*South African Journal of Industrial Engineering November 2024 Vol 34(3), pp 148-168*

# DEVELOPING AN INDUSTRIAL ENGINEERING CAPABILITIES FRAMEWORK FOR THE ADOPTION OF ENGINEERED WOOD PRODUCTS IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

**F.S. Hassan[1]* & S. Grobbelaar[1]**

## ARTICLE INFO

***Article details***
Presented at the 34th annual conference of the Southern African Institute for Industrial Engineering, held from 14 to 16 October 2024 in Vanderbijlpark, South Africa

Available online 29 Nov 2024

***Contact details***
* Corresponding author
ferdinand.hassan@tuks.co.za

***Author affiliations***
1 Department of Engineering and Technology Management, University of Pretoria, South Africa

***ORCID® identifiers***
F.S. Hassan
https://orcid.org/0009-0005-2171-1332

S. Grobbelaar
https://orcid.org/0000-0001-8148-2440

***DOI***
http://dx.doi.org//10.7166/35-3-3088

## ABSTRACT

The construction industry is embracing sustainable practices to combat environmental degradation and climate change, and engineered wood products (EWPs) offer promise as structural materials for sustainable infrastructure. Despite the benefits of EWPs, challenges such as supply chain integration and market acceptance have limited their use. This paper explores how industrial engineering could facilitate the adoption of EWPs in the South African construction industry, and provides a framework for developing critical industrial engineering capabilities that the South African timber construction sector should possess to integrate EWPs efficiently into construction projects. We used a comprehensive literature review and a curriculum analysis to achieve the study's objectives. By drawing upon these capabilities, the study identified where industrial engineering as an expertise could drive innovation adoption.

## OPSOMMING

Die konstruksiebedryf aanvaar volhoubare praktyke om omgewingsagteruitgang en klimaatsverandering te bekamp, en vervaardigde houtprodukte (EWP's) bied belofte as strukturele materiaal vir volhoubare infrastruktuur. Ten spyte van die voordele van EWP's, het uitdagings soos voorsieningskettingintegrasie en markaanvaarding die gebruik daarvan beperk. Hierdie artikel ondersoek hoe bedryfsingenieurswese die aanvaarding van EWP's in die Suid-Afrikaanse konstruksiebedryf kan fasiliteer, en bied 'n raamwerk vir die ontwikkeling van kritieke industriële ingenieursvermoëns waaroor die Suid-Afrikaanse houtkonstruksiesektor behoort te beskik om EWP's doeltreffend in konstruksieprojekte te integreer. Ons het 'n omvattende literatuuroorsig en 'n kurrikulum-analise gebruik om die studie se doelwitte te bereik. Deur op hierdie vermoëns te gebruik, het die studie geïdentifiseer waar bedryfsingenieurswese as 'n kundigheid die aanvaarding van innovasie kan dryf.

## 1. INTRODUCTION

Considering its extreme consumption of resources [1], [2], [3] and the corresponding negative effect on the environment [4], [5], [6], [7], the construction industry is under pressure to adopt sustainable solutions [3], [8]. In the building construction sector, the development of engineered wood products (EWPs) – a new class of wood materials made by combining wood elements with adhesives – has led to the revival of interest in timber applications in construction [9] and the consideration of timber as a sustainable alternative to brick, concrete, and steel [6].

EWPs have several benefits in construction. They have structural, load-bearing capabilities, since wood has a strength-to-weight (STW) ratio that is superior to conventional construction materials [10], [11]. Cross-laminated timber (CLT), one of the most commonly used EWPs, can withstand fire conditions, and delivers a better fire performance than standard concrete and steel construction because of its slow and predictable charring process and the strength of its partially burned layers [12].

The flexibility of EWPs extends to prefabricating building elements away from the construction site. This contributes to speedy construction projects and reduced labour costs [13], [14]. In addition, EWPs are more sustainable materials. They are made from wood, which is a renewable resource [15], which helps to store carbon beyond the forest [16] and produces significantly lower carbon dioxide ($CO_2$) emissions during production and use than other materials [17]. Buildings made with EWPs also possess adequate insulation qualities, limiting the need for expensive heating apparatus and reducing energy costs and emissions [18].

Despite these benefits, the adoption of EWPs in building construction could be higher. One possible enabler to increase the adoption rate of EWPs would be collaboration between the construction industry and other sectors [19]. This study explores how industrial engineering could facilitate the adoption of EWPs in the building construction sector, and provides a framework for developing critical industrial engineering capabilities that the South African timber construction sector should possess to integrate EWPs efficiently into construction projects.

## 2. LITERATURE REVIEW

Engineered wood products (EWPs) are composite materials from wood fibres, strands, or particles bonded together using adhesives and other binding agents [9]. These products are designed to enhance the structural performance, durability, and versatility of wood in construction and other applications [20]. Sawn-board-based EWPs, including cross-laminated timber (CLT) and glue-laminated timber (glulam) [21], are some of the most widely used EWPs in building construction [9], where they are referred to as ‘mass timber’ [22]. Mass timber building construction (MTC) projects are seeing significant use cases in multi-storey timber construction, with the Stadhaus (an eight-storey building in the United Kingdom), the UBC Brock Commons (an 18-storey building in Canada), and the HoHo Wien (a 24-storey building in Austria) serving as some of the most widely known examples [23].

Despite the benefits of MTC and building with EWPs, adoption still needs to be improved. A review of the adoption of EWPs revealed that many of the barriers to using them are perceptions about the quality of timber, inherited from a negative historical view of solid wood as a building material, and that do not necessarily reflect the present abilities of EWPs [19]. However, some barriers are tangible and substantial. One crucial aspect is the limited supply of EWPs for building construction projects [14], [24], [25]. This is a result of several factors, including the reliance on nearby forests for timber supply [10], the lack of local production facilities in many regions [24], [26], and even transportation problems [24], [25]. Some contractors have imported EWPs for their projects. However, that increases the cost of construction and limits the cost competitiveness of MTC [12]. Without local production, widespread adoption is also difficult [14].

Legislation and building codes also contribute to limiting the adoption of EWPs. Existing construction codes and standards have restrictive rules for using timber in construction [11], [27], [28]. Fire safety regulations limit the use of timber in construction owing to concerns over the flammability and combustibility of wood [29]. These regulations may restrict the height of buildings constructed with wood [30], and include requirements for elaborate and expensive fire prevention mechanisms [31]. In recent years, many studies have demonstrated the safety capabilities of wood products when exposed to fire [32], and positive results have even led to more accommodating building codes for timber construction in some regions [30].

Establishing clear and comprehensive building codes that address the specific properties and requirements of EWPs would be essential to promote their widespread adoption [33].

The lack of familiarity with timber building processes is another limiting factor. A skills and knowledge gap exists in the construction industry about using EWPs [10]. Thus decision-makers are unlikely to consider timber in the project conception phase when the choice of material is made [11]. Moreover, the dominance of concrete as the preferred construction material has led to path dependency in the industry and in established supply and value chains [31]. The perception exists that the use of timber would require a separate supply chain that might not be compatible with the existing model [34]. The dominance of concrete also leads to a reluctance among construction professionals to learn about other materials [27].

Furthermore, although EWPs are labelled as a sustainable alternative for the construction industry, several environmental concerns have attracted attention. One significant issue is the potential impact of wood-based products on forest ecosystems and biodiversity, and the implications for greenhouse gas emission reduction goals [35]. Moreover, using formaldehyde-containing adhesives in wood products has raised environmental and health apprehensions, prompting research to identify formaldehyde-free alternatives [36]. Similarly, the emission of volatile organic compounds (VOCs) from engineered wood products beyond formaldehyde has also been identified as a critical area needing further investigation [37]. Lu *et al.* [38] observed that using chemicals and energy to produce EWPs may limit their sustainability. Therefore, addressing the sustainability of EWPs would be essential for MTC [39].

Several ideas have been proposed to improve the adoption of EWPs in the construction industry. Incorporating EWPs into green building certifications might boost the visibility of MTC and the acceptance of EWPs in the construction industry [40]. Another recommendation is the establishment of more timber production facilities [10]. Timber construction professionals have also been urged to demonstrate and broadcast the positive qualities of EWPs as structural materials [41], and government support has also been deemed critical for the growth of the sector [24]. The literature is rife with suggestions that the construction industry is itself a barrier to the adoption of EWPs [12], [13], MTC [10], [26] and of new technologies generally [17], [27]. Kim *et al.* [42] have suggested that other disciplines could influence the construction industry to consider innovative and alternative approaches.

In that vein, Forbes [43] identified 20 core industrial engineering principles and methodologies that could benefit the construction industry. These principles are automation with radio frequency identification (RFID), automation or robotics, continuous improvement, cycle-time analysis, ergonomics or human factors, facilities layout, the International Standards Organization (ISO) ISO9000 standards, lean methodology, operations research and statistical applications, productivity management, quality function deployment (QFD), quality management, safety management, simulation, sustainable construction, supply chain management, systems integration, the learning curve, value engineering, and work measurement [43]. This study uses these principles to investigate possible industrial engineering applications in promoting the adoption of EWPs in the construction industry. This study provides two specific contributions to the literature. First, it combines findings from several applications of industrial engineering in MTC to provide researchers with comprehensive evidence of their effectiveness. To the best of the authors' knowledge, this paper is also the first to analyse how current South African industrial engineering coursework addresses the use of engineered wood products (EWPs) and mass timber construction (MTC). The analysis highlights a significant gap in industrial engineering curricula, and proposes enhancements to prepare students better for careers in timber construction.

## 3. MATERIALS AND METHODS

This study used a combination of a systematic literature review and a review of the curriculum guides of industrial engineering programmes in South African universities. A preliminary literature search was conducted to identify industrial engineering applications in the construction industry. Forbes [43] proved instructive, as the author identified 18 core industrial engineering principles and methodologies that could benefit the construction industry. After that, a series of search terms were developed from descriptions of the principles. These search terms were combined with "engineered wood" and "mass timber" to search for relevant articles. The Scopus and Web of Science databases were used, as they have emerged as preferred repositories for research articles [44]. The search terms and the number of results are displayed in Table 1.

**Table 1: Search terms and results**

| Search terms | Number of results<br>Scopus | Web of Science |
|---|---|---|
| "Industrial engineering", "ergonomics", "work improvement", "learning curve", "productivity", "continuous improvement", "automation", "robotics", "ISO", "cycle time analysis", "supply chain", "RFID", "safety", "systems", "simulation", "quality", "facility", "operations", "statistics", "sustainable construction", "value engineering". | 1,362 | 463 |

From the total number of records, 731 duplicates were identified and removed from the selection. The titles and abstracts of the remaining 1094 records were reviewed to determine whether they fitted the descriptions by Forbes [43]. This resulted in a selection of 128 articles. However, only 95 were available for full-text download and retrieval.

