Uludağ University Journal of The Faculty of Engineering, Vol. 29, No. 1, 2024 REVIEW

DOI: 10.17482/uumfd.1354025

TRENDS AND FUTURE DIRECTIONS OF RISK MANAGEMENT APPROACHES APPLIED IN MODULAR CONSTRUCTION PROJECTS: SYSTEMATIC REVIEW AND META-ANALYSIS

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Received: 01.09.2023 ; revised: 04.01.2024 ; accepted: 13.02.2024

Abstract: In modular construction, given the different undertakings compared to conventional construction, the latter deems less risky. However, the current industry is faced with malpractices which are loopholes disabling full capacity performance. There is a noticeable lack of studies specifically analyzing the risk management approaches. This study aims to vigorously analyze all risk management approaches applied in previous projects by compiling qualitative and quantitative content for the eased risk assessment of modular projects. By performing a systematic literature review and meta-analysis, 175 documents were finalized and manually analyzed. Synthesis of the literature was carried out to generate graphs, illustrations, and tabularized content, followed by critical explanation for relevant risk management approaches identified according to risk category and project criteria. Risk management approaches for modular construction were showcased in terms of yearly trends, geographic involvement, keywords mostly encountered, and universities and institutions involvement. Classified risk management approaches were tabularized alongside a research domain targeting technical risk management approaches. Future work scopes were suggested with percentage initiations from analyzed studies. This study is a fundamental steppingstone in broadening knowledge on risk management approaches of modular construction and will aid both academicians and practitioners to get direct insights on current trends with project-oriented results showcased.

Keywords: Modular construction, Offsite construction, Project management, Prefabrication, Meta-analysis, Risk management

Modüler inşaat projelerinde uygulanan risk yönetimi yaklaşımlarının eğilimleri ve gelecek yöntemleri: Sistematik inceleme ve meta analizi

Öz: Modüler inşaatta, geleneksel inşaata kıyasla farklı taahhütler göz önüne alındığında, ikincisi daha az riskli kabul edilir. Bununla birlikte, mevcut endüstri, tam kapasite performansını devre dışı bırakan boşluklar olan yanlış uygulamalarla karşı karşıyadır. Özellikle risk yönetimi yaklaşımlarını analiz eden çalışmalardan dikkat çekici bir eksiklik vardır. Bu çalışma, modüler projelerin kolaylaştırılmış risk değerlendirmesi için niteliksel ve niceliksel içerik derleyerek önceki projelerde uygulanan tüm risk yönetimi yaklaşımlarını güçlü bir şekilde analiz etmeyi amaçlamaktadır. Sistematik bir literatür taraması ve meta-analiz gerçekleştirilerek 175 dokümana son şekli verilmiş ve manuel olarak analiz edilmiştir. Literatürün sentezi, grafikler, resimler ve tablolaştırılmış içerik oluşturmak için gerçekleştirilmiştir, ardından risk kategorisi ve proje kriterlerine göre belirlenen ilgili risk yönetimi yaklaşımları için eleştirel açıklama yapılmıştır. Modüler yapı için risk yönetimi yaklaşımları, yıllık trendler, coğrafi katılım, en çok karşılaşılan anahtar kelimeler ve üniversiteler ve kurumların katılımı açısından sergilendi. Sınıflandırılmış risk yönetimi yaklaşımları, teknik risk yönetimi yaklaşımlarını hedefleyen bir araştırma alanının yanında tablolaştırılmıştır. Gelecekteki çalışma kapsamları, analiz edilen çalışmalardan başlama yüzdeleri ile önerildi. Bu çalışma, modüler yapının risk yönetimi yaklaşımları hakkındaki bilgileri genişletmek için temel bir adımdır ve hem akademisyenlerin hem de uygulayıcıların, sergilenen proje odaklı sonuçlarla mevcut eğilimler hakkında doğrudan içgörüler elde etmelerine yardımcı olacaktır.

Anahtar Kelimeler: Modüler inşaat, Saha dışı inşaat, Proje yönetimi, Prefabrikasyon, Meta-analizi, Risk yönetimi

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1. INTRODUCTION

Precision in selecting risk management approaches that mitigate the risks is the path to tread for a value-adding modular construction project. The emerging modular construction sector has attained ample interest due to the plethora of benefits compared to traditional construction. Given the exorbitant cost aspect of traditional construction alongside scheduling hassle, the modular construction sector has proven to overcome those hurdles when correctly executed. Modular construction adopts a unique flow in the stages of construction. Raw materials in the inventory can be manipulated into elements and combined to form module components. As for the whole modules, which a building consists of, these are crafted based on the convenience of transportation and the vulnerability of the installation site. Off-site construction also has numerous environmental benefits (Jin et al., 2018, 2020), so it is categorized as sustainable.

Since the labor force has not dealt with similar workflow concepts before, the main concern arises when the latter adopts the “stick-built” method under a roof (Zhang et al., 2020). Consequently, this leads to exceeding the project’s budget and schedule. Awareness of the appropriate and most effective risk management approaches is crucial in maximizing the modular sector's actual benefits. Given this, the ever-growing interested bodies shifting to modular construction do not have an established guide for efficient risk management.

