry professionals’ perceptions of the existing emergency alert systems, and identify any gaps in the market for new technologies or the potentials for improving existing ones. This study utilizes a survey of 34 industry professionals to identify the most commonly used emergency alert systems on jobsites and their knowledge and perceptions of app-based and remote emergency alert systems. Results indicate that while the air horn is the most used method of emergency alerts, the construction industry may be willing to spend more on remote emergency alert systems than app-based emergency alert systems. The primary concerns from the construction industry are the overall cost, the reliability of the high-tech systems, and the potential for false alarms. It appears that if the construction professionals’ concerns are addressed, they would be willing to spend more on app-based systems.
Job quality has an impact on construction worker’s health and well-being. Research shows that impacts of job quality vary between countries due to institutional differences. The study aims to examine the experiences of job quality and associated impact on construction workers’ health and well-being in the context of a developing country. A quantitative research approach has been adopted for the purpose of this study. A face-to-face questionnaire survey was conducted among 212 blue-collar construction workers in Bangladesh to understand the extent of the impact of job quality factors on the worker’s health and well-being. A descriptive statistical analysis conducted on the collected data revealed the important job quality factors impacting construction worker’s health and well-being, including job and organisational, physical, psychosocial, and control factors. The findings will also help the relevant stakeholders to develop strategies to address key job quality factors to protect the health and well-being of construction workers in the context of developing countries.

**Keywords:** Bangladesh, construction workers, health, job quality
URBAN RESILIENCE: IMPLICATIONS, CONSIDERATIONS, AND THE WAY FORWARD
Many people in the world live in hazardous environments and are susceptible to disasters. In the time of a destructive event, a resilient community must be prepared, able to mitigate the event and quickly respond. An effective mitigation plan can lead to fewer fatalities and damages.

One of the most critical tasks for mitigation is the evacuation process. Wherein, short notice time, and overcrowding and pushing in crowds, bottlenecks in infrastructure and steep slopes may worsen the situation. The evacuation process encompasses, amongst other things, transportation infrastructures to be named corridors, signs, pedestrian footpaths, and/or shelter infrastructures for keeping people safe. Evacuation infrastructure can also become damaged after the event.

An evacuation scoring system for pedestrians will be developed to investigate evacuation infrastructure in terms of different resilience features, such as redundancy, safe to fail, readiness, capacity. A systematic methodology for reviewing articles has been implemented to understand how vulnerable cities can be more prepared, especially for pedestrian evacuation.