The second method was a review of curriculum guides to determine whether industrial engineering programmes in South African institutions provided educational content and training to assist students in applying industrial engineering principles in the construction industry. A three-step process guided the investigation. An initial online search led to the South African Department of Basic Education's list of higher educational institutions, with a database of 26 institutions on record [45]. The websites of these institutions were reviewed to identify industrial engineering programmes. Eleven institutions displayed information about having industrial engineering programmes. In the second stage of the search, the number of industrial engineering programmes from these 11 institutions was identified, amounting to 45 programmes. Full research programmes, such as Master's by research and Doctor of Philosophy programmes, were excluded, leaving 28 programmes with teaching and learning content.

The last stage of the review involved listing the modules/subjects in these programmes to investigate their relevance. The 27 programmes contained 538 modules, of which 37 were duplicates. (Duplicate modules were defined as modules within the same institution with the same names and module descriptions across multiple programmes.) The module names for the remaining 501 modules were then reviewed against the industrial engineering principles and methodologies listed in Table 1 for their relevance. This led to the selection of 126 relevant modules. Finally, module descriptions were retrieved for analysis. When module descriptions were unavailable, module outcomes were retrieved instead, if available, to assist in deciphering the purpose of the modules. Descriptions and outcomes for 85 modules were retrieved.

## 4. RESULTS

The results from the literature and curricula reviews are presented in two tables. Table 2 shows the distribution of articles identified for each principle/methodology outlined in this study.

**Table 2: Articles with industrial engineering applications in timber construction**

| Industrial engineering principle/methodology | Number of articles | Corresponding article references |
|---|---|---|
| Automation | 4 | [46], [47], [48], [49]. |
| Continuous improvement | 2 | [50], [51]. |
| Ergonomics | 1 | [52] |
| ISO | 2 | [53], [54]. |
| Operations and statistical analysis | 1 | [55] |
| Quality management | 1 | [56] |
| Safety management | 4 | [57], [58], [59], [60]. |
| Simulation | 37 | [61], [62], [63], [64], [65], [66], [67], [68], [69], [70], [71], [72], [73], [74], [75], [76], [77], [78], [79], [80], [81], [82], [83], [84], [85], [86], [87], [88], [89], [90], [91], [92], [93], [94], [22], [95]. |

| Industrial engineering principle/methodology | Number of articles | Corresponding article references |
|---|---|---|
| Supply chain management | 5 | [96], [97], [98], [99], [100]. |
| Sustainable construction | 3 | [101], [102], [103]. |
| Value engineering | 35 | [104], [105], [106], [107], [108], [109], [110], [111], [112], [113], [114], [115], [116], [117], [118], [119], [120], [121], [122], [123], [124], [125], [126], [127], [128], [129], [130], [131], [132], [133], [134], [135], [136], [137], [138]. |

Table 3 shows the distribution of industrial engineering modules whose descriptions aligned with the 18 relevant principles and methodologies previously identified in this paper. The table provides each module's name and the degree level at which it was offered. These levels were Diploma, Advanced Diploma, Bachelor of Engineering (BEng), Bachelor of Engineering Technology (BEngTech), Bachelor of Engineering with Honours (BEngHons), Bachelor of Engineering Technology with Honours (BEngTechHons), and Postgraduate Diploma (PGDip). The table also shows whether the modules were offered at the undergraduate or postgraduate level and at which institutions. The institutions from which this information was accessed were the Cape Peninsula University of Technology (CPUT) [139], the Durban University of Technology (DUT) [140], North West University (NWU) [141], [142], Stellenbosch University [143], the University of Pretoria (UP) [144], [145], the Tshwane University of Technology (TUT) [146], and the Vaal University of Technology (VUT) [147].

**Table 3: A selection of industrial engineering modules at South African universities**

| Industrial engineering | Module | Qualification | Level | Institution |
|---|---|---|---|---|
| Automation/ RFID/Robotics | Automation 3 | Diploma | Undergraduate | VUT |
| Ergonomics | Industrial ergonomics 414 | BEng | Undergraduate | Stellenbosch |
| | Human factors and ergonomics | Advanced Diploma | Undergraduate | VUT |
| Facilities layout | Facility layout and materials handling | Diploma | Undergraduate | CPUT |
| | Facilities planning | BEngTech | Undergraduate | DUT |
| | Facilities design | BEng | Undergraduate | NWU |
| | Facilities planning 320 | BEng | Undergraduate | UP |
| | Facilities layout and material handling 2 | Diploma | Undergraduate | VUT |
| | Facility planning and design | Advanced Diploma | Undergraduate | VUT |
| | Advanced facility design | PGDip | Postgraduate | VUT |
| Operations research and statistical analysis | Operations research | Diploma | Undergraduate | CPUT |
| | Statistics I | BEngTech | Undergraduate | DUT |
| | Operations research | BEngTech | Undergraduate | DUT |
| | Operations management for engineers | BEng | Undergraduate | NWU |
| | Statistics for industrial engineering | BEng | Undergraduate | NWU |
| | Operational excellence | BEng | Undergraduate | NWU |
| | Statistical learning for engineers | BEng | Undergraduate | NWU |
| | Operations excellence | PGDip | Postgraduate | NWU |
| | Operations management and supply chains | PGDip | Postgraduate | NWU |

| Industrial engineering | Module | Qualification | Level | Institution |
|---|---|---|---|---|
| | Engineering statistics 220 | BEng | Undergraduate | UP |
| | Operational management 310 | BEng | Undergraduate | UP |
| | Operational research 312 | BEng | Undergraduate | UP |
| | Operational research 410 | BEng | Undergraduate | UP |
| | Operations research | BEngHons | Postgraduate | UP |
| | Operations research (Eng) | BEng | Undergraduate | Stellenbosch |
| | Operations research (Eng) 415 | BEng | Undergraduate | Stellenbosch |
| | Operational research | BEngTech | Undergraduate | TUT |
| | Operations management | BEngTechHons | Postgraduate | TUT |
| | Advanced operational research | BEngTechHons | Postgraduate | TUT |
| | Operations research 3 | Diploma | Undergraduate | VUT |
| Productivity management | Industrial production engineering | Diploma | Undergraduate | CPUT |
| | Production engineering 1 | BEngTech | Undergraduate | DUT |
| | Production engineering 2 | BEngTech | Undergraduate | DUT |
| | Production engineering 3 | BEngTech | Undergraduate | DUT |
| | Production engineering 4 | BEngTechHons | Postgraduate | DUT |
| | Productivity 220 | BEng | Undergraduate | UP |
| | Production management 212 | BEng | Undergraduate | Stellenbosch |
| | Production and automation | BEngTech | Undergraduate | TUT |
| | Production engineering | BEngTech | Undergraduate | TUT |
| | Production engineering 1 | Diploma | Undergraduate | VUT |
| | Production engineering 2 | Diploma | Undergraduate | VUT |
| Quality Management | Qualitative techniques | Diploma | Undergraduate | CPUT |
| | Quality engineering | Advanced Diploma | Undergraduate | CPUT |
| | Quality engineering | BEngTech | Undergraduate | DUT |
| | Quality assurance for engineers | BEngTechHons | Postgraduate | DUT |
| | Quality assurance | BEng | Undergraduate | NWU |
| | Quality management | PGDip | Postgraduate | NWU |
| | Quality assurance 410 | BEng | Undergraduate | UP |
| | Quality management | BEngHons | Postgraduate | UP |
| | Quality assurance 344 | BEng | Undergraduate | Stellenbosch |
| | Quality management 444 | BEng | Undergraduate | Stellenbosch |
| | Quality engineering and management systems | BEngTech | Undergraduate | TUT |
| | Quality engineering | BEngTechHons | Postgraduate | TUT |
| | Quality assurance 2 | Diploma | Undergraduate | VUT |

| Industrial engineering | Module | Qualification | Level | Institution |
|---|---|---|---|---|
| | Quality control and improvement | Advanced Diploma | Undergraduate | VUT |
| Safety management | Safety principles and law 1 | Diploma | Undergraduate | VUT |
| Simulation | Simulation modelling | BEngTech | Undergraduate | DUT |
| | Simulation modelling | BEng | Undergraduate | NWU |
| | Modelling and simulation | PGDip | Postgraduate | NWU |
| | Simulation modelling 321 | BEng | Undergraduate | UP |
| | Simulation modelling | BEngHons | Postgraduate | UP |
| | Simulation 442 | BEng | Undergraduate | Stellenbosch |
| | Simulation design | BEngTech | Undergraduate | TUT |
| | Modelling and simulation | Advanced Diploma | Undergraduate | VUT |
| | Advanced modelling and simulation | PGDip | Postgraduate | VUT |
| Supply chain management (SCM) | Logistics engineering | Advanced Diploma | Undergraduate | CPUT |
| | Supply chain management | BEng | Undergraduate | NWU |
| | Industrial logistics 320 | BEng | Undergraduate | UP |
| | Supply chain processes | BEngHons | Postgraduate | UP |
| | Supply chain design | BEngHons | Postgraduate | UP |
| | Supply chain systems | BEngTech | Undergraduate | TUT |
| Sustainability | Sustainable management | BEngTechHons | Postgraduate | TUT |
| Systems integration | Systems engineering | Diploma | Undergraduate | CPUT |
| | Systems engineering | Advanced Diploma | Undergraduate | CPUT |
| | Systems engineering | BEng | Undergraduate | NWU |
| | Systems engineering 410 | BEng | Undergraduate | UP |
| | Systems engineering | BEngHons | Postgraduate | UP |
| | Systems engineering | BEngTech | Undergraduate | TUT |
| | System dynamics | BEngTechHons | Postgraduate | TUT |
| Work measurement | Engineering work study | Diploma | Undergraduate | CPUT |
| | Engineering work systems | BEngTech | Undergraduate | DUT |
| | Engineering work systems 2 | BEngTech | Undergraduate | DUT |
| | Engineering work systems 3 | BEngTech | Undergraduate | DUT |
| | Engineering work systems 4 | BEngTechHons | Postgraduate | DUT |

## 5. DISCUSSION

The discussion section is presented in two parts. First, a discussion of the industrial engineering applications in MTC is presented. Then, a discussion of the industrial engineering curriculum in South Africa is provided. Finally, a framework for implementing industrial engineering in adopting EWPs and MTC is provided and discussed.

## 5.1. Application of industrial engineering principles and methodologies in MTC

### *5.1.1. Automation*

Automation is the process of developing systems that function autonomously [148]. Since its first reported use in the 1930s [149], automation has been used in various industries such as aerospace, agriculture, energy, healthcare, manufacturing, and transportation [148], [149], [150]. In the construction industry, automation may improve operations by using robots and RFID [43]. Robots can move components, tools, materials, and specialised equipment for intricate jobs [151], while RFID technology may help to track goods and ensure a more effective supply chain that offers real-time accountability [152]. RFID can also increase worker efficiency in repeated processes such as framing systems and modular components, and decrease equipment selection and installation errors [43].