Studies did not consider the overall lifecycles of projects. Researchers looking deeper into which risk categories demand immediate attention, Gan et al. (2018) identified that stakeholders such as government and developers have the highest impact on tackling the latter. Accordingly, design risks not only hinder the quality and pace of production but also decrease the confidence of stakeholders to adopt off-site construction methods (Sutrisna et al., 2019). Effective communication and early involvement of stakeholders from the supply chain stage are the success determinants for modular integrated construction projects (Wuni et al., 2019). Intensive quantitative modeling of critical risk factors, critical success factors, barriers, and critical failure factors in modular construction was performed by Wuni et al., 2020 whereby comprehensive data was derived to aid the target audience. Whilst aiming to handle modular construction efficiently, a review of digital technologies with managerial integration sets the foundation for upcoming studies. Since the focus was laid on specific stages of a modular project, there is an obvious need for overall lifecycles consideration. (Olawumi et al., 2022). Although the mentioned studies have resulted in insightful data, limited work was seen in specific analysis of risk management approaches which are meticulously categorized according to project relevancy.

Since limited work was seen in holistic risk management approaches analysis., providing a clear pathway for key decision-makers is needed. This can start off by developing guidelines for industry practitioners to effectively deploy decision-making (Wuni et al., 2019). This study has the following aims: (1) qualitative analysis of literature published to date focusing on risk management of modular construction risks to clearly indicate risk management approaches for individuals in the AEC industry, (2) quantify data retrieved by performing a meta-analysis, (3) discussing on the feasible risk management approaches showing efficiency performance during integration, (4) showcasing technical risk management approaches found in the literature analysis with the relevant authors and stage during the project where the latter were implemented, and (5) providing future work scopes with percentage initiation based on current shown interest from the academy.

2. RESEARCH BACKGROUND

With due consideration to the different stages involved in modular construction and despite being an innovative method, risks are still involved (Li et al., 2013). Many populated countries have opted for modular construction, being a cleaner production strategy, to meet the demands of the citizens (Lu et al., 2018). Life Cycle Assessments (LCA) and simulations carried out determine, at the building operation phase, which monitored aspects handle environmental risks

(Zhu et al., 2018). Saad et al., 2021 suggest a qualitative framework based on concepts to aid the target audience in offsite construction. An educational and innovative early-on risk management approach was determined, which not only inculcates the knowledge in participants but also shows how scheduling, quality, and cost risks are tackled. The outputs of time optimized and meeting budgets were noticeable to participants keen to implement such techniques in real world projects (X. Li et al., 2018). Jang et al., 2021 mapped out insights to aid in achieving productivity for offsite projects. The stakeholder fragmentation and management complexity has ranked as first among the identified critical risk factors (Sun et al., 2020; Wuni et al., 2019). This deduction indicates which organizational level demands focus on risk management. Increased cost and risks are identified among major factors affecting the productivity of modular construction. Analyzing risks that impact the cost and scheduling of modular construction, shortage of skilled labor, and late design changes take the lead, and establishing mitigation plans early on is necessary (Abdul Nabi et al., 2021; Li, Li and Wu., 2017). As supported by Lee and Kim (2017), while carrying out a Failure Mode and Effects Analysis, half of the risk factors are workforce failures, and the cost risk increases alarmingly in the design phase. Similarly, rework risks analyzed in the Chinese prefabrication sector add to the industry's inefficiency (Shen et al., 2021). Prefabrication safety risks need attention (Jeong et al., 2021; Liu Q. et al., 2019). The occupant's health risks, such as overheating of modular projects should be handled urgently (Fifield et al., 2018). Inexperienced contractors dealing with multiple types of components in prefabrication, root for scheduling risks (Cho K. et al., 2021; Wong P. et al., 2021). Investment risks have seen less attention, but should be tackled for successful uptake of prefabrication (Li M. et al., 2017, Li X. et al., 2020).

3. RESEARCH METHODOLOGY

This study has adopted a systematic literature review as the methodology to attain qualitative input followed by meta-analysis to interpret the findings in a quantitative manner. Systematic literature reviews have the potential to clearly illustrate boundaries of scientific progress alongside current industrial practices in the research field (Wuni et al., 2019). This performed to shed light on existing mixed empirical findings involving large amounts of literature (Donthu et al., 2021). Figure 1 presents the research methodology adopted in the study.

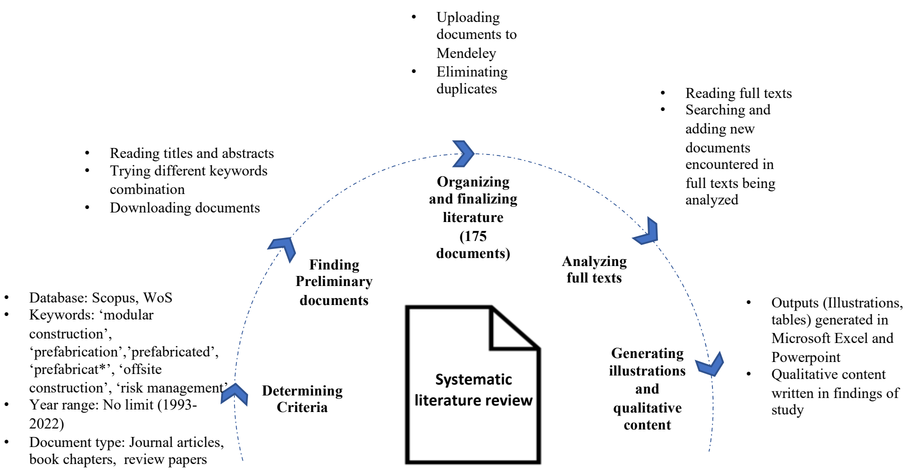

Figure 1:
Research methodology

4. RESULTS and DISCUSSION

4.1. Yearly publication trend

The graph in Figure 2 shows yearly trend in publications relating to risk management in modular construction. With developments and academic diversity, modular construction reigned again. The ultimate interest was seen in 2021 with 55 documents.

