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RISK IDENTIFICATION IN INDUSTRIALIZED TIMBER CONSTRUCTION

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ABSTRACT:

Industrialized timber construction (ITC) has emerged as an efficient alternative in the construction sector, optimizing processes and enhancing project control. ITC adoption is increasing due to benefits such as execution time reductions of up to 25%. Existing studies on ITC focus on its benefits and challenges by addressing aspects such as efficiency, quality control, and sustainability while disregarding others such as its risks. Furthermore, risk management in traditional construction has been extensively studied. In contrast, identifying and classifying risks in ITC remains limited. So, this study addresses this gap using a systematic literature review. This paper reports the identification and analysis of risks over the phases of an ITC project to develop a tailored Risk Breakdown Structure (RBS). The research reviewed 84 relevant articles, identifying 176 risks mostly concentrated on the design and construction phases of ITC, which exhibit hierarchical ties with technical risks and quality issues. Therefore, ITC risk, identified in the literature, suggests a focus on phases related to design and construction stages. Future research will validate the RBS during a real construction project.

KEYWORDS: Risks, Timber construction, industrialized construction.

1 – INTRODUCTION

The construction industry is an important socio-economic activity that accounts for 8% of the global GDP. Nonetheless, despite its importance, in comparison to other sectors, its productivity has remained stagnant [1]. Over the past decade, productivity growth in construction (1.0%) lagged the global economy (2.7%) and other industries (3.6%) . One plausible explanation may be the sector's limited adoption of innovative technologies to enhance productivity, mass production, standardization, prefabrication, and modularization [2]. These strategies could transform the planning and execution of projects, increasing productivity by five to ten times [3].

In this regard, *industrialized construction* is a promising solution for improving productivity in construction. According to Johnsson (2009), using an industrialized approach could enhance efficiency, reduce costs, and improve quality in construction projects. In turn, industrialized construction categories involve the type of materials used, such as timber, steel, concrete, or hybrids [1]. Timber use has become popular due to its environmental and aesthetic properties and potential role as a structural material in multi-story timber buildings [2].

Current studies on the use of *industrialized timber construction* (ITC) focus on diverse challenges and issues faced by this construction approach. The existing literature describes a variety of factors such as material pathologies (e.g., Aguilera M, 2020; Gaspari A, 2021), manufacturing defects and errors (e.g., Pheng and Wee, 2001), fire risks (e.g., Alastair I.B; 2018), and design and assembly defects in wooden modules (e.g., Johnsson, H 2009). For instance, the use of timber as a structural material in high-rise buildings, given the uncertainty of its behavior in the event of a fire, requires particular attention [3]. Another relevant factor to pay attention to is supply, where the selection of materials during the design of the building is crucial for project success due to its significant

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impact on aspects such as durability, maintenance requirements, customer satisfaction, and life cycle, among others [4]. Finally, another relevant studied issue is the affectation of the material by biotic and abiotic agents, a decisive causal factor in the deterioration of the wood and therefore of the structure [5].

In the Chilean experience case, studies have focused on aspects such as the benefits and issues of *timber construction*. The Ministry of Housing and Urban Planning has carried out studies on pathologies in buildings (MINVU, 1998), user satisfaction (MINVU, 2002), and construction elements (MINVU, 2004). However, none of them focuses specifically on the risks associated with using timber as a building material, nor on the occupants' perception regarding this material. More recently, the study "Percepción Construcción en Madera" [6] partially explores these advantages and disadvantages, coinciding with the international literature on the vulnerability of timber to fire, humidity, and fungal attack.

Despite the progress achieved, none of these studies have comprehensively analyzed the risks over the distinct stages of an ITC project. This lack of attention represents a significant gap in the literature, as very few studies have addressed holistically the risks of all the distinct phases of ITC projects [7]. Instead, the available literature privileges risk within phases (e.g., Meiling H; 2009, Heisel F, 2024, Cubbage F,2010)

This condition raises the following research question:

> *What are the risks related to the distinct stages of an ITC project?*

This work uses a systematic literature review to address this question by analyzing the observed risks related to each phase of an ITC project and by developing an ad-hoc Risk Breakdown Structure (RBS). This study involves the following objectives:

1. To identify risks associated with each stage of an ITC project using a systematic literature review.
2. Develop an ad-hoc *Risk Breakdown Structure* (RBS) for ITC projects.

