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Exploring the barriers and enablers of industrial solutions in renovation projects: a mixed-methods study in the finnish AEC industry

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Offsite construction is a major approach to promote industrialisation in construction. However, implementation of prevailing industrial solutions is often less adequate and unsatisfactory, especially in renovation projects. Thus, the overall objective of this study is to understand the reasons behind the poor performance in implementation of the industrial solutions. The specific objectives include identifying the prominent barriers and enablers of prefabricated products in renovation projects. This study employed exploratory sequential mixed method. The qualitative data were gathered via semi-structured interviews to collect experiences and perception of experts related to industrial solutions. This was followed by quantitative data collection via questionnaire survey using a seven-point Likert scale. The major barriers and enablers of industrial solutions in renovation projects have been ranked in this study. The findings reveal that immutability of heritage buildings, the tolerances of old buildings and insufficient spaces to ensure construction work ranked the top three barriers for implementing industrial solutions in renovation projects. Moreover, the study identifies the most significant enablers including shorter project schedules, quality improvement and work safety improvement. The novelty of the research lies in the comprehensive presentation of the barriers and enablers of industrial solutions in the renovation project context. Policymakers, designers, and contractors can utilize these findings as guiding principles to enhance decision-making processes and create viable solutions for the obstacles encountered in renovation projects. This study further represents a vital step towards the efficient and effective implementation of industrial solutions in renovation projects, resulting in more sustainable and cost-effective outcomes.

KEYWORDS

renovation project, industrial solutions, mixed-method, barriers and enablers, construction

1 Introduction

Construction industrialisation (CI) is a transformation from traditional site-based construction to industrial methods by integrating manufacturing design and optimisation tools to solve complex barriers in construction projects (Pan et al., 2012; Attouri et al., 2022). Several offsite fabrication techniques have been adopted for industrial construction, including prefabrication, pre-assembly and modularisation (Junnonen, 2012). In all techniques, building activities are shifted from the actual site to an offsite manufacturing facility.

Various industrial solutions are produced using offsite fabrication techniques which are readily available in the construction industry. These solutions are classified into modular buildings (such as medical camp motels), volumetric products (including modular bathrooms and shower rooms), non-volumetric products (such as wall panels and structural frames), and component manufacture and subassembly products (like bricks, mortar, and iron) (Chauhan et al., 2022a; Jonsson and Rudberg, 2014). Many of these solutions are implemented in new construction and renovation projects.

The construction industry has numerous monetary and non-monetary enablers while adopting industrial solutions. The factors affecting monetary enablers include, among others, material, labour, installation, and schedule-related costs, while factors for non-monetary enablers include quality, ergonomics, and overhead costs, to name a few (Shen et al., 2019; Antillon et al., 2014; Sandanayake et al., 2019). The use of some industrial solutions in construction has higher initial cost however the total cost is lower than the traditional construction techniques (Chauhan et al., 2022b). Moreover, Boyd et al. (2013) found that offsite construction saves 30% of the overall cost. Therefore, overall cost of construction using industrial solutions is lower than traditional methods.

Industrial renovation is essential to achieve sustainable and economically efficient solutions for enhancing industrial infrastructure, complying with regulations, and conserving historical significance (Kemmer, 2018). Old buildings possess various characteristics that necessitate careful consideration before undergoing renovation. These factors include the existing purpose of the building, the structural durability, the ground conditions, and the comprehensive scope of essential construction tasks (Kemmer, 2018; Cao et al., 2021). These characteristics increase the uncertainty of renovation projects, such as when the extent of the work required and related problems are not discovered until dismantling and stripping work has begun. In addition, due to uncertainties that often arise from variations in the work scope during renovation work, various risk factors (e.g., inappropriate installation and over budget) are typically associated with renovation projects (Cho and Kim, 2018a; Cho and Kim, 2018b).