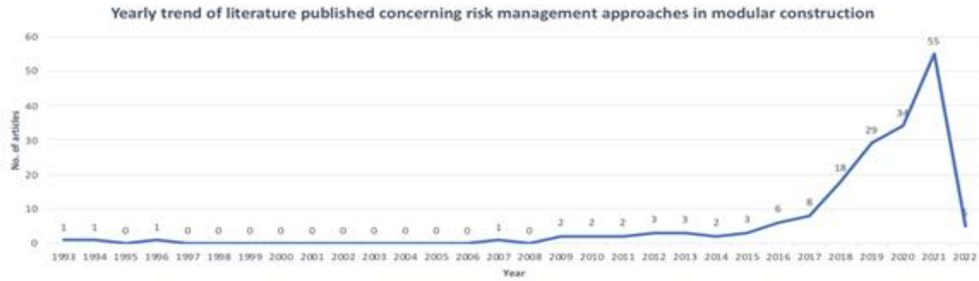

Figure 2:
Yearly trends of literature published

4.2. Geographic involvement

Figure 3 shows the geographical involvement of countries that participated in modular construction studies, and those consisting of 2 or more documents were included in the illustration. China is leading, indicating the eased availability of modern facilities, which smoothens the adoption and execution process of modular construction. The Hong Kong modular construction benefits from identified critical success factors for embedding a circular economy (Wuni and Shen, 2022). Hindrances to using prefabrication in Hong Kong were dissected, and new incentives were found (Zhang W. et al., 2018). Being the second most populated country worldwide, India's construction sector showed interest in modular construction techniques, which currently lack guidance and resources (Bendi et al., 2021). Australia has a potential interest in the sector (Steinhardt et al., 2016).

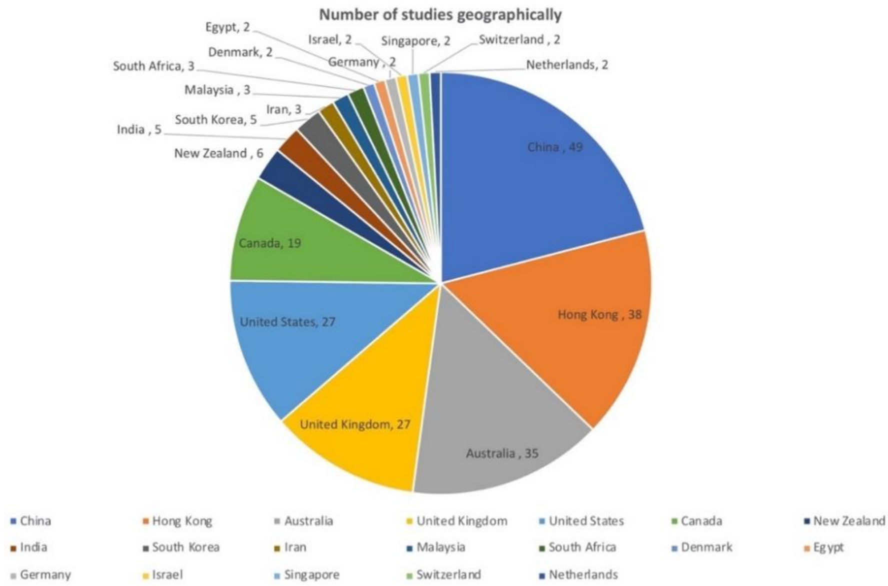

Figure 3:
Geaographic involvement

4.3. Frequently encountered keywords

Figure 5 shows an illustrative visual of the proportion occupied by keywords encountered more than 5 times. It was deduced that ‘prefabrication’ and ‘offsite manufacturing/construction’ were more implemented than ‘modular construction’. This could be due to the literal and direct meaning these words hold. A greater percentage appearance of ‘building information modeling’ was seen than ‘risk management’. The link between BIM and modular projects is abundant, given the success evidence seen. The appearance of keywords such as ‘Life Cycle Analysis (LCA),’ ‘Embodied carbon emission,’ ‘Carbon reduction,’ ‘Environmental performance,’ and ‘Construction waste’ depicts academic involvement to widen the sustainability scope. Frequent mentions of IoT and blockchain prove strong risk management abilities. BIM and lean methods’ collaboration have successfully tackled design or safety risks and ensured overall quality.