This article begins with a literature review to establish a conceptual framework for risk. Then, the methodology section describes the research design used to analyze the literature and develop the RBS. Next, it reports results related to the literature evaluation and risk analysis. After, it addresses the meaning discussion of these findings. Finally, the document presents the conclusions and next steps.

2 – Risk Management and ITC Projects

Proper risk handling is critical for project performance. Risk creates uncertainties throughout the project life cycle, affecting technical feasibility, cost, market timing, financial performance, and strategic objectives (Hillson, 1999; Loch, Solt, & Bailey, 2008; Thieme, Song, & Shin, 2003). Often, risks are hidden and unpredictable, making their early identification crucial to mitigate potential negative impacts [8]. In project management, this risk identification and structured assessment process is known as risk management, a key factor in ensuring the success of construction projects [9].

Risk management in construction involves a systematic effort over the project delivery stages. This process includes stages such as identifying, assessing, and mitigating uncertainties from various sources, including technical, managerial, environmental, and commercial factors [12]. Risk identification is an important phase of risk management, given that recognizing potential risks at an early stage enables better project control and decision-making [13]

Risk identification includes diverse types of techniques. Arosen in different industries and levels of risk, risk identification involves techniques such as documentation review, assumption analysis, brainstorming, Delphi technique, checklist analysis, root cause analysis, SWOT analysis, flowchart analysis, cause-and-effect analysis, and affinity diagram analysis [10]. Among these methodologies, documentation review is widely used in the construction industry because it offers insights into existing project risks by analyzing past experiences and reference studies [14].

Evidence backs up the relevance of risk identification based on documentation review in the construction industry. Studies in 453 construction organizations in the UK revealed that 75% of firms were familiar with risk identification through documentation review, and 73% considered it their preferred tool [11]. Similarly, research in South Africa demonstrated that literature-based risk identification is a common industry practice [12]. Moreover, [13] reported that 68% of construction firms considered documentation review an effective approach for identifying risks.

Risk Categorization Needs in ITC Projects

RBS provides systematic identification, categorization, and management of risks. Traditional risk identification methodologies, such as those proposed by the Project Management Institute (2000), often result in unstructured risk lists, making it difficult to understand risk interdependencies and their potential impacts. Simply listing risks is insufficient; risk categorization is necessary to establish impact thresholds and contingency measures

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[13]. To address this limitation, Hillson (2002) introduced the Risk Breakdown Structure (RBS):

> *"A better solution to the structuring problem for risk management would be to adopt the full hierarchical approach used in the WBS, with as many levels as are required to provide the necessary understanding of risk exposure to allow effective management. Such a hierarchical structure of risk sources should be known as a Risk Breakdown Structure (RBS)*"[14].

In this regard, ITC features support using a structured approach such as RBS for risk analysis. For instance, [15] analyzed risk factors in industrialized construction processes, emphasizing that a structured classification is essential to understanding risk interactions and their influence on project outcomes. Despite progress in risk identification, there remains a critical need to improve evaluation processes and develop more robust response strategies [19]. While ITC shares common phases with traditional construction (e.g., planning, design, construction, construction, and use), it also includes additional phases such as material supply, prefabrication, logistics, and final disposal, which introduce unique and specific risk factors, due to its prefabrication, transportation, and on-site assembly processes (e.g., Hansson F,2011, Švajlenka J, 2017, Cappellazzi J,2020, Ioannidou D,2019).

3 – RESEARCH METHODOLOGY

The research design for this study is based on a systematic literature review and subsequent analysis to build an RBS. This approach involves four main stages: (1) defining objectives, (2) conducting a systematic literature review, (3) identifying and classifying risks, and (4) developing the Risk Breakdown Structure (RBS). Each stage follows a sequential process to ensure a structured approach to risk identification in industrialized timber construction. Figure 1 presents an overview of this research design.