Based on the research mentioned above, a considerable number of studies have been conducted in the field of renovation. However, there is significant gap in previous studies that specifically analyze the enablers and barriers of implementing industrial solutions into renovation projects. While some efforts have been made to examine the enablers and barriers of utilizing industrial solutions in new construction projects, such as the work by Attouri et al. (2022), it is important to note that there may be additional complexities when implementing these solutions in renovation projects. For example, issues like the immutability and reduced load-bearing capacities of old or heritage buildings can pose obstacles to the implementation of industrial solutions. These unidentified barriers in renovation projects related to industrial solutions need to be thoroughly investigated, as they can provide valuable insights for construction stakeholders who are considering the adoption of solutions for renovation projects. Moreover, by identifying the significance of key factors, practitioners can gain a better understanding of whether a particular solution would be beneficial when implemented in their projects. Therefore, there is a strong need to conduct a comprehensive investigation into the enablers and barriers of industrial solutions when applied to renovation projects. Consequently, the primary objective of this study was to examine the advantages and barriers associated with the implementation of industrial solutions in renovation projects.

To achieve the goal of the study, this study has adopted a mixed methods approach featuring a literature review, semi-structured interviews and a questionnaire survey. Previous researchers have adopted and highlighted the drivers of using a mixed methods research design in the construction engineering and management field (Lau et al., 2019). This approach is adopted to qualitatively understand complex phenomena and to quantitatively explain the phenomena through numbers, charts and basic statistical analyses (Morse, 2016; Zou et al., 2014). We also believe that using multiple research methods is a valuable approach because they can complement the strengths and weaknesses of each individual method and allows a deeper understanding of the issues and offers a novel perspective on improving the performance of industrial solutions in the renovation sector. The application of the methods adopted in this study and their purposes are presented in Table 1.

Overall, the novelty of this research lies in its contextual exploration of the barriers and enablers of industrial solutions in renovation projects, particularly within the Finnish industry. The identified barriers and enablers in this study hold significant potential to guide the concerned stakeholders for successful adoption and implementation of industrial solutions in renovation projects.

2 Literature review

This section reviews previous studies on industrialised construction and industrial solutions implemented in the construction industry. This section provides the theoretical foundation for the current study.

2.1 Construction industrialization

CI is a broad topic to define. In their review, Rashidi and Ibrahim (2017) presented the definition of CI from more than 20 researchers. Some researchers have defined CI as the process, approach, and method, while other researchers have defined it as comprising technology, product and system. Despite the lack of a uniform definition, Lessing's (2006) definition is mostly cited in the literature. In that work, CI is represented as a systematic,

TABLE 1 Descriptions of the adopted research methods.

Purposes of the study	Applied method	Outcomes/results
To identify the industrial solutions implemented in construction projects	1. Literature review	• Identifying the industrial solutions adopted in construction projects
	2. Semi-structured interviews	• Acquiring information about the industrial solutions implemented in Finnish renovation projects
To investigate the enablers and barriers of industrial solutions	1. Literature review	• Obtaining the list of enablers and barriers
	2. Semi-structured interviews	• Identifying the additional enablers and barriers from the list
To evaluate the intensities of enablers and barriers identified	1. Questionnaire survey	• Identifying the most important enablers and barriers from the list

controlled and standardised production process of well-defined elements and building systems, which facilitate the collection of experiences from the design, production and assembly of a building system, which in turn, can be used as a basis for continuous improvement (Lessing et al., 2015).

To date, several approaches have been adopted for CI, including offsite construction, pre-fabrication, pre-assembly and modular construction. 'Offsite construction' refers to the process of manufacturing and pre-assembly of certain numbers of building components, modules and elements prior to their shipment and installation on a given construction site (Jin et al., 2018). "Pre-fabrication" denotes the practice of producing the components of a structure in a factory and transporting complete or semi-complete assemblies to the construction site where the structure is to be located (Tatum et al., 1986). "Pre-assembly" refers to the process wherein different materials and components are joined together at a location that is different from a subsequent installation location (Tatum et al., 1986), while "modular construction" or "modularisation" is the process of designing and fabricating building modules under controlled offsite conditions and transporting the large units to the site for subsequent assembly (Taghaddos et al., 2018).

Several studies have analysed the enablers of CI, and the major documented enablers include reducing overall project cost (Atturi et al., 2022), minimising overall project time (Tam et al., 2007), reducing environmental impact during construction (Li et al., 2020) and mitigating health and safety risks onsite (Choi et al., 2019). At the same time, the literature has identified several limitations of CI, such as increases in initial project cost (Wuni and Shen, 2020), transportation limitations (Sun et al., 2020) and limited or expensive skilled labour (Choi et al., 2019).