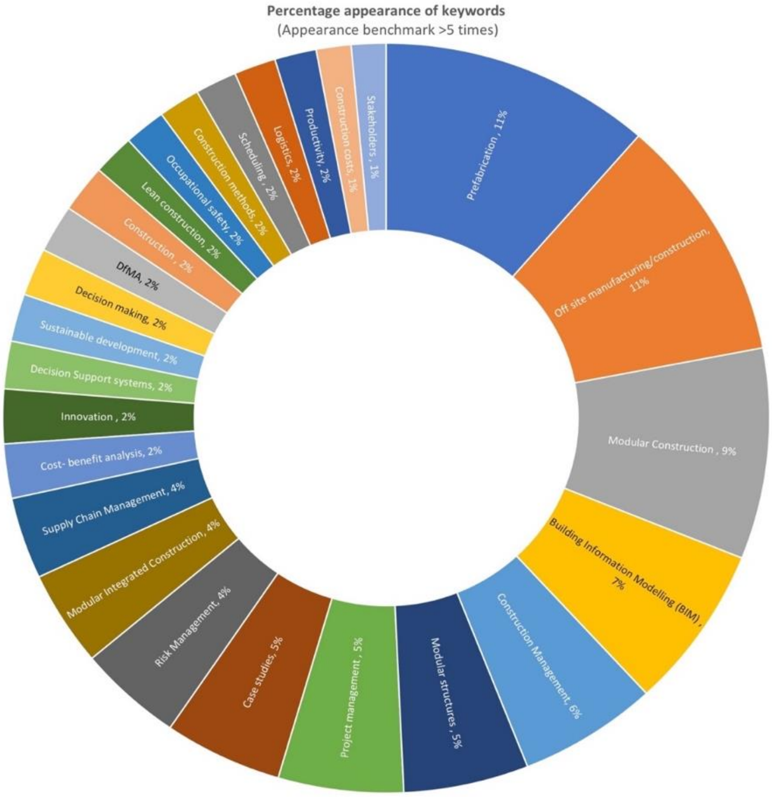

Figure 5:
Keywords frequency of appearance

4.3. Publications’ involvement

Figure 4 shows the involvement of journals, books, and reviews in the field of study. The platforms publishing greater than 2 documents were included in the illustration. Journal of Cleaner Production, known as a high-impact journal, takes the lead. This shows reliability in the content chosen for the literature review of this study as most documents were published in this journal. This high involvement rate proves the potential of modular construction projects in terms of sustainability. Automation in Construction ranks second, which relates to the ever-rising inclusion of digital tools in modular construction. The three journals that are ranked in the top five, Journal of Construction Engineering and Management, Engineering Construction and Architectural Management, and International Journal of Construction Management, show that good management is an important success factor in the field.

Figure 4:
Publications' involvement with the number of documents

4.4. Risk management approaches identified

The risk management process aids in the identification, early preparation, and monitoring of the risk implementation plan (Sutrisna and Goulding, 2019). This study provides meticulously arranged risk management approaches to risk categories and project criteria. Table 1 addresses the detailed risk management approaches trends with relevant reference to the academician.

Table 1. Risk management approaches identified.

Risk category	Risk target area	Risk management approaches	Project criteria for the according risk management approaches	References
Cost	Construction	DfMA	Prefabricated non-structural components of residential buildings	(Wasim et al., 2020), (Bao et al., 2021)
		BIM, Big data, DfMA	Off site construction	(Gbadamosi et al., 2020)
		SWOT analysis	Prefabrication in rural areas	(Zhou et al., 2019)
		Generic risk management framework	Modular construction buildings	(Li et al., 2013)
	Production management	Blockchain-enabled IoT-BIM platform	Off-site production sites	(Wu et al., 2022)
		Collaborative product development framework	Modular products	(Hung, Kao and Ku, 2007)
	Transportation	Optimization model	Modular healthcare facility, office, Commercial and educational buildings	(Almashaqbeh and El-Rayes, 2021), (Hsu et al., 2019)
		Construction site layout plans (CSLP) & genetic algorithm	Prefabricated buildings	(Lu and Zhu, 2021)
	Seismic	Seismic Damage Resisting System (SDRS)	Modular multi-storey building in seismic regions	(Ashcroft et al., 2019)
	Production flexibility	Resource planning algorithms	Off-site manufacturers with variation in demand and resource availability	(Arashpour et al., 2018)
Time	Construction	Last Planner System (LPS)	Modular offshore wind construction	(Lerche et al., 2020)

		DfMA	Prefabricated non-structural components of residential buildings	(Wasim et al., 2020), (Bao et al., 2021)
		BIM, Big data, DfMA	Off site construction	(Gbadamosi et al., 2020)
		Smart Work Packaging (SWP)	Prefabricated housing	(Xiao Li et al., 2019), (C. Z. Li et al., 2018)
		BIM- Lean framework	Modular construction buildings	(Barkokebas et al., 2021)
		RFID-enabled BIM platform	Prefabricated housing	(Li et al., 2017)
		Generic risk management framework	Modular construction buildings	(Li et al., 2013)
	Production management	Just in Time	Off site construction	(Si et al., 2021)
		Collaborative product development framework	Modular products	(Hung, Kao and Ku, 2007)
		Simulated annealing algorithms	Modular construction	(Chen et al., 2020)
Stakeholder	Stakeholder interaction	Information exchange platform	Highly populated developing countries and fragmented construction industry	(Gan et al., 2019)
		Blockchain-enabled cyber-physical smart MiC platform	Modular integrated buildings	(Jiang et al., 2021)
		SNA-based risk management approach	Prefabricated buildings	(Lu and Yuan, 2013)
Design	Design	Detailed framework on Information feeding at design phase	Prefabricated schools in developed countries	(Sutrisna and Goulding., 2019)
		Construction Method Selection Model (CMSM)	Concrete prefabricated buildings	(Chen et al., 2010)
Supply chain	Supply chain	Communication, information sharing, early involvement	Modular integrated buildings	(Wuni and Shen., 2021), (Bao et al., 2021)
		Blockchain-enabled IoT-BIM platform	Modular construction buildings	(Li et al., 2022)
	Supply chain (Schedule risk)	Digital twin framework with BIM, IoT sensors and GIS	Modular project with full modules transportation	(Lee and Lee., 2021), (Zhou et al., 2021)
		Two-stage stochastic programming	Modular construction	(Hsu et al., 2018)
	Supply chain (Cost mitigation, quality guarantee)	Locally made material, Components based prefabrication	Low rise residential buildings	(Lin et al., 2021)
Governmental	Governmental inclusion	Add to emergency response plan (given speedy delivery), renovate with prefabrication methods, demonstrate success case for robust conclusions	Prefabricated housing	(Steinhardt and Manley, 2016)
Safety	Safety	Safety Performance Cloud Model Evaluation	Prefabricated buildings	(Liu et al., 2018)
		Construction site layout plans (CSLP) & genetic algorithm	Prefabricated buildings	(Lu and Zhu, 2021)
		Noise risk assessment & probability based modelling	Modular construction	(Chen et al., 2020)
		Kaizen	Modular housing	(James et al., 2014), (Nahmens and Ikuma., 2011, 2012)
		Digital twin framework with BIM and IoT	Prefabricated building Hoisting	(Liu et al., 2021)
		Bayesian Network probabilistic model	Off site manufacturing	(Vithanage et al., 2022)
	Ergonomic	Automated post-3D visualization ErgoSystem	Modularized projects	(Xinming Li et al., 2019), (Golabchi et al., 2015)
Geometric	Geometric	Probability impact risk model	Modularized projects	(Rausch et al., 2019), (Enshassi et al., 2019, 2020), (Shoval and Efatmaneshnik, 2019), (Shahtaheri et al., 2017)