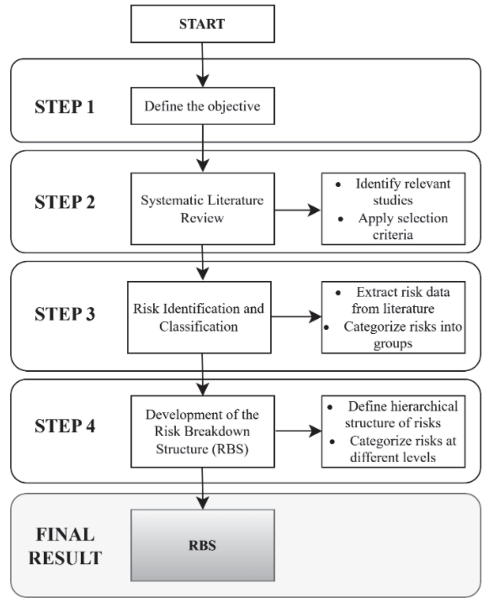

Figure 1, Research Design

Step 1 focused on limiting the research scope. Thus, the methodology states two main goals: (1) justifying the need for ITC risk analysis and (2) developing an ad-hoc RBS.

During step 2, a set of 140 relevant articles was collected to select 84 for review. The literature search used recognized scientific databases such as Web of Science (WOS), ScienceDirect, Scopus, and Google Scholar. Employed keywords include: "*Industrialized construction*," "*industrialized timber construction*," "risks and industrialized construction," "*risks and industrialized timber construction*," and "*barriers in wood construction*," among others. The selection of keywords covers terms related to industrialized timber construction, risk management, and associated challenges. As a result, a systematic review was conducted; it involved 140 scientific articles from various sources, including specialized journals, books, technical reports, and conference papers, to identify risks in industrialized timber construction projects. Of this total, 84 articles were selected for their direct relevance to the subject of the study.

Step 3 extracted relevant risks. So, the first step is to include articles in the databases, followed by analysis and classification. The analysis began organizing the 84 selected articles according to a general theme named "*Construction type"* (level 1), which included categories such as industrialized construction, timber construction, and industrialized timber construction. This level included various synonyms used in the literature to refer to industrialized construction. Subsequently, a sub-category named "*Study Topic"* (level 2) was defined for secondary topics addressed in the articles according to specific mentions of risks, barriers, challenges, and related synonyms. If the study does not explicitly mention a risk, other relevant factors (e.g., barriers, others) helped to analyze the potential presence of an implicit risk. This approach made it possible to structure the information hierarchically, highlighting how risk assessment in the context of industrialized construction and recognizing the diversity of terminology used in existing research.

Finally, Step 4 provides a systematic and structured risk identification approach in the context of ITC. Using a hierarchical approach based on the systematic literature review, the study categorizes the risks to develop a Risk Breakdown Structure (RBS). The classification framework used a structure of three levels to provide a clear and replicable approach for categorizing risks in ITC, as follows:

- *Level 1*. Project Phases (i.e., procurement, supply, design, construction, industrialization, logistics and transportation, assembly, use, and final disposal).
- *Level 2*. Technical, Political, Social/Cultural, Economic, Environmental and Legal
- *Level 3*. Specific Issues (e.g., sustainability, quality, technical aspects, public policies, risk management).

4 – RESULTS

Based on the review of 84 relevant articles, this study found that 243 risk mentions were identified in the literature concentrated on the design and construction phases of ITC projects, risks which, in turn, exhibit nested ties with Technical Risks and Quality Issues. Article analysis revealed that research is often related to timber and industrialized construction, disregarding specific ITC studies. The further analysis helped to relate 176 risks to ITC project stages, principally design and construction phases, whereas phases such as planning, logistics, transport, or use exhibit a knowledge gap in risk literature. Finally, the study creates an RBS to depict the structure and importance of risks over an ITC project.

Risks per construction type and study subject:

The literature analysis reveals a gap in the study of risks related to specific studies on ITC. Fig 2 shows the distribution of the selected articles according to construction type and study subject. Most of the articles focus on Industrialized Construction (42), Timber Construction (25), and Traditional Construction (11), whereas only a minority address ITC (4) and Sustainable Construction (2).