Furthermore, Attouri et al. (2022) conducted a questionnaire survey to rank the enablers and hindrances of industrialised construction in France. According to their results, the top enablers were improved productivity, minimised construction time, improved quality and reduction of environmental impacts. The biggest limitations were the requirement for long coordination work between the design office and the pre-manufacturer before starting production, the inability to block a design early enough to start manufacturing at the plant and key decisions already taken to exclude the modularisation approach.

Likewise, Chauhan et al. (2022a) analysed the monetary and non-monetary enablers of some industrial solutions in new and renovation projects in the Finnish construction market. They found that although some of the industrial solutions incurred higher direct costs, if all the indirect costs were considered, then the overall project cost would be much lower. However, they investigated limited industrial solutions to be able to generalise their results. To date, the industrial solutions adopted in renovation construction remain underresearched.

2.2 Renovation construction project

There is no common definition of 'renovation' in the related literature. Considering studies conducted within the renovation construction domain, 'renovation' has been adopted as an umbrella term to refer to the process of rebuilding, modernising and upgrading old structures (e.g., Vainio, 2011). In addition, the term 'renovation' has been adopted to define a wide range of related activities, including the repair, maintenance and improvement of old structures (Killip et al., 2018). In the current research, we focus on the renovation of residential buildings, particularly the building envelope, and the process of improving or modernising buildings to return them to a good state.

Furthermore, different terms, such as 'retrofit', 'renovation', 'refurbishment' and 'reuse' of buildings, are used in the literature to refer to improvements in existing buildings (e.g., Shnapp et al., 2013). The word 'retrofit' typically means the addition of features for the improvement of performance in a particular area (e.g., structural integrity) (IHBC, 2022). According to European Standards (EN 15978, 2011) the terms 'refurbishment' and 'renovation' both represent a 'modification and improvement to an existing building in order to bring it up to an acceptable condition'. Although multiple terms can be used interchangeably, 'renovation' is commonly used in the literature. For the sake of consistency, this study used the term 'renovation' throughout this paper.

Renovation types can be categorised as minor, major and master renovations (Hassanien, 2007; Stipanuk and Roffmann, 1996). A 'minor renovation' refers to the replacement or renewal of some non-durable furnishings (e.g., carpeting), while a 'major renovation' refers to the replacement or renewal of all furnishings, equipment and finishes within a space (e.g., MEP renovations). Finally, a 'master renovation' is more comprehensive than major renovation and involves the partial or total renovation of an entire property (e.g., new extension). Gaining deeper knowledge of all types of renovations is considered in this research.

While completing the renovation of an existing building, several characteristics of old buildings must be considered. Renovation

TABLE 2 Major industrial solutions implemented in renovation projects.

Categories	Examples	Sources
Mechanical-, electrical- and plumbing (MEP)-related products	Prefabricated and modular MEP systems	Junnonen (2012)
Façade/energy renovation products	Prefabricated energy façade, plug and play modular façade system	Torres et al. (2021)
Products for additional construction	Prefabricated room modules and prefabricated lift and staircase modules	HBS, 2023; Junnonen, 2012

projects differ significantly from a new construction, with the latter requiring more steps, money and time, while also dealing with more unknowns. In comparison, renovation work is often carried out in the midst of an ongoing, active business, and certain aspects of renovation projects make them more complex. For example, the original design documents of old buildings are often unavailable or inaccurate, and the extent of the work required, and the related problems are not discovered until dismantling work has begun. Similarly, additional coordination must be done between the construction team and users; in fact, in some major renovations, users are required to relocate during construction. Sometimes, distinct health and safety concerns appear (Pikas et al., 2021; Kemmer, 2018). Due to these complex characteristics, renovation projects face different barriers, especially during the construction phase and the implementation of industrial solutions.