		Object detection with deep learning algorithms	Construction sites for modular projects	(Liu et al., 2022)
Operational	Managerial (Waste management)	Extended producer responsibility (EPR) analytical framework	Offshore prefabrication construction	(Xu et al., 2021), (Lu and Yuan, 2013)
	Maintenance (structural)	BIM based data management system	Modular construction buildings	(Valinejadshoubi et al., 2019)
Environmental	Environmental	Two-period based carbon-economy equilibrium strategy	Modular products	(Zhu et al., 2021)
	Environmental (Carbon emission)	A Data Quality Index based Monte Carlo Simulation	Prefabricated high rise buildings	(Teng and Pan, 2020)
Quality	Quality	BIM & DfMA	Off site construction	(Bakhshi et al., 2022)
		BIM based automated design and drafting of wood panels	Modular residential buildings	(Alwisy et al., 2019)
		Risk management system with deep learning modified teaching-learning-based optimization	Prefabricated buildings	(Liu et al., 2020)

Using BIM involvement:

BIM was often encountered in real-time projects and academic fields of offsite construction (Yin et al., 2019). BIM authoring software such as Revit, Bentley, and ArchiCAD are adopted by construction practitioners, given the usage flexibility. Factors impacting the application of BIM country-wise should be investigated to facilitate integration in prefabrication (Gong et al., 2021). In the initial phases, BIM was chosen to portray data about the project and suppliers with integration to set criteria. Hereafter, the Analytical Hierarchy Process determines the best supplier for the project (Zhao et al., 2019). An automated BIM-based wood panel drafting and design handles quality risks in residential modular buildings (Alwisy et al., 2019). Targeting clearer data sharing and communication between organizational levels, Gbadamosi et al. (2020) developed a framework combining BIM, DfMA (Design for Manufacture and Assembly), and Big data to showcase information flow and design alternatives. The framework enabled all stakeholders, including clients, to see the model and attributes during the mounting process. Any point can be dealt with instantly, mitigating scheduling, quality, and cost risks (Bakhshi et al., 2022). Blockchain-enabled IoT-BIM platforms are guaranteed risk management approach while tackling cost risks and ensuring the provenance of BIM modifications from multi-sources while escaping ‘single point of failure’ issues accompanying IoT networks (Wu et al., 2022). The supply chain management performed using Blockchain-enabled IoT-BIM platforms reduced cost risks otherwise faced as storage costs (Li et al., 2022). A blockchain-enabled cyber-physical smart MiC platform with digital twin incorporation has aimed to tackle stakeholders' risks by improving information reliability and transparency (Jiang et al., 2021). To handle schedule risks, an RFID-enabled BIM platform eases the overall process with collaboration at all organizational levels and real-time data-capturing construction details (Li C. et al., 2017). A BIM-based data management system allows monitoring of the structural health of modular components with data being sent via sensors attached (Valinejadshoubi et al., 2019). BIM platforms’ potential in interoperability, efficient risk management, and early integration abilities leads to the full performance of modular construction.

IoT, sensors, and GIS:

Lee and Lee, 2021 derived a framework involving the digital twin of the building via BIM platforms integrated with IoT sensors and tracking of transportation via GIS. This framework predicts accurate arrival times of modules to the site from the factory and boosts supply chain coordination. With GPS tags and an integrated IoT risk management approach, real-time capture of progress at work promotes eased decision-making (Zhou et al., 2021). The BIM and IoT framework focused on safety at work, monitored the hoisting process, and optimized workers' safety (Liu et al., 2021). Using the mentioned technologies eliminates non-value-adding activities and enables offsite and onsite teams to collaborate.

Adopting lean methods:

Wasim et al., 2020 applied the Design for Manufacture and Assembly (DfMA) principles to analyze cost risks in a prefabricated residential project. While this was linked to better risk management, scheduling risk also benefitted. Bao et al., 2021 suggest DfMA enablers such as early collaboration and simplistic design approaches to hinder prolonged project delivery. The lean tool, Kaizen, can significantly tackle safety risks (Nahmens and Ikuma., 2011, 2012 and James et al., 2014). Value Stream Mapping (VSM) proves the possibility of achieving modular construction timelines with integration to BIM platforms at all organizational levels (Barkokebas et al., 2021). Schedule risks were successfully handled with the Last Planner System (LPS) applied in a modular offshore wind construction (Lerche et al., 2020). Just in Time, a lean tool was adapted to form a component delivery framework hindering scheduling risks (Si et al., 2021). Integrated design and construction project delivery have proven to tackle risks early on, however, practitioners in the off-site construction sector indicated the necessity of having experience (Wu P. et al., 2019).