LEVEL 2 (STUDY TOPICS)	LEVEL 1 (CONSTRUCTION TYPES)					
	Timber Construction	Industrialized Construction	Industrialized Timber Construction	Sustainable Construction	Traditional Construction	Grand Total
Barriers and Opportunities	2	1	1			4
Benefits and Barriers	1					1
Success Factors		2				2
Project Management		1				1
Risk Management	1	1		1	4	7
Risk Identification					1	1
Innovation	1	2	2			5
Best Practices		1				1
Regulations	1					1
Risks	10	16	1		5	32
Risks and Benefits		1				1
Sustainability	3	1				4
Benefits and Challenges	2	1				3
Technical Failures	1					1
Structural Defects	1					1
Benefits	2	2				4
Project Management					1	1
Uncertainties		1				1
Barriers		3		1		4
Governance		1				1
Challenges		1				1
Structural Behavior		3				3
Sustainability in Off-site Construction		1				1
Limitations		1				1
Operational Efficiency		1				1
Transportation and Logistics		1				1
Grand Total	**25**	**42**	**4**	**2**	**11**	**84**

Figure 2, Articles according to construction type and study topic.

Visualization of the literature classification:

In the literature, articles that explicitly address risks are mostly related to timber construction and industrialized construction. Figure 3 depicts the observed relationship pattern between the sum of Timber Construction (25), Industrialized Construction (42), and Sustainable Construction (2), and the articles specifically related to Risk (32). This suggests that risks present in the literature are driven mostly by articles related to industrialized construction and timber construction. On the other hand, ITC (4) is considerably less represented and unrelated to other construction typologies.

Figure 3 presents a Sankey diagram comprising two levels, which should be read from left to right. The diagram on the left side (Level 1) shows the Type of Construction categories identified in the literature. On the right side (Level 2), it displays the thematic areas derived from the analysis of academic articles. The width of each flow represents the number of authors who have

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addressed each theme concerning a specific type of construction.

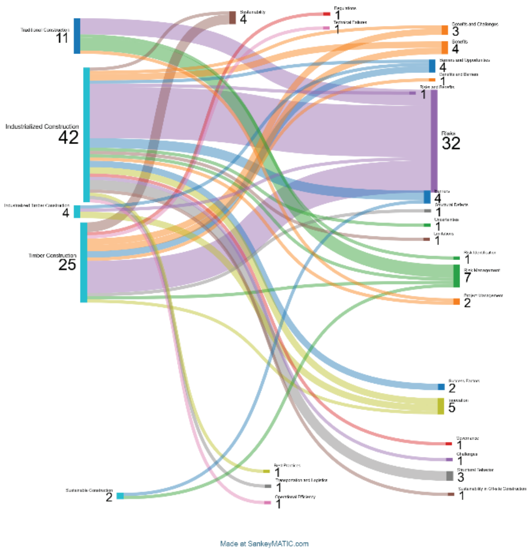

Figure 3. Relationship between articles classified according to construction type and topic.

In Level 1, five types of construction are represented: Traditional Construction, referenced by 11 authors; Industrialized Construction, referenced by 42 authors; Industrialized Timber Construction, referenced by four authors; Timber Construction, referenced by 25 authors; and Sustainable Construction, referenced by two authors. These categories reflect the main construction approaches addressed in the literature reviewed.

In Level 2, the thematic areas and the number of authors associated with each are as follows: Risks (32), Sustainability (4), Regulations (1), Technical Failures (1), Benefits and Challenges (3), Benefits (4), Barriers and Opportunities (4), Benefits and Barriers (1), Risks and Benefits (1), Barriers (4), Structural Defects (1), Uncertainties (1), Limitations (1), Risk Identification (1), Risk Management (7), Project Management (2), Success Factors (2), Innovation (5), Best Practices (1), Transportation and Logistics (1), Operational Efficiency (1), Governance (1), Challenges (1), Structural Behavior (3), and Sustainability in Off-Site Construction (1).

This visualization provides a clear overview of the connections between the construction types and the various themes addressed in the literature. It highlights a strong focus on the theme of Risks, especially in the context of Industrialized Construction and Timber Construction, and also reveals the diversity of topics associated with emerging construction approaches.

Identification of Risks as per Project Stage

Further literature analysis helped identify 176 risks related to ITC projects. Some were explicitly mentioned in the selected articles, while others were identified by analyzing the texts. As a result, 243 risk mentions were identified over 10 stages for an ITC. Given that several authors could cite the same risk, the frequency of mentions allowed quantifying its relevance within the articles analyzed. This led to the further refinement of the risk data, reducing the number of risks to 176.