One automation application in MTC is the Greenbuild Pavilion, a construction workflow that used a robot to develop a modular timber structure. The robot, equipped with various tools and a digital parametric model, constructed the pavilion with standard-sized timber pieces [46]. Similarly, Janakieska *et al.* [47] documented a project at the University of Stuttgart that blended computing technology and robotics to develop a lightweight structure from fibre composites. Current construction methods and materials are made for human sizes and assembly; however, engineered wood products could push the size and scale of building construction projects that can be developed. Robotics could assist in reconceptualising the design and manufacturing possibilities of MTC [49].

### *5.1.2. Continuous improvement, cycle-time analysis, productivity management, and work improvement*

Adopting an approach of reviewing completed projects and endeavouring to document the lessons learned to develop best practices for construction may eventually improve the value derived from construction projects [43]. Implementing process optimisation techniques could pinpoint the optimal approaches for completing repetitive tasks, which constitute a significant part of building projects [43]. Kasbar *et al.* [50] and Poirier *et al.* [51] reviewed different aspects of the construction of the Brock Commons Tallwood House, an 18-storey mass timber hybrid building at the University of British Columbia, to derive and document lessons from the project that could inform future projects. Poirier *et al.* [51] examined innovations in the design process, and found that a ‘balanced triple-helix’ system involving the government, industry, and academia enabled innovation in the project.

Kasbar *et al.* [50] focused on the project’s productivity with specific data on crane usage, installation productivity, and schedule reliability. The findings revealed a notable increase in labour productivity that was attributed to the prefabrication of mass timber components and the integration of virtual design and construction modelling in both the planning and the construction phases [50]. The project specifically demonstrated the importance of the learning curve effect, as installation times reduced by more than half as construction approached the top floors compared with the lower floors [50]. Cycle time analysis allows for the implementation of process optimisation techniques to pinpoint the optimal approaches for completing repetitive tasks [43]. In addition, the structural installation and envelope cladding were finished almost seven weeks before schedule, demonstrating increased project productivity [50]. However, the discrepancy between estimated and actual installation times reflected the need for more familiarity with the process [50].

### *5.1.3. Ergonomics and safety management*

The construction industry has a poor reputation for experiencing occupational accidents [153], [154], and safety is a significant focus [155]. Worker safety is a particular cause for concern, with stringent occupational health and safety requirements for managing safety on the construction site [156]. MTC involves the use of wood screws and nails, which require power tools such as nail guns [157]. Using these tools has health and safety consequences, including a condition known as hand-arm vibration syndrome (HAVS) that mainly afflicts carpenters and joiners [158]. Industrial ecology and safety engineering could be used to identify and quantify the effects of construction activities on worker health and safety [43]. Research by BuHamdan *et al.* [52], for instance, attempted to predict the risk of workers getting HAVS when using various carpentry tools.

### *5.1.4. ISO and quality management*

In the current competitive global landscape, quality management is essential as businesses seek an advantage [159]. In recent years, construction companies have begun exploring methods of adopting ISO standards, with mixed results [160]. Many clients now expect vendors to have and meet these certifications and standards so that ISO standards may play a role in construction practices in the future [43]. The effect of fire on timber is one significant perception to be overcome [33], and many tests have been performed to investigate the performance of EWPs. Alves *et al.* [53] conducted experimental tests to determine the behaviour of multilayered wood systems in fire, based on a specific ISO 834 standard. Similarly, Chang *et al.* [54] assessed the thermal bridging performance of CLT structures, based on the ISO 10211 standard. Tests such as these provide helpful information for designing and constructing buildings with EWPs [53].

### *5.1.5. Simulation*

Simulation is considered one of the most essential industrial engineering methodologies, and is widely acknowledged for its value in aiding decision-making [161]. The results of this literature review support that claim, as simulation is the methodology most often used in the programmes that were reviewed. Autengruber *et al.* [62] developed a tool to analyse the scope of the heat and moisture dynamics of timber in several operational contexts because of the tendency of wood to exhibit different properties with moisture. Bezabeh *et al.* [66] used Monte Carlo simulations to assess the vulnerability of tall MTC buildings to strong winds. Similarly, Bolvardi *et al.* [68] designed a system to make tall MTC buildings more seismic-resistant, and tested the system using time-history simulations. Bui *et al.* [70] analysed the vibration frequencies of new adhesive-free EWPs and compared them with experimental results, while Caniato *et al.* [72] also simulated the sound properties of MTC buildings and proposed suggestions to make timber structures more sound-proof. One of the benefits of simulations is their ability to evaluate the results of experimental tests at lower costs [62].

### *5.1.6. Supply chain management*

Several authors have highlighted the limited availability of EWPs as a significant barrier to adoption [12], [14], [25], [27]. Location [10], transportation [25], and inventory management [14] are some specific supply chain-related barriers that have been highlighted. One approach to managing the supply chain is identifying locations for setting up manufacturing plants [96], [98]. Long transport distances within the supply chain for EWPs may negate the carbon gains from using wood, and even demonstrate higher global warming potential (GWP) than locally produced reinforced concrete [105]. Thus locating a production facility near a forest could help to reduce the cost of EWPs [97]. An effective supply chain management system in the construction industry would require holistic approaches that considered all parts of the supply chain rather than fragmented approaches that looked to only one section of the value chain [43].

### *5.1.7. Sustainable construction and value engineering*

One of the significant benefits of EWPs in construction is their sustainability. The use of wood in the production of EWPs allows for carbon storage beyond the forest, and timber structures have a lower environmental footprint than conventional materials [162]. Still, industrial engineering could help to ensure that this material is used along with sustainable methods and processes. For instance, studies are ongoing on the ability of bamboo to serve as an alternative ‘wood’ material in areas with extensive bamboo plantations, such as Ethiopia [101]. There is also an increased focus on the role of mass timber in the circular economy. A scenario analysis of post-end-of-life options for mass timber buildings showed that the reconstruction of a new building from the timber components of the old building was possible and would have the most negligible impact on the environment [104]. Tumbaga *et al.* [103] argued that MTC aligns with many of the goals of the circular economy. Thus adopting EWPs would be a valuable opportunity for proponents of sustainability.

Life cycle assessment/analysis (LCA) was a recurring methodology identified in this review. This included the comparison of different types of EWPs to measure their environmental impact [107], [136], the comparison of wood and concrete in tall building construction [133] and residential buildings [113], [116], using reprocessed wood cuttings to produce CLT panels [135], and composite timber systems [109], [131]. LCA is an effective tool for selecting, designing, and constructing building projects [133].

## 5.2. Industrial engineering studies at South African universities

The industrial engineering principles and methodologies identified and outlined in Table 1 are well represented as modules in industrial engineering programmes in South African universities. Quality management is well reflected in the curriculum, as quality modules make up a significant proportion of the industrial engineering modules in this paper. CPUT's qualitative techniques module provides an in-depth introduction to quality management, focusing on quality systems such as ISO 9000 and the challenges and opportunities in maintaining high-quality standards [139]. The quality engineering modules provide a comprehensive understanding of the critical importance of quality in maintaining a competitive advantage in various industries. Total quality management, statistical process control, and quality function deployment are some quality principles that these modules cover [139], [140].

The productivity modules teach students to measure, analyse, and improve productivity in various organisational contexts, and emphasise the importance of designing workspaces and processes that enhance worker behaviour and motivation [144]. Similarly, the engineering work modules cover various aspects of productivity, including principles, management, human factors in operations, and time study techniques to measure work [139], [140]. The ergonomics modules in this review emphasise optimising the relationship between people and their work environments [143], [147]. They exploredoperations analysis, work standards, and the design of effective work processes [143], [147]. Anthropology is a key focus as a tool for designing workstations and tools that fit workers' characteristics. Futuristic approaches considering cognitive work and digital technologies are also addressed, preparing students for ergonomics and safety management in a digital world [143].

The design of effective spaces is also tackled in the facility design modules. Well-designed facilities that optimise space, workflow, and productivity are essential industrial engineering goals. The modules include practical exercises that encourage students to combine various factors, such as logistics, cost, and accessibility, to design optimal spaces. The simulation modules provide a grounding in simulation approaches such as the discrete-event simulation and Monte Carlo methods [141]. In particular, identifying and representing the randomness and uncertainty of real-world systems to enable the creation of accurate and reliable models is a key focus [140]. They also introduce systems thinking and systems approach to give students a holistic perspective on the complex interactions in systems [140]. These skills are developed further in the systems engineering modules, as they provide students with real-world problems to assist them in integrating system components to work seamlessly [144], [146]

VUT's automation 3 module is one of only a few modules that focus on production systems working autonomously. It covers foundational concepts such as production, automation, and systems, and explores various considerations for automation [147]. Students learn to design progression tooling and to perform calculations to minimise material usage in order to ensure cost-effectiveness. The practical module allows students to create systems and workstations and to implement solutions in order to enhance production efficiency [147]. Similarly, the safety principles and law module provides a comprehensive overview of occupational health and safety concepts and regulations, equipping students with the ability to identify, assess, and manage workplace hazards effectively [147].

One major drawback of these modules is their limited focus on construction and the use of mass timber. A cursory review of materials-related modules in these institutions revealed an absence of wood or EWPs as materials for consideration in these programmes. Continuous improvement and cycle-time analysis are also not represented in these modules, although several module descriptions, including operations management for engineers, operational excellence, and quality assurance, adopt a continuous improvement approach to aspects of the curriculum [142]. As shown above, there are numerous potential applications of industrial engineering principles and methodologies in improving construction outputs [43], and extending the coverage of these principles to include sustainable construction practices such as timber construction could improve adoption prospects [163].

## 5.3. Industrial engineering capabilities framework

The use of engineered wood products in construction faces several significant barriers that hinder its adoption despite its environmental and structural benefits. As discussed in this paper, these barriers include uncertainties about material performance, regulatory barriers, cost concerns, and a lack of engineering and training in timber construction [19]. However, industrial engineering could play a critical role in overcoming these difficulties and promoting the adoption of EWPs. In developing the framework, similar and related benefits were grouped, creating seven major beneficial categories to explore industrial engineering's ability to influence the use of EWPs in construction. These include construction process improvement (CPO), which encompasses improving modular construction [49] and the evolution of construction into a structured manufacturing process [164]. A continuous improvement approach to MTC could lead to speedier execution of projects as knowledge is gained and shared in the building construction industry [50].