Early involvement:

Collaboration between research groups, designers, builders, clients, and suppliers can direct a project toward significant success rates while mitigating risks (Nolan., 2018). Vendor involvement enables handling execution risks (Choi J. et al., 2016). With this implementation, project risks can be mitigated (Wuni and Shen., 2021; Bao et al., 2021). SWOT (strengths, weaknesses, opportunities, and threats) analysis can be performed early on, especially in rural areas where prefabrication will be implemented. This would enable determining success scopes and have better managerial scopes (Zhou et al., 2019). Procurement risks can be handled using procurement models aiding in identifying barriers to the offsite sector and taking novel measures (Charlson J. et al., 2021). A framework for collaborative product development and production of modular products was developed linking customer demands until achieving optimal choice. This efficient approach can be incorporated in the design and manufacturing stages (Hung et al., 2007). The extended producer responsibility (EPR) analytical framework allows early on ability for offshore extended producer responsibility to be analyzed, agreed upon, and allocated. Benefits to sustainability aspects are expected too due to less waste generation (Xu et al., 2021 and Lu and Yuan., 2013). Early involvement of every stakeholder promotes the eradication of reworks.

Optimization models:

To minimize transportation costs and storage of materials, an optimization model states the accurate arrangement of storage areas, vehicles position and arrival times, optimal warehouse location and favorable assembly phases (Almashaqbeh and El-Rayes, 2021a, 2021b; Hsu et al., 2019). Being generic, the concept can be applied to multiple project types. Mathematical optimization models tackle scheduling risks in modular construction factories (Hammad et al., 2020). Construction site layout plans (CSLP) supported by genetic algorithms has tackled the safety and cost risks related to transportation in prefabrication due to the optimized hoisting usage suggestions (Lu and Zhu, 2021). A Construction Method Selection Model (CMSM) determines the feasibility of a project and suggests alternatives accordingly (Chen Y. et al., 2010). Applying a programming model during logistics planning for waste management of offsite production, Zhao and Ke., 2019, tackle environmental risks. Hsu et al., 2018 use a two-stage stochastic programming approach to allow for logistics planning and mitigate schedule risks for massive modular projects leaving environmental impacts. A two-period-based carbon-economy equilibrium strategy for modular construction tackles environmental risks by establishing optimal construction schemes focused on reducing carbon emissions (Zhu et al., 2021). Simulated annealing algorithms allow for the coordination of the scheduled performance of offsite and onsite teams. The latter can optimize scenarios and give construction managers alternatives (Chen W. et al., 2020). Object detection from deep learning algorithms significantly improves factory monitoring and diminishes errors (Liu et al., 2022). Due to uncertainties in the manufacturing sector, usage of probabilistic methods will support the optimized process based on project criteria (Arashpour et al., 2018). Safety risks can cause significant harm to the labor force leading to cost overruns. Safety Performance Cloud Model Evaluation deals with fuzziness and randomness to picture the most realistic outputs for actualization (Liu et al., 2018). Focussing on workers' well-being, an optimization framework has been derived to determine the best-fit design options (Zaalouk and Han, 2021).

Probabilistic methods and simulation:

The tolerance behavior in prefabrication can be predicted with Monte Carlo tolerance simulation. Thus, concerned individuals analyze alternatives and handle the rework risks (Rausch et al., 2019, Enshassi et al., 2019, 2020; Shoval and Efatmaneshnik., 2019; Shahtaheri et al., 2017). A generic risk management framework identifies risk factors ranked according to the highest impact on cost and schedule risks, indicating the required action (Li et al., 2013). Prefabricated housing sees fragmentation that initiates scheduling risks. To tackle this, Smart Work Packaging (SWP) including social network analysis, system dynamics, discrete event simulation, and scenario analysis service, are appropriate risk management approaches (C. Z. Li et al., 2016, 2018; Li X. et al., 2019a, 2019b; Xiao Li et al., 2019). The team benefits from identifying optimal processes and multiple scenarios early to meet scheduling demands. A cause-and-effect model, alongside a cost control model that determines key cost drivers, performs likewise. For example, whilst running a simulation on a prefabricated building, cost-influencing factors are determined, and the degree of standardization gets ranked as major. This informs the project team to improve the industrial chain holistically, tackling cost overruns (Lou and Guo, 2020). A Data Quality Index-based Monte Carlo Simulation aids in determining carbon emission levels and handling environmental risks (Teng and Pan, 2020). Automated post-3D visualization ErgoSystem provides the best lifting and placing positions for workers which also minimizes cost overruns due to human error, followed by delays (Xinming Li et al., 2019 and Golabchi et al., 2015). The project team should ensure that noise risk assessment is conducted integrated with probability-based modeling to achieve optimized conditions (Dabirian et al. , 2020). A Bayesian Network probabilistic platform was used in off-site manufacturing to predict safety performance of manufacturing zones, targeting safety climate factors (Vithanage et al.,2022). The bayesian network demonstrates a relationship between risk parameters and guides the project team toward the best design concepts (Goswami et al., 2014). A similar approach was seen in evaluating the stakeholder's variety of impacts on the frequency occurrence of offsite projects' quality defects (Yu et al., 2019).