By analyzing 243 risks, identification gaps related to the initial, final, and logistical stages were found. Figure 4 reveals that most risks mentioned per project stage are observed in Construction (52), Design (48), supply chain (39), Operation (35), Manufacturing (28), and Assembly (16), whereas in contrast, Contracting and End of life stage (3), Prefeasibility – Feasibility (9), Logistics and Transport (9) and procurement (4) exhibit fewer mentions. Thus, Construction in broad terms and Design account for 41% of all risk mentions (100 out of 243 mentions). Manufacturing and Procurement, two key stages in industrialized construction, represent 28% of total mentions. Contracting, Acquisition, and Final Disposal collectively account for only 3% of the total mentions. The data suggests that a higher number of risk mentions arise in the stages where the project is physically materialized, such as construction, design, procurement, and commissioning. Meanwhile, planning, logistical, and closure stages exhibit a lower presence in literature.

RBS for Risk Identification

To better understand risk composition and emphasis, the authors developed an RBS to classify and organize risks observed over an ITC project systematically. The RBS structure was hierarchically organized into three levels, ensuring that each identified risk was assigned to a specific category based on its nature and impact. The RBS was represented using a Sankey diagram (Figure 5) to depict the distribution and relationship of risks between the different levels, where line thickness indicates the frequency or concentration of risks into

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specific categories, providing specific and explicit visualization of the relationships.

AUTHORS	PROJECT STAGES										
	Supply Chain	Construction	Procurement	Design	End-of-Life Stage	Manufacturing	Logistics and Transportation	Assembly	Operation	Pre-feasibility - Feasibility	Total general
	Number of Risks Identified per Author										
Adel M. Ahmed, 2023	1			1							2
Adel M. Ahmed; 2023	5	3			1				1	3	13
Arif et al., 2017		1									1
Arif M.; 2017						1					1
Bartuska, B; 2023								6			6
Bizoń et al., 2023							1				1
Bukauskas, A ; 2019	1			5		5		4	1		16
Bukauskas, A ; 2020				1		1					2
Clyde Zhengdao Li; 2024		3				3	5		1		12
D. Kremer; 2019	2	2		1					1		6
Franzini F; 2018	1	5		4					8		18
Gaspari, A; 2022	2	5		3					3		13
Guimarães, L.G.d.A; 2024	2			3							5
Hansson, EF ; 2011	1	2		2		2		2	1		10
Hart J; 2020	2	1		1	2						6
Hirai T;2007	7										7
Huang 2017	1										1
Hurmekoski E; 2015		2									2
Ioannidou D; 2019	5										5
J. Kirkham; 2019	1	3		1							5
J. Y. Wang; 2018									1		1
Kampmeier, B ; 2015		3		1					1		5
Kirkham J.; 2019						1					1
Leszczyszyn E; 2022	4	10							7		21
Li y Ellingwood, 2009		1									1
Li Y; 2015									1		1
Li, T; 2022	1	5	4	9		12	3	1	1	3	39
Li, T; 2023								2		1	3
Li, T; 2024								1		2	3
Rakotonjanahary, M ; 2020		3		1							4
Samimi D; 2019				1							1
Samimi y Safiuddin, 2019	1										1
Solarte A.		1							1		2
Švajlenka J; 2017						1					1
Wang et al;2018	1										1
Wuni et al., 2022				1							1
Wuni I.Y; 2020	1										1
Wuni y Shen, 2020				1							1
Yue Li, M.ASCE; 2009				6					1		7
Yue Li, M.ASCE; 2010				1					3		4
Yue Li, M.ASCE; 2011									1		1
Zhang X; 2022		2				1			2		5
Zhang X;2022				5		1					6
Total general	**39**	**52**	**4**	**48**	**3**	**28**	**9**	**16**	**35**	**9**	**243**

Figure 4. Risk mentions according to the project stage

Figure 5 presents a Sankey diagram organized into three levels. The diagram should be read from left to right, starting with Level 1 (Project Stage), followed by Level 2 (Risk Environment), and ending with Level 3 (Specific Factors). Within each level, the items are arranged from top to bottom.