Several industrial solutions available on the market can be adopted in renovation projects. Following current market trends, sustainable industrial solutions, such as the plug-and-play modular façade system and the timber-based element system (TES) energy façade, have become more popular in recent years (Torres et al., 2021). However, several activities in a renovation project can affect the implementation of industrial solutions. For example, to install a new window, coordination with occupants is necessary during the preparation of the site logistic activities (Singh et al., 2014; Amorocho and Hartmann, 2021). Thus, the present study analyses the enablers and barriers of industrial solutions implemented in renovation projects.

2.3 Industrial solutions adopted in renovation construction

The implementation of prefabricated solutions in various construction projects brings the construction industry towards greater industrialisation (Tatum et al., 1986). To further promote the industrialisation of the construction industry, several industrial solutions are being adopted, many of which could be implemented in both new construction and renovation construction. However, their adoption in renovation projects is often challenging. For instance, the designs and structures of old/heritage buildings cannot be changed during renovation. Thus, the current research focuses on the industrial solutions adopted in renovation projects.

By analysing several earlier studies (e.g., Pikas et al., 2021; Torres et al., 2021; Chauhan et al., 2022b) the industrial solutions implemented in renovation projects can be categorised into three groups, as shown in Table 2: 1) mechanical-, electrical- and plumbing (MEP)-related products; 2) façade and energy renovation products; and 3) industrial solutions suitable for additional construction.

Although some industrial solutions are available in the market, several studies (e.g., Wang et al., 2018) have reported that the adoption of those industrial solutions in construction projects has largely been unsatisfactory. Thus, the current study aimed to evaluate the enablers and barriers of adopting industrial solutions in Finnish construction projects. The findings will provide useful knowledge, enabling various stakeholders to have a better understanding of the enablers and barriers of using industrial solutions in renovation projects.

3 Methods

In order to accomplish the objective of the research, this study have implemented an exploratory sequential design mixed methods approach. This approach entails commencing with the collection and analysis of qualitative data, and subsequently proceeding with the collection and analysis of quantitative data to interpret the findings (Morse, 2016). Previous researchers have adopted and highlighted the enablers of using a mixed methods research design in the construction engineering and management field (Lau et al., 2019). This approach is adopted to qualitatively understand complex phenomena and to quantitatively explain the phenomena through numbers, charts and basic statistical analyses (Morse, 2016; Zou et al., 2014). We also believe that using multiple research methods is a valuable approach because they can complement the strengths and weaknesses of each individual method. In this study, the collection of qualitative data involved conducting literature reviews and semi-structured interviews, while the collection of quantitative data was accomplished through a questionnaire survey. The application of the methods adopted in this study is presented in Figure 1.

The semi-structured interviews are the most common method of collecting qualitative data. This technique is chosen to acquire a comprehensive understanding of particular subjects, as it grants the interviewers the ability to generate further inquiries based on the responses of the participants (Kallio et al., 2016). The literature review results formed the basis of the semi-structured interview design. Semi-structured interviews were conducted to obtain an in-depth understanding of the industry's perceptions of industrial solutions implemented in renovation projects. The interview questions were structured into three main parts: the basic information of interviewees and their companies, information about the industrial solutions implemented in their projects and the enablers and barriers identified while implementing industrial solutions in their renovation projects. Fourteen professionals from various industrial backgrounds were chosen to participate in interviews, ensuring a diverse range of perspectives and insights. They include including four project managers, three business development managers, two site managers, two site supervisors, two project engineers and a marketing manager. Data saturation was reached when no new information could be obtained through further data collection, leading to the conclusion of the interviews.

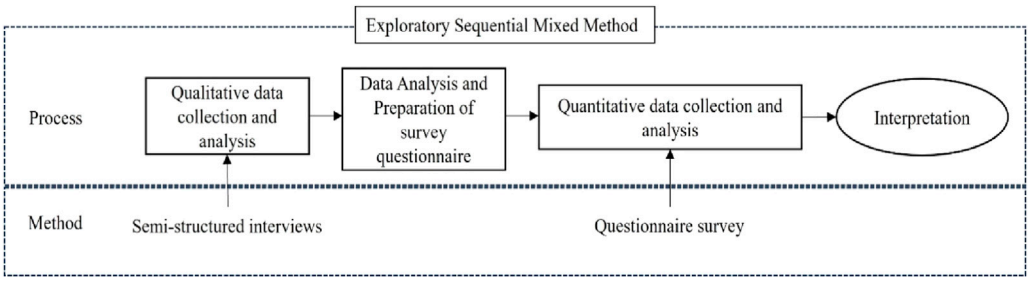

FIGURE 1
Research framework adopted in this study.