Seismic Damage Resisting System (SDRS):

By integrating the SDRS, cost impacts from seismic risks for modular projects can be tackled. Ashcroft et al., 2019 came up with a specific SDRS that showed evidence of being more economically feasible for modular construction projects. The brief details of such a system would include how the frames and damper systems are designed and installed. Hence, seismic risks are dealt with cost-effectively with early adoption of such systems. Advancements in connections and methods applied for steel-based modular projects in seismic zones are analyzed and classified so that key decision-makers can easily establish management approaches (Chen Z. et al., 2021).

Locally made materials & component-based prefabrication:

While using overseas materials for module production, scheduling, cost, and quality risks are highly likely to be encountered. Using locally made materials, offsite production will proceed with quality until the assembly phase. Similarly, depending on the project's location, component-based prefabrication is recommended due to ease of transportation (Lin et al., 2021). In developing countries, restrictions on the road-transported modular components' size are set to 3.5- 4 meters wide and 15- 16.5 meters long (Akinradewo O. et al., 2021). The risk management approach stated promotes value-adding activities in a project.

4.5. Research domain about technical risk management approaches

Current technological innovations have radically boosted the scope for modularization. BIM, RFID, GIS, sensors, blockchain, and IoT have great potential to be adopted as digital technologies in the current offsite construction projects (Wang M. et al., 2020). Figure 6 demonstrates a research domain regarding trends and connections between the technical risk management approaches identified in this study. The link is shown between the relevant authors with similar research aims and risk categories targeted while also indicating continuation studies. Furthermore, the risk management approach implemented was specified into specific phases, i.e., design and construction.

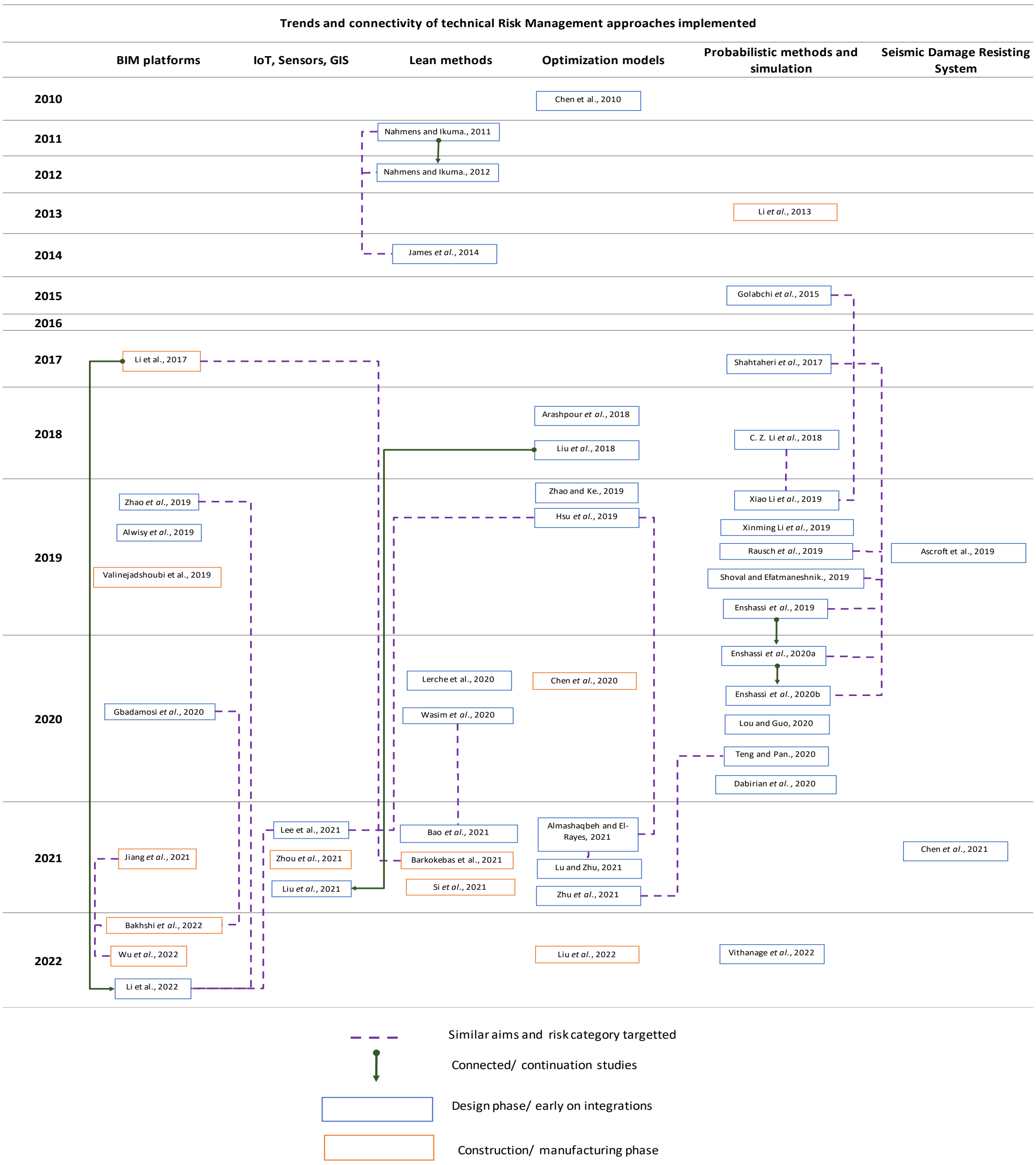

Figure 6:
Research domain on technical risk management approaches trend

5. Future research directions

Figure 7 shows the future directions according to the percentage value. No studies have considered the overall lifecycle of modular projects when it comes to risk management. Hence, this study highlights this potential future research.