In Level 1, located on the far left of the diagram, the project stages are presented vertically in the following order: Supply Chain (7 risk events), Contracting and Procurement (4 events), Design (36 events), Manufacturing (34 events), Logistics and Transportation (25 events), Assembly (2 events), Assembly on Site (12 events), Construction (7 events), Operation (23 events), and End of Life Phase (16 events). Each stage is connected to one or more risk environments, as Level 2 shows.

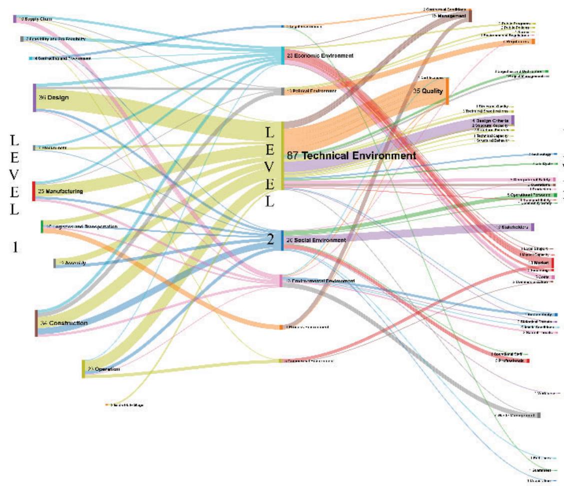

Fig. 5. Quantity of risk patterns over different RBS levels

In Level 2, the diagram displays the environments from which the risk events originate. Six main environments are identified: Technical Environment (87 events), Social Environment (26 events), Environmental Environment (16 events), Economic Environment (12 events), Legal Environment (6 events), and Cultural Environment (3 events). These environments are intermediate nodes that link project stages to the specific risk factors in Level 3.

In Level 3, specific factors within each environment are detailed. For the Technical Environment, the following factors are included: Quality (35 events), Structure (13), Materials (14), Installations (2), Manufacturing Process (3), Design Tools (2), Construction Method (5), Resources (7), Supervision (2), Foundations (1), Transportation Process (2), Load-Bearing System (1), Waste (1), Technology Change (1), Inspection (1), and Testing Process (1). Within the Social Environment, the identified factors are: Stakeholder Engagement (5), Community Context (4), Social Acceptance (2), Labor (10), Communication (1), Local Knowledge (1), Organizational Context (2), and Training (1). The Environmental Environment includes: Environmental Impact (5), Waste Management (3), Emissions (2), Material Selection (2), Resource Efficiency (1), Sustainable Criteria (1), Reuse Potential (1), and Climate Conditions (1). For the Economic Environment, the factors are: Cost Control (4), Material Availability (2), Market Access (2), Local Suppliers (1), Production Cost (1), and Transportation Cost (2). The Legal Environment includes Regulations (4) and Contractual Aspects (2). Lastly, the Cultural Environment contains Material Perception (2) and Local Traditions (1).

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Risk Distribution over the RBS Levels

The Sankey diagram (Figure 5) illustrates how risks are distributed across the levels of the RBS, starting in Level 1 (Project Phases), through Level 2, up to reach Level 3 (Specific Risk Themes). Key insights include:

- Relevant connections are observed between the Design, Construction, Industrialization, Use, and Logistics phases (level 1), which converge into Technical, Social, and Economic aspects (level 2) and finally into Quality issues (level 3).
- The most prominent connections are observed in the relationship between Technical Risks and Quality Issues (The thicker lines indicate a strong concentration of risks in Technical and Quality categories, emerging as a key issue).
- Categories exhibit different risk distribution quantities. For instance, risk categories, such as Economic or Political, have thinner lines than technical ones, indicating fewer mentions in the literature.

Most relevant Risk Concentrations

Figure 5 also highlights the variation in risk distribution over the RBS, showing which areas have a stronger presence in the literature. The most relevant relationship is observed between technical risks, quality issues, and sustainability concerns (represented by thicker lines). In this regard, technical risks display the strongest connections, particularly with Quality and Sustainability concerns, which indicate a high presence in the literature. In contrast, risks related to Political and Economic factors appear less frequently, as indicated by the thinner lines, suggesting that these aspects have received less focus in risk-related studies on industrialized timber construction.