This study will investigate the characteristics of the available evacuation infrastructure and outlines the general drawbacks. The most practical evacuation system will be estimated, with a final output being to provide the characteristics of a successful pedestrian evacuation system for future policy use.
The occurrence of disasters, especially in the post disaster phase, could be an opportunity to empower women in housing reconstruction. Despite that the disasters are on increase globally; they affect women and men differently. Women are still passive in disaster management and they have been found more vulnerable to disasters than men. This study provides insights into the experiences of women empowerment in post disaster housing reconstruction (PDHR) in the Gaza Strip-Palestine. The study used a questionnaire survey to obtain data from women who had been involved in post conflict housing reconstruction. The results indicated that, five of nine practices of women empowerment were determined statistically significant. The findings showed that, the top three practices for women empowerment are: ensuring rights of land titles for female-headed households in the PDHR, equal distribution of financial assistance to both men and women, and equal access to resources and information related to reconstruction. Gaza Strip lacks researches regarding women empowerment in general and in PDHR in particular. This study fills the knowledge gap relating to women empowerment in post conflict housing reconstruction. The study results established a basis for better understanding of the women empowerment and could minimize their vulnerabilities to future disasters.
The economic, social, and environmental losses from earthquakes caused a significant amount of efforts in enhancing risk assessment of natural hazards in the past few years. Earthquakes bring varying levels of structural and non-structural damage. Many damage assessment tools have been introduced and adopted by engineers to facilitate the recovery and reconstruction after earthquakes. Engineers must receive sufficient training to conduct safe, timely, effective, and cost-efficient damage assessments on site. Nowadays, with the rapid advancement of digital technologies, Virtual Reality (VR) and Building Information Modelling (BIM) are emerging as effective training tools for earthquake damage assessment. This paper aims to introduce the applications of BIM and VR to develop a visualisation framework for the seismic damage of buildings. This framework will be a useful starting point to develop training tools for earthquake damage assessment. In this framework, structures and building components are modelled in BIM. The BIM model can be further applied for structural time-history analysis, which provides a detailed structural seismic response. Based on the results of the time-history analysis, FEMA P-58 is employed to determine seismic damage. Finally, a prediction method is proposed to assess the overall seismic damage of the entire build based on the seismic damage of building components.
Ensuring liveability and accessibility in medium to high density urban housing and precincts is critical to maximise investment and minimise future risks to our community. This research investigates and develops our understanding of liveable and accessible social and affordable housing, with a focus on medium- and high-density urban precincts. The paper presents the findings of a Queensland, Australia case study undertaken in the Green Square Close precinct in Fortitude Valley, Brisbane. The findings of this research are derived from a series of in-depth interviews with key stakeholders from the housing industry and government and form the basis of a liveability framework for social and affordable medium to high density housing utilising five key components. These components includes; 1) Liveability – place-based and community focused, 2) Accessibility - person centred and community focused, 3) Value equation – cost benefit, 4) Regulatory and policy environment, and 5) Adoption and overcoming barriers. The liveability framework also establishes 53 sub-components across these 5 components to improve understanding of whole of life needs. The development of a liveability framework for social and affordable medium and high density housing presents opportunities for decision making in the co-creation of and investment in this critically needed housing.
The focus is on the influence of urban ‘woods’ on people’s quality of life in disadvantaged neighbourhoods investigated via the lens of architecture in a Sub-Saharan metropolis. The New Urban Agenda acknowledges that current urban and state-wide management plans, policies, and practices are failing. While the architectural sector—tasked with enhancing people’s quality of life, must promote more environmentally sustainable approaches to human-made surrounding management and design. The increasing attention on people’s health and well-being in human-made surroundings, as the intra-covid renaissance of a new age unfolds, calls into question the role of society’s environmental relationships. The study explicates psychologic, ecologic, and epidemiologic engaging scenarios. A city’s environment redesigned as Eco-equitable Community Absorbent Spaces (ECaS) foster neighbourhoods with physical, economic, and mental cohesion—that in part encourage habitat disaster risk reduction and the health of the citizenry.
145. Sustainability of post-disaster temporary houses: a review of principles and assessment methods

Alireza Shamloo
PhD candidate at School of Built Environment, Massey University, Auckland, New Zealand

Suzanne Wilkinson
School of Built Environment, Massey University, Auckland, New Zealand

Niluka Domingo
School of Built Environment, Massey University, Auckland, New Zealand

Mohamed Elkharboutly
School of Built Environment, Massey University, Auckland, New Zealand

Post-disaster construction is a challenging and time-consuming process. This fact is rooted in a diverse set of problems, from costs and resourcing to land tenure and human resources. In such complex circumstances, sometimes using temporary or transitional houses as part of recovery process is inevitable, especially in adverse weather conditions and large-scale disasters. As a result, post-disaster temporary houses are built and used around the world each year which include a variety of structural systems and materials. In recent years, because of climate change, and the need to be more environmentally aware, the building of temporary houses and the material with which they are built has come into focus. According to the global reports on internal and international displacement, the number of people who are displaced because of the consequences of climate change is increasing and the need for green post-disaster shelters and temporary houses built around the world is felt more than before. Therefore, sustainability of temporary houses and the green shelter concept are becoming increasingly important. On the other hand, post-disaster housing usually is concerned with urgency, time pressure, resourcing issues and other conflicting objectives, which make sustainability issues neglected or of less priority. In this regard, reconstruction sustainability guidelines and assessment methods may help decision-makers in choosing appropriate types of housing and materials in the critical post-disaster situations or in preplanning stages. Using a critical literature review, this paper aims to examine and classify the sustainability principles and assessment methods of post-disaster housing reconstruction.
177. Prototyping an immersive virtual reality training system for urban-scale evacuation using 360-degree panoramas