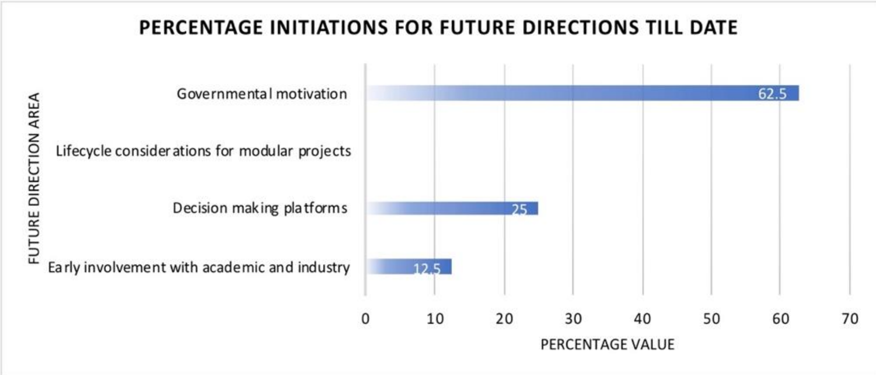

Figure 7:
Future research area and current initiation percentage

Early involvement of academics and industry:

Whilst determining decision-making factors of modular construction, Abdul Nabi et al., 2020 advise scholars to integrate with decision-making tools. The identification of skills needed to implement offsite construction in Australia successfully guides to a more efficient construction industry (Ginigaddara et al., 2022). The risk management systems can also be shifted to teaching-learning-based optimization in the prefabricated sector (Liu H. et al., 2020).

Decision-making platforms:

Among the factors considered in the decision-making platform initiative by Murtaza et al., 1993, the risks of projects are ranked in the major categories. While determining if a project is suited for modularization, reliable decision support tools are required (Goodier et al., 2019). Wuni et al., 2019 states the importance of establishing reliable decision support for modular integrated construction since the latter is deemed as an eligible success factor. Decision-making support enables team members to settle for accurate and innovative options from the starting phases (Gledson et al., 2021). Simulations that enable testing different changes at the design phase to support decision-making greatly aid project teams in massive modular projects (Du J. et al., 2019; Hwang et al., 2018). Analytical Hierarchy Process-based decision tools show efficacy evidence when integrated into urban area modular projects (Sing et al., 2021).

Lifecycle considerations:

A lack of academic involvement was noticed in the facilities management involvement during the design phase. Upcoming studies can consider carrying out case studies or guidelines relating to the early involvement of facility managers and designers. This integration alongside BIM platforms will smoothen the overall process. The characteristic of modules also permits reallocation and reuse (Abdelmageed et al., 2020). Future works can elaborate on environmentally-friendly scopes of modular projects' demolition.

Governmental motivation:

The first stage to motivate the government is determining factors impacting the adoption (D. Li et al., 2019). Interactions between factors were found by Gan et al., (2019) with fuzzy cognitive maps that provided outputs such as best combinations for overcoming barriers in modular construction adoption. Commercial and legal aspects of offsite construction analyzed in the United States provided guidance to interested personnel (Assaad et al., 2020). Similarly, Xu et al., (2020) state the Singaporean government established applaudable measures to welcome modular construction. Gumusburun Ayalp and Ay., (2021) started with a major study to identify hindrances disabling prefabrication adoption in Turkey and overcoming measures. Further, ways of actualizing the best measures identified and supporting interested stakeholders need immediate attention worldwide.

6. CONCLUSIONS

The existing gap in the modular construction sector relates to a lack of studies and aid to key decision-makers regarding optimizing their choice of risk management approach. This study analyzes modular construction literature systematically to derive current trends in risk management approaches graphically and suggest future works. A vast range of qualitative inputs were meticulously considered to form part of the foundation of this research. These enabled the strengthening of the findings, which aim to fill the gap concerning the lack of direction in choosing risk management approaches. This study's unique value lies in considering overall lifecycles and risk categories upon generating outputs for implementing risk management approaches. The contributions of this study towards the industry are as follows: (1) fundamental steppingstone to help broaden the existing knowledge level on risk management approaches for modular construction early on, (2) act as preliminary decision-making support with qualitative datasets covering the timeline from 1993 to 2022, (3) current trends in applicability of risk management approaches for various countries, projects (with specified criteria), academic and industry collaboration, and technical approaches most applied, (4) future work scopes which have high potential demonstrated by percentage initiation from researchers in the field.

CONFLICT OF INTEREST

Author(s) approve that to the best of their knowledge, there is no conflict of interest or common interest with an institution/organization or a person that may affect the paper's review process.

AUTHOR CONTRIBUTION

Sabah Khodabocus contributes to determining the concept and/or design process of the research, management of the concept and/or design process of the research, data collection, data analysis, interpretation of the results, preparation of the manuscript, and critical analysis of the intellectual content, final approval, and full responsibility. Senem Seyis contributes to determining the concept and/or design process of the research, management of the concept and/or design process of the research, preparation of the manuscript, critical analysis of the intellectual content, final approval, and full responsibility.

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