The negative perception of the fire performance of timber is a major barrier, and extensive research has been done and is ongoing to demonstrate the superior qualities of EWPs in combustion circumstances. A quality approach to fire perceptions and to material performance concerns in general could pay dividends as consumers become more quality-conscious and pay attention to ISO ratings and guidelines [43], thereby contributing to the quality management and standardisation of EWPs. Supply chain management could help to improve the availability of timber products, the design of the timber supply chain, cost reduction in the prices of EWPs, and even better sustainability outputs [97], [105]. Similarly, LCA might provide more information on the merits and demerits of MTC for continuous improvement purposes [133].

Beyond overcoming the barriers, industrial engineering may help to explore new avenues for using EWPs. Simulation and modelling software, already quite popular in research, could be used to improve product and process design [62], [63]. Proponents of green building and circular economy principles could use value engineering approaches to combine EWPs with other sustainable materials for the building industry [108]. Furthermore, although the curriculum review revealed the need for more MTC content, it has been demonstrated that the skills and knowledge they impart could still be useful in improving EWP adoption. Similarly, facility design and layout modules could prove useful as EWPs are used in more complex building construction projects [165].

Systems thinking skills and approaches may prove useful in helping to integrate EWP and MTC into a construction industry that is infamous for being resistant to innovation [162]. A continuous improvement approach – a core tenet of industrial engineering – could be applied throughout the process to ensure that learnings from the timber construction industry are used to improve teaching and learning activities at educational institutions, and in turn to improve the principles and methodologies. Figure 1 provides a diagrammatic framework showing the areas in which industrial engineering principles and methodologies could influence the prospects of EWPs.

## 6. CONCLUSION

This paper set out to demonstrate how industrial engineering could be used to promote the adoption of engineered wood products. We identified 20 critical industrial engineering principles, and methodologies that have been recommended for the construction industry, and demonstrated how they have been used in timber construction practice and research. These principles and methods include automation, ergonomics, productivity, quality management, simulation, supply chain management, and value engineering.

Our analysis of university curricula in South Africa revealed a strong alignment with these principles and methodologies. However, it also highlighted a significant gap in construction and EWP-related content. This absence suggests that, while industrial engineering programmes are equipping students with valuable skills and knowledge, they may need to prepare them explicitly to apply these competencies in the context of timber construction. This disconnect represents a missed opportunity to leverage industrial engineering expertise in an emerging sector.

Given the substantial potential of EWPs and MTC to contribute to sustainable practices, it is imperative to bridge this gap. We have thus proposed a framework based on the principles and methodologies identified in the review as a potential starting point for industrial engineering practitioners in industry and academia to venture into the timber construction sector in order to drive the adoption of EWPs. A continuous improvement approach to these activities would, in turn, benefit the industry and academic development. We also recommend that curriculum enhancements be developed in collaboration with the timber construction industry, along with interdisciplinary research initiatives that focus on integrating industrial engineering and timber construction. One possible initiative would be a systems approach to influencing the factors that affect the adoption of timber construction.

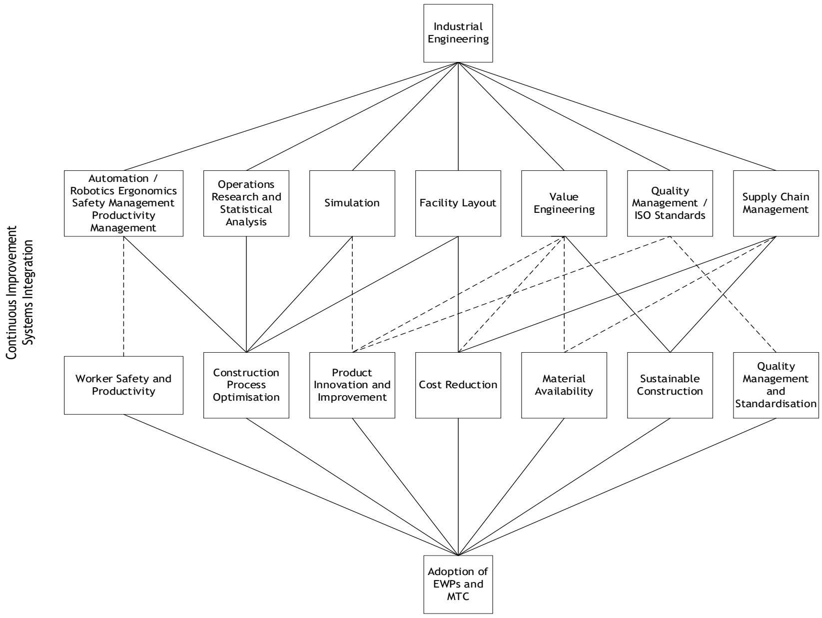

**Figure 1: An industrial engineering capabilities framework for adopting engineered wood products**

While this paper provides a comprehensive overview of how industrial engineering principles could support the adoption of EWPs and mass timber construction, it has certain limitations. The systematic literature review, while thorough, may have included only some of the relevant studies owing to the dynamic and evolving nature of both fields. Future research could benefit from continuous updates to capture the latest developments. The curriculum analysis was also limited to publicly available information on yearbooks and prospectuses from South African universities. Future research could include information from study guides or from interviews with the lecturers teaching these modules to get a more holistic view of module content. Similarly, the opinions of industrial engineers and construction stakeholders have the potential to provide more context.

## REFERENCES

[1] L. van Wyk, K. Kajimo-Shakantu, and A. Opawole, “Adoption of innovative technologies in the South African construction industry,” *International Journal of Building Pathology and Adaptation*, vol. 42, no. 3, pp. 410-429, 2021. doi: 10.1108/IJBPA-06-2021-0090

[2] L. F. Anzagira, D. Duah, and E. Badu, “A conceptual framework for the uptake of the green building concept in Ghana,” *Science African*, vol. 6, e00191, 2019. doi: 10.1016/j.sciaf.2019.e00191

[3] U. Berardi, “Clarifying the new interpretations of the concept of sustainable building,” *Sustainable Cities and Society*, vol. 8, pp. 72–78, 2013. doi: 10.1016/J.SCS.2013.01.008

[4] B. Alabi and J. Fapohunda, “Effects of increase in the cost of building materials on the delivery of affordable housing in South Africa,” *Sustainability*, vol. 13, no. 4, pp. 1–12, 2021. doi: 10.3390/su13041772

[5] S. Roh, S. Tae, S. J. Suk, and G. Ford, “Evaluating the embodied environmental impacts of major building tasks and materials of apartment buildings in Korea,” *Renewable and Sustainable Energy Reviews*, vol. 73, pp. 135–144, 2017. doi: 10.1016/J.RSER.2017.01.081

[6] E. Giama and A. M. Papadopoulos, “Assessment tools for the environmental evaluation of concrete, plaster and brick elements production,” *Journal of Cleaner Production*, vol. 99, pp. 75–85, 2015. doi: 10.1016/J.JCLEPRO.2015.03.006

[7] I. Zygomalas, D. Kaziolas, G. Stavroulakis, and C. Baniotopoulos, “Quantification of the influence of life cycle parameters on the total environmental impact of steel-framed buildings,” *International Journal of Sustainable Engineering*, vol. 9, no. 5, pp. 329–337, 2016.

[8] R. Marsh, A. C. Brent, and I. de Kock, “An integrative review of the potential barriers to and drivers of adopting and implementing sustainable construction in South Africa,” *South African Journal of Industrial Engineering*, vol. 31, no. 3, 2020. doi: 10.7166/31-3-2417

[9] J. van Acker, “Opportunities and challenges for hardwood based engineered wood products,” in *9th Hardwood Conference Proceedings Part 2*, pp. 5-14, 2021.

[10] S. Ahmed and I. Arocho, “Feasibility assessment of mass timber as a mainstream building material in the US construction industry: Level of involvement, existing challenges, and recommendations,” *Practice Periodical on Structural Design and Construction*, vol. 26, no. 2, pp. 2-12, 2021. doi: 10.1061/(asce)sc.1943-5576.0000574

[11] D. C. Evison, P. D. Kremer, and J. Guiver, “Mass timber construction in Australia and New Zealand — Status, and economic and environmental influences on adoption,” *Wood and Fiber Science*, vol. 50, pp. 128–138, 2018. doi: 10.22382/wfs-2018-046

[12] M. F. L. Mallo and O. A. Espinoza, “Outlook for cross-laminated timber in the United States,” *Bioresources*, vol. 9, no. 4, pp. 7427–7443, 2014.

[13] K. Jones, J. Stegemann, J. Sykes, and P. Winslow, “Adoption of unconventional approaches in construction: The case of cross-laminated timber,” *Construction and Building Materials*, vol. 125, pp. 690–702, 2016. doi: 10.1016/j.conbuildmat.2016.08.088

[14] P. Penfield, R. Germain, W. B. Smith, and S. V Stehman, “Assessing the adoption of cross laminated timber by architects and structural engineers within the United States,” *Journal of Green Building*, vol. 17, no. 1, pp. 127–147, 2022. doi: 10.3992/jgb.17.1.127

[15] M. Chutturi *et al.*, “A comprehensive review of the synthesis strategies, properties, and applications of transparent wood as a renewable and sustainable resource,” *Science of the Total Environment*, vol. 864, 161067, 2023. doi: 10.1016/J.SCITOTENV.2022.161067

[16] N. Perković, V. Rajčić, and M. Pranjić, “Behavioral assessment and evaluation of innovative hollow glue-laminated timber elements,” *Materials*, vol. 14, no. 22, 6911, 2021. [Online]. Available: https://www.mdpi.com/1996-1944/14/22/6911

[17] M. Kitek Kuzman, S. Klarić, A. Pirc Barčić, R. P. Vlosky, M. M. Janakieska, and P. Grošelj, “Architect perceptions of engineered wood products: An exploratory study of selected countries in Central and Southeast Europe,” *Construction and Building Materials*, vol. 179, pp. 360–370, 2018. doi: 10.1016/J.CONBUILDMAT.2018.05.164

[18] A. Roos, L. Woxblom, and D. McCluskey, “The influence of architects and structural engineers on timber in construction — Perceptions and roles,” *Silva Fennica*, vol. 44, no. 5, pp. 871–884, 2010.

[19] F. S. Hassan and S. Grobbelaar, “Barriers and enablers of the adoption of engineered wood products in the building construction sector,” *Journal of Construction — Southern Africa*, vol. 16, no. 02, pp. 5–13, 2023. Accessed: May 20, 2024. [Online]. Available: http://journalofconstruction.com/wp-content/uploads/2024/03/JOC-Vol16-Issue02.pdf

[20] Y. Ranjana, and K. Jitendra, “Engineered wood products as a sustainable construction material: A review,” in *Engineered wood products for construction*, G. Meng, Ed., Rijeka, Croatia: IntechOpen, 2021, Ch. 2. doi: 10.5772/intechopen.99597

[21] C. Kumar and W. Leggate, “An overview of bio-adhesives for engineered wood products,” *International Journal of Adhesion and Adhesives*, vol. 118, 103187, 2022. doi: 10.1016/J.IJADHADH.2022.103187

[22] Y. Ding *et al.*, “Emerging engineered wood for building applications,” *Chemical Reviews*, vol. 123, no. 5, pp. 1843–1888, 2023. doi: 10.1021/acs.chemrev.2c00450

[23] J. Cover, “Mass timber: The new sustainable choice for tall buildings,” *International Journal of High-Rise Buildings*, vol. 9, no. 1, pp. 87–93, 2020.