TABLE 3 Respondents' profiles (n = 34).

Respondents' occupation	Frequency	Percentage (%)
Project developer	4	12
Researcher	2	6
Project manager	7	21
Site manager	6	18
Site supervisor	4	12
Design consultant	4	12
Site engineer	4	12
Business director	3	9
Years of experience in handling renovation projects		
<5 years	5	15
5–10 years	8	24
10–15 years	12	35
>15 Years	9	26

Next, we conducted a questionnaire survey. As a research method, a questionnaire survey is used to collect experts' views on a research topic and is a popular research approach in the construction management field (Groves et al., 2009). Accordingly, the current study adopted a questionnaire survey approach to gather professionals' perceptions regarding the barriers and enablers of construction-related industrial solutions implemented in renovation projects.

Based on the results of the literature review and the semi-structured interviews, a questionnaire survey was developed consisting of four sections. The first section included background information about the survey and instructions on how to respond to the survey. The second section solicited the respondents' background information, including their fields of expertise and years of experience in the industry. The third and fourth sections respectively collected information on the barriers and enablers of implementing industrial solutions, which were identified through the literature review and semi-structured interviews. The seven-point Likert scale is often preferred over simpler scales such as the three-point or five-point scale due to its ability to offer greater response differentiation, enabling more precise distinctions to be made between varying levels of agreement and disagreement (Dawes, 2008). To fulfil the objective of the study, a comprehensive detail of the indicators is necessary which is facilitated by seven-point scale. Thus, respondents were then asked to rate the barriers and enablers using a seven-point Likert scale ranging from 7 ('extremely important') to 1 ('Not important at all').

Once an online survey questionnaire platform was set up, we sent the form by e-mail to the project participants (including renovation project experts). We also distributed the form via the LinkedIn social media platform to gather more responses. To ensure a higher response rate, the research team occasionally reminded potential respondents to respond to the questionnaire. Finally, we received 34 responses. The respondents' profiles are presented in Table 3. To analyse the response data, we conducted basic statistical tests. According to Hwang et al. (2018), statistical analysis could be performed because the central limit theorem is true as long as the sample size is not less than 30. Additionally, a greater quantity of survey responses might not be required for an exploratory investigation of a specific phenomenon, such as the utilization of industrial solutions in renovation (Ott and Longnecker, 2015). However, they failed to clearly mention what the minimum response rate should be. Compared with previous research, our response rate is sufficient to draw the overall conclusion (e.g., Javed et al., 2018; survey respondents: n = 32).

4 Results and analysis

This section presents the results and analyses of the literature review, semi-structured interviews and questionnaire survey.

4.1 Results of the literature review and semi-structured interviews

This section provides an overview of the findings derived from the analysis of qualitative data. These findings were obtained through a combination of literature review and expert interviews. Subsequently, the results were utilized to design a questionnaire survey in order to quantitatively analyze the data.

TABLE 4 Project-level barriers in implementing industrial solutions in renovation projects.