Zhenan Feng
School of Built Environment, Massey University, Auckland, New Zealand

Canlong Liu
Department of Civil and Environmental Engineering, University of Auckland, Auckland, New Zealand

Vicente González
Department of Civil and Environmental Engineering, University of Auckland, Auckland, New Zealand

Ruggiero Lovreglio
School of Built Environment, Massey University, Auckland, New Zealand

Daniel Nilsson
Department of Civil and Natural Resources Engineering, University of Canterbury, Canterbury, New Zealand

Urban-scale evacuation may take place because of disasters or emergencies. Efforts have been made to enhance the preparedness of communities for urban-scale evacuation. For instance, wayfinding systems are installed and implemented in tsunami-prone regions, indicating the evacuation routes to high ground or inland. However, communities tend not to familiarise themselves with wayfinding systems and the best evacuation routes because tsunami evacuation drills are not normally carried out given the difficulty to plan and run them. This study proposes a rapid development approach for immersive virtual reality (IVR) training systems suited to urban-scale evacuation. This approach utilises 360-degree panoramas to represent an urban environment in IVR, getting rid of the process of 3D modelling or reality capture to reconstruct a virtual urban environment. The 360-degree panoramas used in this study were directly acquired via a 360-degree camera. Immediate feedback is applied as a pedagogical approach to train participants. The training objective is to make users capable of identifying evacuation signs and the best evacuation route. This paper outlines a development framework to demonstrate the prototyping workflow of a 360-degree panoramic IVR training system suited to urban-scale evacuation. 360-degree panoramic IVR requires low levels of development efforts and computational resources. Therefore, urban-scale evacuation drills become possible to be rolled out easily and quickly to a broader population using 360-degree panoramic IVR.

Keywords: 360-degree panoramas, immersive virtual reality, tsunami evacuation, urban-scale evacuation, training
Northland river is determined by having a short stream and large catchments. Heavy rains in the region trigger the rapid rise of the water surface and cause flooding. Flooding affects the urban community in many places of the flood plain due to the double threats, flash floods from the hills and overflowing rivers in the valley. Apart from government efforts to protect urban communities, risk reduction strategies such as ‘predict and mitigate’ primarily focus on physical infrastructure protection. While providing infrastructure is beneficial to the community, being a resilient community comprises much more than just having a robust physical infrastructure. We argue that there is a need to support local communities’ human capacity to reduce flood risk. What is essential here is to provide a resilient, human-focused mitigation plan that fits the profile of people living in urban floodplain areas and complements existing infrastructure-focused government plans. This paper explores how the Northland community in the urban flood plain area navigates the existing flood risks, including how they perceive the current flood protection offered. This study investigates the social and cultural elements that influence risk response. As the main finding, this research advocates community-orientated risk management to complement the government’s strategy in understanding urban flooding in the Northland.