[24] A. Zaman, Y.-Q. Chan, E. Jonescu, and I. Stewart, “Critical challenges and potential for widespread adoption of mass timber construction in Australia — An analysis of industry perceptions,” *Buildings*, vol. 12, no. 9, 1405, 2022. doi: 10.3390/buildings12091405

[25] M. F. Laguarda Mallo and O. Espinoza, “Awareness, perceptions and willingness to adopt cross-laminated timber by the architecture community in the United States,” *Journal of Cleaner Production*, vol. 94, pp. 198–210, 2015. doi: https://doi.org/10.1016/j.jclepro.2015.01.090

[26] P. D. Kremer, P. Fahy, and A. Zaman, “Understanding the risk and reward in the adoption of mass timber construction in Australia,” *Mass Timber Construction Journal*, vol. 2, no. 1, pp. 15–20, 2019.

[27] A. Gosselin, P. Blanchet, N. Lehoux, and Y. Cimon, “Main motivations and barriers for using wood in multi-story and non-residential construction projects,” *Bioresources*, vol. 12, no. 1, pp. 546-570, 2017.

[28] A. Viļuma and U. Bratuškins, “Barriers for use of wood in architecture: The Latvian case,” *Architecture and Urban Planning*, vol. 13, no. 1, pp. 43–47, 2017.

[29] B. Östman, D. Brandon, and H. Frantzich, “Fire safety engineering in timber buildings,” *Fire Safety Journal*, vol. 91, pp. 11–20, 2017. doi: 10.1016/J.FIRESAF.2017.05.002

[30] D. Barber, “Fire safety of mass timber buildings with CLT in USA,” *Wood and Fiber Science*, vol. 50, no. Special, pp. 83–95, 2018. doi: 10.22382/wfs-2018-042

[31] F. Franzini, R. Toivonen, and A. Toppinen, “Why not wood? Benefits and barriers of wood as a multistory construction material: Perceptions of municipal civil servants from Finland,” *Buildings*, vol. 8, no. 11, 159, 2018. [Online]. Available: https://www.mdpi.com/2075-5309/8/11/159

[32] F. Wiesner, R. Hadden, S. Deeny, and L. Bisby, "Structural fire engineering considerations for cross-laminated timber walls," *Construction and Building Materials*, vol. 323, 126605, 2022. doi: 10.1016/J.CONBUILDMAT.2022.126605

[33] F. S. Hassan and S. Grobbelaar, "Adoption of engineered wood products in the building construction industry — A conceptual model," in *Association of Schools of Construction of Southern Africa*, 2023. Accessed: Mar. 20, 2024. [Online]. Available: https://asocsa.org/wp-content/uploads/2024/01/Conference-Proceedings-17thBEC-NOV2023.pdf#page=236

[34] P. D. Kremer and M. A. Symmons, *Overcoming psychological barriers to widespread acceptance of mass timber construction in Australia*, Melbourne, Victoria: Forest & Wood Products Australia, Report no. PNA309-1213, 2016.

[35] V. H. Dale, E. Parish, K. L. Kline, and E. Tobin, "How is wood-based pellet production affecting forest conditions in the southeastern United States?" *Forest Ecology and Management*, vol. 396, pp. 143–149, 2017. doi: 10.1016/j.foreco.2017.03.022

[36] M. Podlena, M. Böhm, D. Saloni, G. Velarde, and C. Salas, "Tuning the adhesive properties of soy protein wood adhesives with different coadjutant polymers, nanocellulose and lignin," *Polymers (Basel)*, vol. 13, no. 12, 1972, Jun. 2021. doi: 10.3390/polym13121972

[37] C. Frihart and S. Zylkowski, "Volatile organic compounds emissions from North American engineered wood products," *Forestry Research and Engineering: International Journal*, vol. 2, no. 4, pp. 204-207, 2018. doi: 10.15406/freij.2018.02.00049

[38] H. (Ray) Lu, A. El Hanandeh, B. Gilbert, and H. Bailleres, "A comparative life cycle assessment (LCA) of alternative material for Australian building construction," *MATEC Web of Conferences*, vol. 120, 02013, 2017. doi: 10.1051/matecconf/201712002013

[39] Z. Yu *et al.*, "Emerging bioinspired artificial woods," *Advanced Materials*, vol. 33, no. 28, 2001086, 2021. doi: 10.1002/adma.202001086

[40] C. Piccardo, A. Alam, and M. Hughes, "The potential contribution of wood in green building certifications," *Architectural Research in Finland*, vol. 5, no. 1, pp. 130-146, 2021. doi: 10.37457/arf.113262

[41] B. Giorgio, P. Blanchet, and A. Barlet, "Social representations of mass timber and prefabricated light-frame wood construction for multi-story housing: The vision of users in Quebec," *Buildings*, vol. 12, no. 12, 2073, 2022. doi: 10.3390/buildings12122073

[42] C. Kim, H. Kim, S. H. Han, C. Kim, M. K. Kim, and S. H. Park, "Developing a technology roadmap for construction R&D through interdisciplinary research efforts," *Automation in Construction*, vol. 18, no. 3, pp. 330–337, 2009. doi: 10.1016/J.AUTCON.2008.09.008

[43] L. H. Forbes, "Industrial engineering applications in the construction industry," in *Handbook of industrial and systems engineering* 2nd ed., A. B. Badiru, Ed., CRC Press, 2013, pp. 99–143. doi: 10.1201/b15964

[44] M.-A. Vera-Baceta, M. Thelwall, and K. Kousha, "Web of Science and Scopus language coverage," *Scientometrics*, vol. 121, no. 3, pp. 1803–1813, 2019. doi: 10.1007/s11192-019-03264-z

[45] Department of Basic Education, South Africa, "List of South African universities." Accessed: May 16, 2024. [Online]. Available: https://www.education.gov.za/FurtherStudies/Universities.aspx

[46] H. Hasan, A. Reddy, and A. TsayJacobs, "Robotic fabrication of nail laminated timber," in *Proceedings of the 36th International Symposium on Automation and Robotics in Construction, ISARC 2019*, M. Al-Hussein, Ed., 2019, pp. 1210–1216. doi: 10.22260/isarc2019/0162.

[47] M. M. Janakieska *et al.*, "Computational lightweight - constructions high-tech architecture," in *12th WoodEMA Annual International Scientific Conference on Digitalisation and Circular Economy: Forestry and Forestry Based Industry Implications*, 2019, pp. 93–98. [Online]. Available: <Go to ISI>://WOS:000496016400014

[48] G. Joyce and A. Pelosi, "Robotic connections for CLT panels," in *RE: Anthropocene, Design in the Age of Humans - Proceedings of the 25th International Conference on Computer-Aided Architectural Design Research in Asia, CAADRIA 2020*, D. Holzer, W. Nakapan, A. Globa, and I. Koh, Eds., 2020, pp. 405–414. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85091709994&partnerID=40&md5=c880b368bd5e332d940c45c535a0924a

[49] O. D. Krieg and O. Lang, "Adaptive automation strategies for robotic prefabrication of parametrized mass timber building components," in *Proceedings of the 36th International Symposium on Automation and Robotics in Construction, ISARC 2019*, M. Al-Hussein, Ed., 2019, pp. 521–528. doi: 10.22260/isarc2019/0070

[50] M. Kasbar, S. Staub-French, A. Pilon, E. Poirier, Z. Teshnizi, and T. Froese, "Construction productivity assessment on Brock Commons Tallwood House," *Construction Innovation*, vol. 21, no. 4, pp. 951–968, 2021. doi: 10.1108/CI-11-2019-0118

[51] E. Poirier *et al.*, "Design process innovation on Brock Commons Tallwood House," *Construction Innovation*, vol. 22, no. 1, pp. 23–40, 2022. doi: 10.1108/CI-11-2019-0116

[52] S. BuHamdan, T. Duncheva, and A. Alwisy, “Developing a BIM and simulation-based hazard assessment and visualization framework for CLT construction design,” *Journal of Construction Engineering and Management*, vol. 147, no. 3, 2021. doi: 10.1061/(asce)co.1943-7862.0002000

[53] M. Alves, L. Mesquita, P. Piloto, D. Ferreira, L. Barreira, and F. Mofreita, “Fire behaviour of wood and wood-based composite panels towards the development of fire-resistant multilayer systems,” in *AIP Conference Proceedings*, M. Marschalko, I. Yilmaz, and M. Drusa, Eds., 2023. doi: 10.1063/5.0170443.

[54] S. J. Chang, S. Wi, and S. Kim, “Thermal bridging analysis of connections in cross-laminated timber buildings based on ISO 10211,” *Construction and Building Materials*, vol. 213, pp. 709–722, 2019. doi: 10.1016/j.conbuildmat.2019.04.009

[55] M. Ghiyasinasab, N. Lehoux, S. Ménard, and C. Cloutier, “Production planning and project scheduling for engineer-to-order systems — Case study for engineered wood production,” *International Journal of Production Research*, vol. 59, no. 4, pp. 1068–1087, 2021. doi: 10.1080/00207543.2020.1717009

[56] A. Achim, N. Paradis, P. Carter, and R. E. Hernández, “Using acoustic sensors to improve the efficiency of the forest value chain in Canada: A case study with laminated veneer lumber,” *Sensors*, vol. 11, no. 6, pp. 5716–5728, 2011. doi: 10.3390/s110605716

[57] A. Filiatrault and I. P. Christovasilis, “Example application of the FEMA P695 (ATC-63) methodology for the collapse performance evaluation of wood light-frame systems,” in *9th US National and 10th Canadian Conference on Earthquake Engineering 2010, including Papers from the 4th International Tsunami Symposium*, 2010, pp. 3966–3975. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84867149538&partnerID=40&md5=cf0a4852e5573f12735cf70ed72dd48f

[58] A. W. Howard, C. Macarthur, L. Rothman, A. Willan, and A. K. Macpherson, “School playground surfacing and arm fractures in children: A cluster randomized trial comparing sand to wood chip surfaces,” *PLoS Med*, vol. 6(12), 2009. doi: 10.1371/journal.pmed.1000195

[59] P. Kotsovinos *et al.*, “Impact of ventilation on the fire dynamics of an open-plan compartment with exposed timber ceiling and columns: CodeRed #02,” *Fire Mater*, vol. 47, no. 4, pp. 569–596, 2023. doi: 10.1002/fam.3082