Barriers	Explanations	References
Poor tolerance of buildings	The lower load-bearing capacities of old buildings make it difficult to implement industrial solutions in project sites	Interviews
Immutability of heritage buildings	The designs and structures of old/heritage buildings cannot be changed	Interviews
Lack of coordination	There is a lack of coordination among architects and structural and MEP specialists	D'Oca et al., 2018; Naaranoja and Uden, 2007
Lack of appropriate decision-making tools for choosing solutions	There is a lack of suitable decision-making tools given that the available tools (e.g., cost-benefit method, RENO-VALUE decision making and MCDM) typically do not consider viewpoints from multiple stakeholders	Interview; Chauhan et al. (2022a); Ruiz-Perez et al., 2019
Lack of trust	It is difficult for project team members to obtain information from other persons	Naaranoja and Uden (2007)
Insufficient spaces	There are insufficient spaces in which to facilitate the construction work in a way that ensures safety and prevents damages	Interview; Zhang et al., 2018
Difficulty in following regulations	Construction professionals need to know several rules and have difficulties in remaining up to date about all the new rules implemented	Naaranoja and Uden (2007)
Difficulty in finding proper documents	Finding proper project documents from archives has become more time-consuming and difficult	Naaranoja and Uden (2007)
Failure to learn from successful projects	It is generally acknowledged that much of the knowledge of construction companies resides in the minds of the individuals working within the industry	Interview; D'Oca et al., 2018; Naaranoja and Uden, 2007
Poor data management	Data are not managed as they are created. Instead, they are only captured and archived at the end of construction	Naaranoja and Uden (2007)
Resistance against the use of information technology (IT)	Being up-to-date with new technologies is difficult for many employees	Naaranoja and Uden, 2007; D'Oca et al., 2018
Lack of change management	Changes in plans are not passed on to other participants. Although changes need to be made, the information is seldom passed on to those who should have it. This creates resentment among those who have no idea what is happening. Even though they receive information about certain changes, they are often not told why such necessary changes are made	Larsson et al. (2014)
Lack of understanding by end users	How property owners perceive technological changes and how they assess their enablers and potential disadvantages may clash with those of project team members	D'Oca et al. (2018)
Lack of confidence in construction professionals	Construction professionals cannot guarantee that industrial solutions can definitely benefit property owners	Naaranoja and Uden (2007)
Lack of consumer acceptance	Users and owners often feel distrust towards innovation in industrial solutions	D'Oca et al. (2018)
Insufficient information about the proposed solutions	The lack of knowledge about available solutions is a major obstacle and is particularly relevant for energy efficiency solutions	Zhang et al. (2022)
Difficult decision-making in condominium projects	Decision making on renovation approaches is difficult, as it requires satisfying the majority of a group of owners	D'Oca et al., 2018; Ruiz-Pérez et al., 2019
Additional transportation costs	The delivery of larger modules to a job site incurs significant transportation costs	Pikas et al. (2021)
Necessity of additional coordination	Additional coordination is required, for example, with manufacturers, delivery personnel and installers	Aapoja and Haapasalo (2014)

4.2 Barriers of industrial solutions

After analysing industrial solutions implemented in renovation projects, this study identified 27 barriers that can be categorised at the project and product levels. Often, project-level barriers emanate from project-specific characteristics, whereas product-level barriers are associated with the solutions and installation techniques.

Based on the aim of our research, we analysed the documented barriers that emerge while installing industrial solutions in renovation construction projects. Table 4 presents the major project-level barriers and their explanations. These barriers evolved within the area of project management.

Analysing the semi-structured interview contents, several informants mentioned that industrial solutions were successfully adopted in their projects. However, installation in some projects proved difficult, especially because the load-bearing capacities of some old buildings prevented solutions from being installed. Moreover, the informants were equally concerned about the openings of the building structures that prevented industrial solutions from being installed at specific locations.

TABLE 5 Product-level barriers.

Barriers	Explanations	References
Achieving precise data	It is difficult to obtain the accurate dimensions of old building structures	Interview; Pikas et al., 2021
Design complexity	These involve difficulties in changing the design after the manufacturing process	Chauhan et al. (2022b)
Inappropriate installation	Some wall elements do not fit between the new 3D connections on different floors	Torres et al. (2021)
Lack of skilled workers	There is a lack of skilled workers to carry out the work	D'Oca et al. (2018)
Unavailability of spare parts	Finding spare parts is difficult while maintaining industrial solutions	Interview
Limited demand in the market	There is a limited demand in the construction sector	Zhang et al. (2022)
Higher manufacturing cost	In building an optimal prefabricated solution, it is difficult to strike a balance between structural integrity and affordability	Zhang et al. (2018)
Uncertain life span	The lifespan of an industrial solution is uncertain	D'Oca et al. (2018)

TABLE 6 Enablers of industrial solutions.