Trends in Risk Classification

The Sankey diagram also reveals additional trends in risk categorization. These include a high concentration of *Technical Risks* (i.e., an emphasis on risks related to construction execution and design, with less emphasis on external factors like Political or Legal risks), *Risk interactions across multiple dimensions* (i.e., some risks are widely distributed across multiple thematic areas, while others remain concentrated within a specific risk category), and *multi-connected risks* (i.e., particularly those classified under Technical Risks, are connected to multiple themes, highlighting their relevance across different project stages).

Summary of the RBS Sankey Analysis

By structuring the Risk Breakdown Structure (RBS) using a Sankey Diagram, the distribution and categorization of risks can be systematically observed, providing a clear visualization of risk assignment across multiple dimensions.

- Thicker lines in the diagram highlight the most frequently identified risks, with the prevalence of technical risks.
- Thinner lines indicate less frequently mentioned risks, particularly in political, economic, and legal categories.
- The distribution of risks varies, with some risks connecting multiple categories while others remain concentrated on specific themes.
- Visual representation allows for a structured understanding of which risk categories are most frequently discussed in the literature.

5– DISCUSSION

Previous studies disregard the study of Risks specifically related to ITC Projects. This work confirmed this gap and aims to address it by developing (1) *a database of risks associated with each stage of an ITC project using a systematic literature review* and (2) a *Risk Breakdown Structure (RBS) for ITC projects*. These findings suggest that risks for an ITC project observed in the literature may involve a hybrid cause that draws from traditional and industrialized approaches to project delivery.

In this study, as per the literature, the risks over the stages of an ITC project may arise driven by some subjacent system, which includes hybrid features from traditional and industrialized approaches to project delivery. Findings reveal that reported risks often focus on the design, construction, industrialization, and commissioning stages. In contrast, risks related to planning, logistical, and use stages are disregarded (Figure 4). Furthermore, the RBS analysis suggests that risks related to these stages converge mostly into three major subjacent risk categories, i.e., technical, social, and economic risks, where technical risks are explained mostly by quality and design criteria risks (Figure 5). In this regard, one plausible explanation for this pattern of risk for an ITC project, as found in the literature, is the presence of project delivery stages that suggest a hybrid model between traditional and industrialized approaches (Figure 6). This model suggests a project delivery that involves the use of industrialization, assembly, and conventional construction as part of ITC, where the most prioritized risks are related to a nested structure that progressively involves the relationships between the physical transformation stages over the project course, then technical risks, and ultimately quality issues.

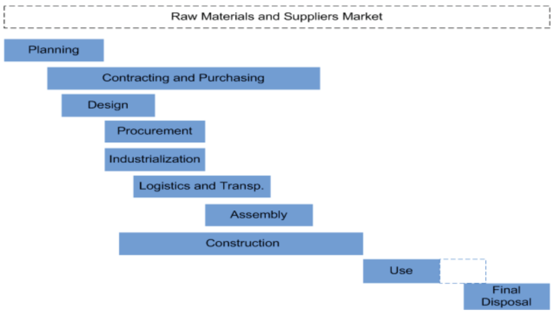

Figure 6. Plausible hybrid project delivery stages subjacent to the risk pattern observed in the literature

Compared to previous studies, this work reports a gap related to the lack of specific studies on risks related to ITC. Despite the current literature on industrialization and timber construction risks, evidence shows that specific studies on ITC are still disregarded (Figure 2 and Figure 3). By focusing on risks specific to this construction method, such as those associated with material supply chains, design processes, and assembly phases, this study bridges the gap between generalized risk studies and the unique challenges posed by industrialized timber construction.

This work also has developed an RBS for ITC projects. This tool's structure is designed to classify risks related to this type of project systematically. This ITC-RBS uses a three-level hierarchical and nested structure, organized as follows (given the space limitation, for levels 2 and 3, only the most mentioned categories are included); the result is depicted using a Sankey diagram to express the relationship between levels, categories, and sub-categories of risks:

- Level 1: Project phases (i.e., planning, contracting & purchasing, design, procurement, industrialization, logistics and transportation, assembly, construction, use, and final disposal; besides the project, the market of raw materials and suppliers is included as a source of risks).
- Level 2: Internal and external environments of the stages (i.e., technical, social, financial, environmental, and others).
- Level 3: Specific issues (e.g., quality, design criteria, legal and regulatory compliance, etc.).