**Keywords:** Community-based FRM, urban community resilience, urban flooding
Urban resilience is the ability of a city to return or maintain its full functioning in the face of some unexpected or usual disruption. Several cities around the world have sought to achieve urban resilience considering a scenario of several challenges related to the climate change and the growing population demand. The built environment needs to adapt and innovate its way of building in order to absorb the concepts of resilience and to produce changes in the current production model of construction. In addition, it is important to evaluate the urban context of each city, since urban resilience strategies adopted in a given place do not necessarily meet the needs of other places. Therefore, this work aims to analyze urban resilience actions applied and applicable to the built environment of the city of Salvador - Bahia - Brazil, in view of studies and practices identified in the world. To this end, a systematic literature review, a documental analysis and semi-structured interviews with agents of academia, industry and local government were carried out. As a result, actions at the local and global level were identified and categorized. Then, these actions were analyzed based on the perception and experience of the interviewees. Finally, a current overview on particularities, difficulties and opportunities for improvement on the urban resilience actions applied and applicable to the built environment of the city of Salvador was obtained, in order to better direct the actions of the regional construction industry.
Inadequate housing in a dense, dilapidated, and patchy serviced informal urban settlement adds to the health, education, social and economic disadvantage of its occupants. What’s more, natural hazards exacerbated by climate change, pose increasing risks to the integrity of housing. Solomon Islands, one of the Small Island Developing States (SIDS) in the Pacific Ocean region, is a case in point. It is rapidly urbanising, has a high rate of poverty, limited governance capacity, and declining living conditions with 40% of its residents living in urban informal settlements. These challenges are further compounded by land conflicts, ethnic tensions and high vulnerability to natural hazards and climate change. The country also relies heavily on international aid. Given the challenges facing urban informal settlements, it is evident that although the shelter sector seeks to assist they lack experience in urban areas. Moreover, shelter recovery in urban areas can be expensive and existing shelter guides do not provide holistic guidance. This paper aims to address the identified gap by developing a shelter guide that considers whole of lifecycle of (pre-, during- and post-) disaster, gender-sensitive, and disability-inclusive; informed by the needs, values and aspirations of the communities living in the urban informal settlements of Honiara, capital of the Solomon Islands. This study focuses on five informal settlements as case studies. Qualitative data is gathered through community workshops and stakeholder interviews, with their needs used to identify the roles and responsibilities of Government and Non-Government shelter responders, given the likely high degree of self-response.
Buildings are responsible for 39% of total global CO2 emissions worldwide, with 33% of energy consumption attributed to space heating in commercial buildings. Adaptive Heating Behavior (AHB) of office users has a direct impact on energy use and depends on building characteristics which determine the heating load. This pilot field study focuses on the assessment of the AHB of office users of a recently retrofitted university building in Christchurch, New Zealand. AHB was reported by users during three consecutive days with a total heating degree days (HDD at 18°C) of 26.8. Indoor temperature and relative humidity were monitored during the study, and a qualitative analysis was performed to understand occupants’ behavioural patterns to maintain or recover thermal comfort in office settings. Participants were categorized according to their reported thermal comfort issues at work, the adaptive responses they took to recover thermal comfort, and the effectiveness of such actions. The results showed that despite a difference in solar incidence on the offices due to the building orientation, there was not a clear correspondence between categories and orientation. It was also found that effective recovery of thermal comfort was not necessarily associated to an overall indoor temperature drop and perceived window draftiness, but it was also influenced by habitual operation of the heating controls and other personal factors. Identifying patterns and triggers for AHB on a per-case basis is necessary, especially as AHB can significantly influence the building’s energy consumption.
It is projected that internal displacement of populations in the aftermath of natural hazards will occur more frequently due to climate change (Internal Displacement Monitoring Centre, 2017). However, to date, 35 nations have implemented policy or legal protections at a national level to plan for displacement or to protect the rights of internally displaced people (IDPs) (Global Protection Cluster, 2021). While no cohesive national strategy for internal displacement has been developed in Australia, a thematic analysis of climate change, disasters, and emergency management policies was conducted to determine if Australian policy acknowledges the issue of internal displacement or plans for its effects. The study found that Australian policy fails to recognise the needs of IDPs and the threat of displacement risk. The failure of national governments to implement policy and legislation on internal displacement has the potential to undermine the 2030 Agenda for Sustainable Development and stifle the progression of international initiatives such as the Sendai Framework and the Paris Climate Agreement. Furthermore, the lack of recognition for the issue at the governmental level contributes to disaster displacement risk creation, placing vulnerable populations at risk of displacement and associated stressors. As displacement governance is an integral part of addressing the human impacts of climate change and natural hazards (McAdam, 2018), this research suggests how displacement risk could be reduced in Australia through national-level policy interventions.
Typhoon Washi hit the southern Philippine city of Cagayan de Oro in December 2011 causing massive destruction and displacing 40 per cent of the city’s population, 85 per cent of them were informal settlers of highly vulnerable areas in the riverbanks. Informal settlers considered by the government as the most vulnerable residents were forcibly resettled in relocation sites in the peri-urban areas. The new settlements and houses fulfilled minimum Philippine standards for emergency housing with limited understanding of local conditions and creating gaps in the residents’ needs. In the following years, residents proactively modified their houses to fulfil the gaps in the initial housing. The impacts of the residents’ self-help initiatives related to construction safety and the creation of new risks associated with low construction quality, materials and increased density in the houses are major concerns for the government which is responsible for policies to guide the urban development of these sites. This paper aims to assess the impacts of policies in the urban development of the resettlement sites for low-income disaster-affected communities. To do so, this paper analyses interviews with local government officials, analysing residents’ self-help housing construction seven years after the disaster and how these were considered in the local planning policies. Furthermore, the changes in the post-disaster recovery planning in the country will be analysed. The findings will provide insights into government-related challenges to guarantee the technical performance of the houses and the advances and crucial remaining governance challenges for the implementation of urban development policies.
Providing shelters for animals during disasters such as floods, bushfires and storms requires adequate planning and preparedness. Planning for animals during the disaster response and recovery phases is critical to mitigating the negative effects that animal loss or separation can have. The human-animal bond has the potential to influence people’s decisions during emergencies, such as how they will respond and when or if they will evacuate. Evacuation with animals during a disaster event can be difficult and complicated. It is critical, however, that animals are rescued and kept safe during and after disasters. Any compromise can result in the death of such animals. Similarly, even in disaster-related situations, animal handling should be consistent with the Australian Animal Welfare Standards and Guidelines. This project aims to better understand disaster preparedness and resilience, as well as the recovery of animals during a disaster event. Twenty-five potential animal evacuation sites, including saleyards, showgrounds, animal shelters, and racecourses, were identified and accessed in nine local government areas (LGAs) across the Hunter region of New South Wales, Australia. On-site survey using a 5-point Likert scale questionnaire was used to collect data. While none of the facilities are of high standard, 16% would require cosmetic work, 76% would require minor work, and the remaining facilities would require significant work. The project’s implication is that the assessment guideline can be included in the local council’s emergency management plan to improve adequate planning for safe animal evacuation.
Beyond early self-evacuation from bushfire: factors influencing non-evacuation of at-risk communities