[60] G. L. Oliveira and F. L. de Oliveira, “Preliminary investigation on safety performance of CLT wall panels under impact and suspension tests,” in *13th World Conference on Timber Engineering, WCTE 2023*, A. Q. Nyrud, K. A. Malo, K. Nore, K. W. L. Alsen, S. Tulebekova, E. R. Staehr, G. Bergh, and W. Wuyts, Eds., 2023, pp. 175–181. doi: 10.52202/069179-0024

[61] C. Allen *et al.*, “Modelling ambitious climate mitigation pathways for Australia’s built environment,” *Sustainable Cities and Society*, vol. 77, 103554, 2022. doi: 10.1016/j.scs.2021.103554

[62] M. Autengruber, M. Lukacevic, and J. Füssl, “Finite-element-based moisture transport model for wood including free water above the fiber saturation point,” *International Journal of Heat and Mass Transfer*, vol. 161, 120228, 2020. doi: 10.1016/j.ijheatmasstransfer.2020.120228

[63] N. A. Abd. Aziz *et al.*, “Influence of activated carbon filler on the mechanical properties of wood composites,” *ARPN Journal of Engineering and Applied Sciences*, vol. 10, no. 1, pp. 376–386, 2015. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84921810005&partnerID=40&md5=ff5b7fedbe3c94dc34a224bdd2e9b361

[64] B. M. Balboni, S. T. Chatukuta, B. Muller, and C. B. Wessels, “The sawmill yield increase potential with manufacturing increased wane and random width boards for engineered wood products,” *Wood Material Science & Engineering*, vol. 19, no. 1, pp. 160–167, 2024. doi: 10.1080/17480272.2023.2229279

[65] S. Berg, J. Turesson, M. Ekevad, and A. Björnfot, “In-plane shear modulus of cross-laminated timber by diagonal compression test,” *Bioresources*, vol. 14, no. 3, pp. 5559–5572, 2019. doi: 10.15376/biores.14.3.5559-5572

[66] M. Bezabeh, G. Bitsuamlak, and S. Tesfamariam, “Risk-based wind design of tall mass-timber buildings,” in *6th International Structural Specialty Conference 2018, held as part of the Canadian Society for Civil Engineering Annual Conference 2018*, K. Arjomandi and A. El Damatty, Eds., 2018, pp. 665–676. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85074322814&partnerID=40&md5=5ca19236cc112457ae2e43da57d8af65

[67] S. Bhandari, E. C. Fischer, M. Riggio, and L. Muszynski, “Numerical assessment of in-plane behavior of multi-panel CLT shear walls for modular structures,” *Eng Struct*, vol. 295, 116846, 2023. doi: 10.1016/j.engstruct.2023.116846

[68] V. Bolvardi, S. Pei, J. W. van de Lindt, and J. D. Dolan, “Direct displacement design of tall cross laminated timber platform buildings with inter-story isolation,” *Engineering Structures*, vol. 167, pp. 740–749, 2018. doi: 10.1016/j.engstruct.2017.09.054

[69] A. Brambilla and E. Gasparri, “Hygrothermal behaviour of emerging timber-based envelope technologies in Australia: A preliminary investigation on condensation and mould growth risk,” *Journal of Cleaner Production*, vol. 276, 124129, 2020. doi: 10.1016/j.jclepro.2020.124129

[70] T. A. Bui, P. Lardeur, M. Oudjene, and J. Park, “Numerical modelling of the variability of the vibration frequencies of multi-layered timber structures using the modal stability procedure,” *Composite Structures*, vol. 285, 115226, 2022. doi: 10.1016/j.compstruct.2022.115226

[71] A. Busch, R. B. Zimmerman, S. Pei, E. McDonnel, P. Line, and D. Huang, “Prescriptive seismic design procedure for post-tensioned mass timber rocking walls,” *Journal of Structural Engineering*, vol. 148, no. 3, 2022. doi: 10.1061/(ASCE)ST.1943-541X.0003240

[72] M. Caniato *et al.*, “A reliability study concerning the acoustic simulations of timber elements for buildings,” *Construction and Building Materials*, vol. 315, 125765, 2022. doi: 10.1016/j.conbuildmat.2021.125765

[73] C. Chen *et al.*, “Structure–property–function relationships of natural and engineered wood,” *Nature Reviews Materials*, vol. 5, no. 9, pp. 642–666, 2020. doi: 10.1038/s41578-020-0195-z

[74] L. K. X. Chin, A. A. B. Baharuddin, and K. B. Mustapha, “Characterisations of medium-density fibreboards derived from Malaysian Merbau and rubberwood,” *Journal of the Indian Academy of Wood Science*, vol. 18, no. 2, pp. 116–127, 2021. doi: 10.1007/s13196-021-00287-z

[75] G. Flechas, P. C. Tabares-Velasco, G. Fierro, E. A. Holt, and M. Salonvaara, “A field study and OpenStudio calibration of two mass timber buildings in the United States,” in *Thermal performance of the exterior envelopes of whole buildings*, Peachtree Corner GA: American Society of Heating Refrigerating and Air-Conditioning Engineers, 2022, pp. 435–444. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85167609009&partnerID=40&md5=1cd47af53d213332851eadf9513a3e02

[76] D. Huang and S. L. Pei, “A generalized artificial neural network for displacement-based seismic design of mass timber rocking walls,” *Journal of Earthquake Engineering*, vol. 26, no. 15, pp. 7921–7932, 2022. doi: 10.1080/13632469.2021.1988768

[77] L. M. M. B. Jayasekara and R. M. Foster, “Numerical modelling of mass timber beam-column connections,” in *13th World Conference on Timber Engineering, WCTE 2023*, A. Q. Nyrud, K. A. Malo, K. Nore, K. W. L. Alsen, S. Tulebekova, E. R. Staehr, G. Bergh, and W. Wuyts, Eds., 2023, pp. 2841–2850. doi: 10.52202/069179-0372

[78] P. Khairnar, “Lightweight floor systems for tall buildings: A comparative analysis of structural material efficiencies,” *International Journal of High-Rise Buildings*, vol. 12, no. 2, pp. 145–152, 2023. doi: 10.21022/IJHRB.2023.12.2.145

[79] A. M. Khavari, S. Pei, and P. C. Tabares-Velasco, “Energy consumption analysis of multistory cross-laminated timber residential buildings: A comparative study,” *Journal of Architectural Engineering*, vol. 22, no. 2, 2016. doi: 10.1061/(ASCE)AE.1943-5568.0000206

[80] R. D. Labati, A. Genovese, E. Munoz, V. Piuri, F. Scotti, and G. Sforza, “Improving OSB wood panel production by vision-based systems for granulometric estimation,” in *2015 IEEE 1st International Forum on Research and Technologies for Society and Industry, RTSI 2015 - Proceedings*, 2015, pp. 557–562. doi: 10.1109/RTSI.2015.7325157.

[81] R. McClung, H. Ge, J. Straube, and J. Y. Wang, “Hygrothermal performance of cross-laminated timber wall assemblies with built-in moisture: Field measurements and simulations,” *Building and Environment*, vol. 71, pp. 95–110, 2014. doi: 10.1016/j.buildenv.2013.09.008

[82] F. Morandi *et al.*, “Modelling the sound insulation of mass timber floors using the finite transfer matrix method,” in *Building simulation applications*, G. Pernigotto, F. Patuzzi, A. Prada, V. Corrado, and A. Gasparella, Eds., Bolzano, Italy: Free University of Bozen Bolzano, 2020, pp. 117–122. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85090838038&partnerID=40&md5=e7df49c7891490022c60f741d77b89f1

[83] H. Mpidi Bita, J. A. J. Huber, P. Palma, and T. Tannert, “Prevention of disproportionate collapse for multistory mass timber buildings: Review of current practices and recent research,” *Journal of Structural Engineering*, vol. 148, no. 7, 2022. doi: 10.1061/(ASCE)ST.1943-541X.0003377

[84] G. Nunes, J. D. D. Moura, S. Güths, C. Atem, and T. Giglio, “Thermo-energetic performance of wooden dwellings: Benefits of cross-laminated timber in Brazilian climates,” *Journal of Building Engineering*, vol. 32, 101468, 2020. doi: 10.1016/j.jobe.2020.101468

[85] L. Opacic, T. Sowlati, and M. Mobini, “Design and development of a simulation-based decision support tool to improve the production process at an engineered wood products mill,” *International Journal of Production Econpmics*, vol. 199, pp. 209–219, 2018. doi: 10.1016/j.ijpe.2018.03.010

[86] B. Peters, N. Hoban, and K. Kramer, “Sustainable sonic environments,” in *Re: Anthropocene, Design in the Age of Humans — Proceedings of the 25th International Conference on Computer-Aided Architectural Design Research in Asia, CAADRIA 2020*, D. Holzer, W. Nakapan, A. Globa, and I. Koh, Eds., 2020, pp. 455–464. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85091710316&partnerID=40&md5=5b3e349b7864670a9cb623c919cab842

[87] M. Robati and P. Oldfield, “The embodied carbon of mass timber and concrete buildings in Australia: An uncertainty analysis,” *Building and Environment*, vol. 214, 108944, 2022. doi: 10.1016/j.buildenv.2022.108944

[88] Y. L. Shen, Z. G. Mu, J. Schneider, and S. F. Stiemer, “Numerical simulation study and damage analysis of cross laminated timber connections,” *Gongcheng Kexue Xuebao/Chinese Journal of Engineering*, vol. 38, no. 1, pp. 149–157, 2016. doi: 10.13374/j.issn2095-9389.2016.01.020

[89] Q. Sun, Y. Turkan, and E. Fischer, “Develop and benchmark FDS numerical models to simulate fundamental fire behavior in CLT structures,” in *Proceedings of the International Symposium on Automation and Robotics in Construction*, C. Feng, T. Linner, and I. Brilakis, Eds., International Association for Automation and Robotics in Construction (IAARC), 2021, pp. 319–326. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85127559711&partnerID=40&md5=7ef1e0bc43ee6a2fd7d0f5ab8eba0eac

[90] Q. Sun, Y. Turkan, and E. C. Fischer, “A building information modeling-fire dynamics simulation integrated framework for the simulation of passive fire protection in a mid-scale cross-laminated timber compartment: Numerical implementation and benchmarking,” *Fire and Materials*, vol. 47, no. 4, pp. 525–541, 2023. doi: 10.1002/fam.3070

[91] L. Wang, J. Wang, and H. Ge, “Wetting and drying performance of cross-laminated timber related to on-site moisture protections: Field measurements and hygrothermal simulations,” in *E3S Web of Conferences*, J. Kurnitski and T. Kalamees, Eds., EDP Sciences, 10003, 2020. doi: 10.1051/e3sconf/202017210003