This hierarchical approach allows for a more structured identification of risks, facilitating their prioritization and strategic allocation of resources, aligning with the risk management principles proposed by Hillson (2003), and [16]

In the practical realm, using an ITC-RBS is expected to help provide critical insights related to risk distribution over ITC project stages, for instance, in project planning and feasibility stages. Mitkus (2006) points out that procurement and acquisition are crucial in project planning. Meanwhile, Mukuka (2015) highlights that poor procurement planning leads to significant delays in executing construction projects. Figure 4 reveals that contracting and acquisition risks are underrepresented despite their importance for planning and feasibility of projects. Furthermore, the Sankey diagram analysis provides a visual representation of the nested structure and concentration of risks, where planning is related only to economic and social categories, this condition suggests that the lack of relationship between contracting and technical risk may require further analysis given its relevance. So, ITC-RBS for risk management provides a way to analyze the effect of risks between different stages, types of risks, and root causes.

This study highlights the need to explore underrepresented stages further to ensure comprehensive risk management in ITC. It lays the groundwork for future research by providing a structured framework for identifying and classifying risks. However, the ITC-RBS must be validated in practical scenarios and complemented with quantitative tools to assess the likelihood and impact of risks. In this way, it is expected to strengthen the utility of ITC-RBS in decision-making in ITC projects.

6 – CONCLUSIONS

This study reports a systematic literature review that drives the development of an RBS specifically designed for ITC projects. The study fills a critical gap in the literature by providing a structured classification of risks. Then, it develops an RBS, a tool for understanding and organizing risks over different phases and hierarchical levels. It allows for a systematic approach to risk management in ITC projects. Therefore, this will help to improve the identification of ITC risks and lay the groundwork for future research.

The outcomes of this work involve the following *Implications for theory*: First, (i) It provides evidence about the existence of a gap in the literature related to the

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specific study of risk related to ITC projects. Then, (ii) it provides an alternative for the analysis of risks through an RBS tailored to ITC projects. Finally, (iii) it argues that current literature on ITC risks involves a subjacent implicit project model of a hybrid structure between industrialized and conventional project delivery stages.

The study involves the following practical implications:

- It provides a tool for risk management. A risk list is organized into three hierarchical levels, allowing for a detailed analysis of risks over ITC project phases. Therefore, this facilitates the identification and prioritization of critical risks.
- It provides a way to enhance the decision-making related to risks in ITC Projects. ITC-RBS may strengthen the decision-making in ITC projects, ensuring a more comprehensive, structured, and adaptable approach to risk management.

ITC-RBS is complementary to other approaches for risk analysis. An alternative to RBS for risk analysis is System Dynamics (SD) (Forrester 1956). This methodology allows for a holistic analysis of how risk variables interact and evolve during a period, offering a dynamic perspective on project behavior and risk propagation (e.g., Lyneis 2020, Howick & Eden 2004). An ITC-RBS provides an option to analyze and categorize previous variables for developing an SD model.

The development of the ITC-RBS exhibits limitations related to its scope and data source. First, (i) it uses a classification that aligns with general principles of construction risk management but emphasizes ITC risks; therefore, its use with other construction types of projects may exhibit constraints. Then, (ii) the current ITC-RBS version is based only on a systematic literature analysis, where many reviewed articles do not explicitly mention risks; in such cases, the absence of advantages, benefits, or innovations highlighted in the articles was interpreted as potential risks. Finally, (iii) the subjectivity in the qualitative interpretation of risks; in some cases, during the building of the risk database, classification was influenced by qualitative analysis subjectivity.

This study is part of a bigger project on ITC risk management. Therefore, future research efforts related to this work will include work such as: *First, (i)experts Validation*: The database of identified risks will be validated through interviews with sector experts whose experience aligns with the various phases defined for industrialized timber construction projects. *Then, (ii) risk evaluation*: Once validated, risks probability of occurrence and impact will be assessed. *Next, (iii)case study*: It is expected to validate the ITC-RBS outcomes during a real project. The last step will be the development of a *(iv) Web based tool* for risk management of ITC projects.

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