Olufisayo Adedokun
University of Newcastle, Newcastle, Australia
Federal University of Technology, Akure, Nigeria

Temitope Egbelakin
University of Newcastle, Newcastle, Australia

Willy Sher
University of Newcastle, Newcastle, Australia

Thayaparan Gajendran
University of Newcastle, Newcastle, Australia

Bushfire is a devastating natural hazard. Contrary to bushfire policy on catastrophic fires, some householders prefer to stay and defend their properties. In addition, more frequent destructive events have been predicted because of climate change. To date, little attention has been paid to factors concerning why householders decide not to evacuate, especially in at-risk communities. Recent bushfire fatalities underscore the need to understand the factors influencing decision-making among residents in at-risk communities. This study addresses this imperative by identifying factors through a systematic literature review. Out of 142 articles extracted from the Web of Science and Scopus databases between 1999 – 2020, 32 articles were found relevant. Based on the rationalism classification of knowledge in psychology, these factors were categorized into information, social, protection, and operational factors. The factors may inform further studies involving predictors of residents’ non-evacuation from bushfire hazards. In addition, the significant factors can be leveraged towards early self-evacuation, which could reduce bushfire fatalities and mental health impacts among the residents.
570. Evaluating the spatial variation of heat wave intensity to enhance urban resilience