[92] S. Wijesuriya, A. Nieto, and P. Tabares-Velasco, “Energy and hygrothermal analysis of cross laminated timber (CLT) mid-rise commercial buildings,” in *Thermal performance of the exterior envelopes of whole buildings*, Peachtree Corner GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), 2019. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85102996854&partnerID=40&md5=1d62e2cceff2c7991699442c97fbe3eb

[93] M. Yu, B. Wang, P. Ji, B. Li, L. Zhang, and Q. Zhang, “Simulation analysis of the circular sawing process of medium density fiberboard (MDF) based on the Johnson–Cook model,” *European Journal of Wood and Wood Products*, vol. 82, no. 2, pp. 447–459, 2024. doi: 10.1007/s00107-023-02007-5

[94] Z. Zhang and K. Lan, “Understanding the impacts of plant capacities and uncertainties on the techno-economic analysis of cross-laminated timber production in the southern U.S.,” *Journal of Renewable Materials*, vol. 10, no. 1, pp. 53–73, 2022. doi: 10.32604/jrm.2022.017506

[95] D. Huang, S. L. Pei, and A. Busch, “Optimizing displacement-based seismic design of mass timber rocking walls using genetic algorithm,” *Engineering Structures*, vol. 229, 111603, 2021. doi: 10.1016/j.engstruct.2020.111603

[96] R. K. Adhikari, N. C. Poudyal, C. Brandeis, and P. Nepal, “Identifying optimal locations for hardwood CLT plants in Tennessee: Application of a spatially explicit framework,” *Forest Products Journal*, vol. 73, no. 3, pp. 219–230, 2023. doi: 10.13073/FPJ-D-23-00010

[97] K. Brandt, A. Wilson, D. Bender, J. D. Dolan, and M. P. Wolcott, “Techno-economic analysis for manufacturing cross-laminated timber,” *Bioresources*, vol. 14, no. 4, pp. 7790–7804, 2019. doi: 10.15376/biores.14.4.7790-7804

[98] N. Khanal *et al.*, “Analysis of location, feedstock availability, and economic impacts of potential mass timber processing facilities in Michigan,” *Forest Policy and Economics*, vol. 163, 103203, 2024. doi: 10.1016/j.forpol.2024.103203

[99] M. K. Kuzman *et al.*, “Impact of COVID-19 on wood-based products industry: An exploratory study in Slovenia, Croatia, Serbia, and BiH,” *Wood Material Science & Engineering*, vol. 18, no. 3, pp. 1115–1126, 2023. doi: 10.1080/17480272.2022.2109210

[100] T. J. Venn, J. W. Dorries, R. L. McGavin, and W. Leggate, “Impact of facility location on the financial performance of integrated and distributed LVL production in subtropical Eastern Australia,” *Forests*, vol. 13, no. 11, 1903, 2022. doi: 10.3390/f13111903

[101] F. Böck, “Green gold of Africa — Can growing native bamboo in Ethiopia become a commercially viable business?” *Forestry Chronicle*, vol. 90, no. 5, pp. 628–635, 2014. doi: 10.5558/tfc2014-127

[102] A. Campbell, “Mass timber in the circular economy: Paradigm in practice?” *Proceedings of the Institution of Civil Engineers: Engineering Sustainability*, vol. 172, no. 3, pp. 141–152, 2018. doi: 10.1680/jensu.17.00069

[103] J. Tumbaga, V. Vimonsatit, and J. R. Lopez, “Trends in sustainable practices in the construction industry using green star certified buildings data,” in *Proceedings of International Structural Engineering and Construction*, K. Holschemacher, U. Quapp, A. Singh, and S. Yazdani, Eds., ISEC Press, 2022, SUS-05. doi: 10.14455/ISEC.2022.9(1).SUS-05

[104] N. Ahn *et al.*, “Envisioning mass timber buildings for circularity: Life cycle assessment of a mass timber building with different end-of-life (EOL) and post-EOL options,” in *13th World Conference on Timber Engineering, WCTE 2023*, A. Q. Nyrud, K. A. Malo, K. Nore, K. W. L. Alsen, S. Tulebekova, E. R. Staehr, G. Bergh, and W. Wuyts, Eds., 2023, pp. 3581–3587. doi: 10.52202/069179-0466

[105] S. Atnoorkar, O. A. Ghatpande, S. L. Haile, H. E. Goetsch, and C. B. Harris, “Carbon intensity of mass timber materials: Impacts of sourcing and transportation,” *Frontiers in Built Environment*, vol. 9, 2024. doi: 10.3389/fbuil.2023.1321340

[106] W. F. Baker, D. R. Horos, B. M. Johnson, and J. A. Schultz, “Timber tower research: Concrete jointed timber frame,” in *Structures Congress 2014 — Proceedings of the 2014 Structures Congress*, G. R. Bell and M. A. Card, Eds., American Society of Civil Engineers (ASCE), 2014, pp. 1255–1266. doi: 10.1061/9780784413357.113

[107] A. T. Balasbaneh and W. Sher, “Comparative sustainability evaluation of two engineered wood-based construction materials: Life cycle analysis of CLT versus GLT,” *Building and Environment*, vol. 204, 108112, 2021. doi: 10.1016/j.buildenv.2021.108112

[108] A. T. Balasbaneh, W. Sher, D. Yeoh, and K. Koushfar, “LCA & LCC analysis of hybrid glued laminated timber-concrete composite floor slab system,” *Journal of Building Engineering*, vol. 49, 104005, 2022. doi: 10.1016/j.jobe.2022.104005

[109] A. T. Balasbaneh, W. Sher, D. Yeoh, and M. N. Yasin, “Economic and environmental life cycle perspectives on two engineered wood products: Comparison of LVL and GLT construction materials,” *Environmental Science and Pollution Research*, vol. 30, no. 10, pp. 26964–26981, 2023. doi: 10.1007/s11356-022-24079-1

[110] R. D. Bergman and S. A. Bowe, “Life cycle inventory of manufacturing prefinished engineered wood flooring in eastern US with comparison to solid strip wood flooring,” *Wood and Fiber Science*, vol. 43, no. 4, pp. 421–441, 2011. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-80155157601&partnerID=40&md5=047547ef5d040f5e521e59ee98b63790

[111] R. D. Bergman and S. Alanya-Rosenbaum, “Cradle-to-gate life-cycle assessment of composite I-joist production in the United States,” *Forest Products Journal*, vol. 67, no. 5–6, pp. 355–367, 2017. doi: 10.13073/fpj-d-16-00047

[112] R. Chaggaris, S. Pei, G. Kingsley, and A. Feitel, “Carbon impact and cost of mass timber beam-column gravity systems,” *Sustainability*, vol. 13, no. 23, 12966, 2021. doi: 10.3390/su132312966

[113] C. X. Chen, F. Pierobon, S. Jones, I. Maples, Y. Gong, and I. Ganguly, “Comparative life cycle assessment of mass timber and concrete residential buildings: A case study in China,” *Sustainability*, vol. 14, no. 1, 144, 2022. doi: 10.3390/su14010144

[114] T. Connolly, C. Loss, A. Iqbal, and T. Tannert, “Feasibility study of mass-timber cores for the UBC tall wood building,” *Buildings*, vol. 8, no. 8, 98, 2018. doi: 10.3390/buildings8080098

[115] F. Dolezal, I. Dornigg, M. Wurm, and H. Figl, “Overview and main findings for the Austrian case study,” *Sustainability*, vol. 13, no. 14, 7584, 2021. doi: 10.3390/su13147584

[116] Z. Duan, Q. Huang, Q. Sun, and Q. Zhang, “Comparative life cycle assessment of a reinforced concrete residential building with equivalent cross laminated timber alternatives in China,” *Journal of Building Engineering*, vol. 62, 105357, 2022. doi: 10.1016/j.jobe.2022.105357

[117] Z. Duan, Q. Huang, and Q. Zhang, “Life cycle assessment of mass timber construction: A review,” *Building and Environment*, vol. 221, 109320, 2022. doi: 10.1016/j.buildenv.2022.109320

[118] S. H. Farjana, O. Tokede, Z. Tao, and M. Ashraf, “Life cycle assessment of end-of-life engineered wood,” *Science of the Total Environment*, vol. 887, 164018, 2023. doi: 10.1016/j.scitotenv.2023.164018

[119] L. Felicioni, J. Gaspari, J. Veselka, and Z. Malík, “A comparative cradle-to-grave life cycle approach for addressing construction design choices: An applicative case study for a residential tower in Aalborg, Denmark,” *Energy and Buildings*, vol. 298, 113557, 2023. doi: 10.1016/j.enbuild.2023.113557

[120] M. Hemmati, T. Messadi, and H. Gu, “Life cycle assessment of cross-laminated timber transportation from three origin points,” *Sustainability*, vol. 14, no. 1, 336, 2022. doi: 10.3390/su14010336

[121] M. Hemmati, T. Messadi, and H. Gu, “Life cycle assessment of the construction process in a mass timber structure,” *Sustainability*, vol. 16, no. 1, 262, 2024. doi: 10.3390/su16010262

[122] I. Hens, R. Solnosky, and N. C. Brown, “Design space exploration for comparing embodied carbon in tall timber structural systems,” *Energy and Buildings*, vol. 244, 110983, 2021. doi: 10.1016/j.enbuild.2021.110983

[123] T. Hull and D. Lacroix, “Analytical investigation of the potential of hollowcore mass timber panels for long span floor systems,” in *Lecture notes in civil engineering*, S. Walbridge, M. Nik-Bakht, K. T. Ng, M. Shome, M. S. Alam, A. El Damatty, and G. Lovegrove, Eds., Berlin, Germany: Springer Science and Business Media, 2023, pp. 621–633. doi: 10.1007/978-981-19-0511-7_52

[124] A. Jensen, L. Norford, and J. Grinham, "Mass(ive) timber: Examining the thermally massive behavior of mass timber construction," *Technology Architecture and Design*, vol. 4, no. 2, pp. 186–199, 2020. doi: 10.1080/24751448.2020.1804763

[125] A. Jensen, Z. Sehovic, N. St. Clair Knobloch, J. Klein, P. Richardson, and J. Janiski, "Mass timber solutions for eight story mixed-use buildings: A comparative study of GHG emissions," in *PLEA 2020 — 35th PLEA Conference on Passive and Low Energy Architecture Planning Post Carbon Cities, Proceedings*, 2020, pp. 1400–1405. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85132567418&partnerID=40&md5=541b0ebc8e8b17b778f07418b3861a0d

[126] S. Kontra *et al.*, "Design and cradle-to-grave life-cycle assessment: Full-scale six-story shake-table test building lateral systems," in *13th World Conference on Timber Engineering, WCTE 2023*, A. Q. Nyrud, K. A. Malo, K. Nore, K. W. L. Alsen, S. Tulebekova, E. R. Staehr, G. Bergh, and W. Wuyts, Eds., 2023, pp. 1009–1016. doi: 10.52202/069179-0138