Manan Singh
Florida Institute for Built Environment Resilience (FIBER), College of Design
Construction and Planning, University of Florida, Gainesville, USA

Ryan Sharston
Florida Institute for Built Environment Resilience (FIBER), College of Design
Construction and Planning, University of Florida, Gainesville, USA

With the global rise in frequency and intensity of natural disaster events, the adverse effects of climate change are becoming increasingly evident. A recent example is the extreme heatwave experienced by western North America which has caused a substantial loss of life and damage to the infrastructure and forests in the region. Research suggests that the intensity of heatwaves is amplified in urban areas due to the contribution of the Urban Heat Island effect which is largely a function of the surrounding urban landscape. In order to develop urban resilience to extreme heat, it is important to understand the direct relationship between urban form and the temperature elevations caused by heatwaves. This research will examine the disproportionate effects of heatwaves in urban areas and their dependence on urban form. The key objective is to evaluate the spatial distribution of heatwave intensity in urban areas and identify correlations with surrounding urban form factors of impervious area and tree canopy cover. This research will leverage the microclimatic weather data collected during the heatwave event in western North America to develop generalizable correlations that are applicable globally. The objective will be achieved by analyzing spectral imagery and temperature data from weather stations located in the urban areas of Seattle and Portland. The correlations established here can be used to identify the urban areas most susceptible to extreme heat events and can potentially guide the emergency warning systems and future policy development to enhance urban resilience.
Nowadays with disorderly urban growth into forested areas and climate changes becoming more pronounced, the number of buildings affected by forest fires is increasing. Forest fires are becoming more destructive and socially threatening. However, it is irrefutable that the probability of a forest fire to reach a structure is dramatically reduced by implementing good construction practices and proper fuel management procedures in the environment. Aiming to evaluate the behavior of construction elements of a structure facing a forest fire with testing close to reality, a demonstrative test was performed by the authors in a small house located in a forest environment, in the municipality of Miranda do Corvo, in Portugal. The test consisted of burning a plot of land, with a high forest fuel load, where the house was exposed to a high heat flux originating from the flame front. The separation strip between the fuels and the house was 50cm. With the observation of the results, it was verified that even though the house had an incombustible structure, the construction elements such as window glass, door, thermal insulation and exhaust fans presented vulnerabilities to be considered when it is assumed that a house can serve as shelter in case of fire. It is important to emphasize that the study and research on the vulnerability of buildings in the face of a wildfire at an urban-forest interface must be integrated with all the constraints and variables that surround this topic.
Forest fires have affected the Wildland-Urban Interface (WUI) in the last years with greater violence, causing damage to houses, industrial and commercial buildings. Businesses face the same fire hazard as houses but with a much greater potential due to labor interruption, job losses, and tax revenue impacts. In Canada, forest fires affected oilsand camps in 2011 and 2016, disrupting oil and gas production and damages of billions of Canadian Dollars. Camp Fire in 2018, the most destructive forest fire to date in the United States, destroyed houses, commercial buildings and other structures. In Portugal, the 2017 Large Forest Fires caused damages to almost 600 industrial buildings in the WUI and million euros losses. Assessing post-fire damage provides valuable information for future planning, fire risk mitigation, and improving fire resilience in the built environment.

Considering WUI fires’ economic and social impact in industrial areas is essential to better understand this particular situation. In this sense, following the forest fires of 2017 in Portugal, a field research was conducted to assess the type of industrial building damages endured and know which construction systems were employed in their repair. The assessment considered the type of structure, materials used in facades and roofs, type of openings, ground waterproofing of uncovered areas, and material storage usage. There was also a verification of the materials used after the rehabilitation. This last stage concludes that building fire regulation needs to change for mitigating the risk of industrial buildings getting destroyed by Forest Fires in the WUI.