[127] V. Kumar, M. Lo Ricco, R. D. Bergman, P. Nepal, and N. C. Poudyal, "Environmental impact assessment of mass timber, structural steel, and reinforced concrete buildings based on the 2021 international building code provisions," *Building and Environment*, vol. 251, 111195, 2024. doi: 10.1016/j.buildenv.2024.111195

[128] H. R. Lu, A. El Hanandeh, and B. P. Gilbert, "A comparative life cycle study of alternative materials for Australian multi-storey apartment building frame constructions: Environmental and economic perspective," *Journal of Cleaner Production*, vol. 166, pp. 458–473, 2017. doi: 10.1016/j.jclepro.2017.08.065

[129] R. N. Passarelli and M. Koshihara, "Mass timber system in Japan: Environmental and economic impact of a mid-storey residential building," in *WCTE 2018 — World Conference on Timber Engineering*, 2018. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85058196927&partnerID=40&md5=b0948333e4dcb7fadb8f1154f82f55b9

[130] R. Pommier, G. Grimaud, M. Prinçaud, N. Perry, and G. Sonnemann, "LCA (life cycle assessment) of EVP — engineering veneer product: Plywood glued using a vacuum moulding technology from green veneers," *Journal of Cleaner Production*, vol. 124, pp. 383–394, 2016. doi: 10.1016/j.jclepro.2016.02.130

[131] E. E. Rohde, D. B. Roueche, K. C. Sener, and B. K. Via, "Benchmark life-cycle and constructability assessment of composite steel-timber systems," in *13th World Conference on Timber Engineering, WCTE 2023*, A. Q. Nyrud, K. A. Malo, K. Nore, K. W. L. Alsen, S. Tulebekova, E. R. Staehr, G. Bergh, and W. Wuyts, Eds., 2023, pp. 1027–1033. doi: 10.52202/069179-0140

[132] K. Sahoo, R. Bergman, S. Alanya-Rosenbaum, H. Gu, and S. Liang, "Life cycle assessment of forest-based products: A review," *Sustainability*, vol. 11, no. 17, 2019. doi: 10.3390/su11174722

[133] M. Abolghassem Tehrani and T. M. Froese, "A comparative life cycle assessment of tall buildings with alternative structural systems: Wood vs. concrete," in *6th CSCE-CRC International Construction Specialty Conference 2017 — held as part of the Canadian Society for Civil Engineering Annual Conference and General Meeting 2017*, Canadian Society for Civil Engineering, 2017, pp. 19–28. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85047094911&partnerID=40&md5=2bdbb3548d696989e5070e72cb6a9ac7

[134] J. Thinley and S. Hengrasmee, "Innovating Bhutan's residential construction with mass timber for economic and environmental sustainability," *Journal of Building Engineering*, vol. 78, 107763, 2023. doi: 10.1016/j.jobe.2023.107763

[135] I. Vamza, F. Diaz, P. Resnais, A. Radziņa, and D. Blumberga, "Life cycle assessment of reprocessed cross laminated timber in Latvia," *Environmental and Climate Technologies*, vol. 25, no. 1, pp. 58–70, 2021. doi: 10.2478/rtuect-2021-0005

[136] R. Vaňová and J. Štefko, "Assessment of selected types of the structural engineered wood production from the environmental point of view," *Acta Facultatis Xylologiae Zvolen*, vol. 63, no. 2, pp. 117–130, 2021. doi: 10.17423/afx.2021.63.2.10

[137] R. Vanova, P. Stompf, J. Stefko, and J. Stefkova, "Environmental impact of a mass timber building — A case study," *Forests*, vol. 12, no. 11, 2021. doi: 10.3390/f12111571

[138] K. Nakano, W. Koike, K. Yamagishi, and N. Hattori, "Environmental impacts of cross-laminated timber production in Japan," *Clean Technologies and Environmental Policy*, vol. 22, no. 10, pp. 2193–2205, 2020. doi: 10.1007/s10098-020-01948-2

[139] Cape Peninsula University of Technology, "Faculty of Engineering & the Built Environment 2023," *Cape Peninsula University of Technology*, 2023. Accessed: May 18, 2024. [Online]. Available: https://www.cput.ac.za/storage/faculties/engineering/documents/FEBE%20Faculty%20Handbook%202023-Web.pdf

[140] Durban University of Technology, “Industrial Engineering Handbook 2024,” *Durban University of Technology — Faculty of Engineering and the Built Environment*, 2024. Accessed: May 18, 2024. [Online]. Available: https://www.dut.ac.za/wp-content/uploads/handbooks/ EBE Industrial Engineering.pdf

[141] North-West University, “Faculty of Engineering Undergraduate Handbook 2024,” *North- West University,* 2024. Accessed: May 18, 2024. [Online]. Available: https://studies.nwu.ac.za/sites/studies.nwu.ac.za/files/files/yearbooks/2024/FENG-UG-2024-24-Jan-New-ARules-2024-v1.pdf

[142] North-West University, “Faculty of Engineering Postgraduate Handbook 2024,” *North- West University*, 2024. Accessed: May 18, 2024. [Online]. Available: https://studies.nwu.ac.za/sites/studies.nwu.ac.za/files/files/yearbooks/2024/FENG-PG-2024.pdf

[143] Stellenbosch University, “Engineering Yearbook Part 11 2024,” *Stellenbosch University*, 2024. Accessed: May 18, 2024. [Online]. Available: https://ie.sun.ac.za/wp-content/uploads/2023/12/2024-Engineering.pdf

[144] University of Pretoria, “University of Pretoria Yearbook 2024, BEng (Industrial Engineering),” *University of Pretoria,* 2024. Accessed: May 18, 2024. [Online]. Available: https://www.up.ac.za/yearbooks/2024/pdf/programme/12130001

[145] University of Pretoria, “University of Pretoria Yearbook 2024, BEngHons Industrial Engineering,” *University of Pretoria,* 2024. Accessed: May 18, 2024. [Online]. Available: https://www.up.ac.za/yearbooks/2024/pdf/programme/12240012

[146] Tshwane University of Technology, “2024 Prospectus Part 4 Engineering and the Built Environment,” *Tshwane University of Technology,* 2024. Accessed: May 18, 2024. [Online]. Available: https://www.tut.ac.za/media/docs/Engineering%20and%20the%20Built%20Environment_Prospectus_2024.pdf

[147] Vaal University of Technology, “Engineering and Technology Prospectus 2024,” *Vaal University of Technology,* 2024. Accessed: May 18, 2024. [Online]. Available: https://www.vut.ac.za/wp-content/uploads/2023/09/Prospectus-2024-FET.pdf

[148] K. Goldberg, “What is automation?” *IEEE Transactions on Automation Science and Engineering*, vol. 9, no. 1, pp. 1–2, 2012. doi: 10.1109/TASE.2011.2178910

[149] A. B. Badiru, *Handbook of industrial and systems engineering*. CRC Press, 2005.

[150] O. C. Madubuike, C. J. Anumba, and R. Khallaf, “A review of digital twin applications in construction,” *Journal of Information Technology in Construction*, vol. 27, pp. 145–172, 2022. doi: 10.36680/j.itcon.2022.008

[151] B. Xiao, C. Chen, and X. Yin, “Recent advancements of robotics in construction,” *Automation in Construction*, vol. 144, 104591, 2022. doi: 10.1016/j.autcon.2022.104591

[152] Z. Wang, H. Hu, and W. Zhou, “RFID enabled knowledge-based precast construction supply chain,” *Computer-Aided Civil and Infrastructure Engineering*, vol. 32, no. 6, pp. 499–514, 2017. doi: 10.1111/mice.12254

[153] S. Winge and E. Albrechtsen, “Accident types and barrier failures in the construction industry,” *Safety Science*, vol. 105, pp. 158–166, 2018. doi: 10.1016/J.SSCI.2018.02.006

[154] B. Hoła, T. Nowobilski, I. Szer, and J. Szer, “Identification of factors affecting the accident rate in the construction industry,” *Procedia Engineering*, vol. 208, pp. 35–42, 2017. doi: 10.1016/J.PROENG.2017.11.018

[155] Z. Zhou, J. Irizarry, and Q. Li, “Applying advanced technology to improve safety management in the construction industry: A literature review,” *Construction Management and Economics*, vol. 31, no. 6, pp. 606–622, 2013. doi: 10.1080/01446193.2013.798423

[156] *L. Levine, Worker safety in the construction industry: The crane and derrick standard*, Order Code RL34658, Congressional Research Service, Washington DC, 2008.

[157] D. Albright, E. Hall, Y. Song, W. Pang, and M. Stoner, “Direct housing for post-disaster recovery: Design and logistics for alternative solutions,” *Building Technology Educators’ Society,* vol. 1, pp. 246-253, 2023. doi: https://doi.org/10.7275/btes.1959

[158] E. Tekavec *et al.*, “Adverse health manifestations in the hands of vibration exposed carpenters — A cross sectional study,” *Journal of Occupational Medicine and Toxicology,* vol. 16, no. 1, 16, 2021. doi: 10.1186/s12995-021-00305-3

[159] J. Priede, “Implementation of quality management system ISO 9001 in the world and its strategic necessity,” *Procedia - Social and Behavioural Sciences*, vol. 58, pp. 1466–1475, 2012. doi: 10.1016/J.SBSPRO.2012.09.1133

[160] M. A. S. Hiyassat, “Applying the ISO standards to a construction company: A case study,” *International Journal of Project Management*, vol. 18, no. 4, pp. 275–280, 2000. doi: 10.1016/S0263-7863(99)00051-4

[161] A. Polenghi, L. Fumagalli, and I. Roda, “Role of simulation in industrial engineering: Focus on manufacturing systems,” *IFAC-PapersOnLine*, vol. 51, no. 11, pp. 496–501, 2018. doi: 10.1016/J.IFACOL.2018.08.367

[162] P. D. Kremer and M. A. Symmons, “Mass timber construction as an alternative to concrete and steel in the Australia building industry: A PESTEL evaluation of the potential,” *International Wood Products Journal*, vol. 6, no. 3, pp. 138–147, 2015.

[163] S. Durdyev, S. R. Mohandes, S. Tokbolat, H. Sadeghi, and T. Zayed, “Examining the OHS of green building construction projects: A hybrid fuzzy-based approach,” *Journal of Cleaner Production*, vol. 338, 130590, 2022. doi: 10.1016/j.jclepro.2022.130590

[164] H. T. Thai, T. Ngo, and B. Uy, “A review on modular construction for high-rise buildings,” *Structures*, vol. 28, pp. 1265–1290, 2020. doi: 10.1016/J.ISTRUC.2020.09.070

[165] Z. C. Lefever, “Sustainable architecture in athletics: Using mass timber in an old-fashioned field,” Master’s thesis, University of Massachusetts, Amhurst MA, 2023.