Enablers	Explanations	References
Shortened project schedule	Industrial solutions significantly shortened the project schedule	Chauhan et al. (2022a)
Possibility of owners staying during renovation	The implementation of products allowed occupants to stay at their homes while the building was renovated	Interview, Chauhan et al. (2022b)
Cost saving	Several indirect costs were saved (e.g. overhead cost)	Chauhan et al. (2022a)
Reduces waste	The amounts of material waste were reduced	Hu et al. (2022)
Improved workflow	The implementation of products helps maintain a streamlined workflow	Aapaoja and Haapasalo (2014)
Quality improvement	Product quality is monitored during the manufacturing process	Chauhan et al. (2022b)
Increased value of the apartment	The apartment value is increased due to the addition of several features of the industrial solution	Chauhan et al. (2022a)
Improved work safety	Safety is improved	D'Oca et al. (2018)
New business development	Industrial solutions can help create new market opportunities	Interview
Better energy saving approach	More eco-friendly products could be developed/ implemented	Torres et al. (2021)

In addition, a lack of trust between construction project parties and poor communication among them were prioritised during the semi-structured interviews. Multiple organisations work together during renovation so the ability to rely on other people to do what they are supposed to do can affect all project participants and how they can complete their respective tasks. Trust is about reducing risks and uncertainty through better communication. Some informants mentioned that it was difficult to obtain information from another person. Some interviewees also expressed difficulties accepting a viewpoint different from their own, which resulted in complexities in project completion.

Table 5 presents the identified product-level barriers and their explanations. Regarding these barriers, the interviewees were mainly concerned about the higher costs of industrial solutions at the first scene. However, they further explained that if all indirect costs were considered, the implementation of industrial solutions would be more beneficial than using traditional construction techniques. Moreover, the participants emphasised the inadequate industrial solutions available on the market and their limited experience in installing industrial solutions as some of the barriers they faced when implementing such solutions in renovation projects.

4.3 Enablers of industrial solutions

Based on the review of existing literature and the results of our semi-structured interviews, we identified the 10 major enablers of industrial solutions. These major enablers and their explanations are presented in Table 6.

During the semi-structured interviews, all informants highlighted the minimisation of onsite construction time as a major benefit of the implementation of industrial solutions. They further emphasised the reduction of overall project cost, which was also beneficial for indirect factors, such as minimising overall project time and reducing time-related costs (e.g., overhead cost). Furthermore, improvements in construction productivity and achieving better quality were mentioned during the interview.

5 Results of the questionnaire survey

The major purpose of the questionnaire survey was to identify the importance of each enabler and the related barriers. Such information enables project stakeholders to determine the most

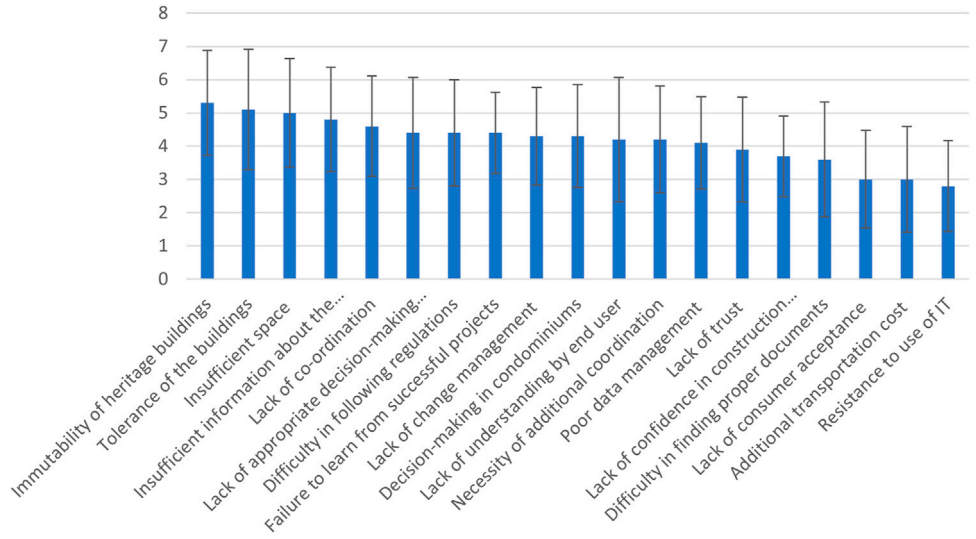

FIGURE 2
Ranking of project-level barriers based on mean and standard deviation values.

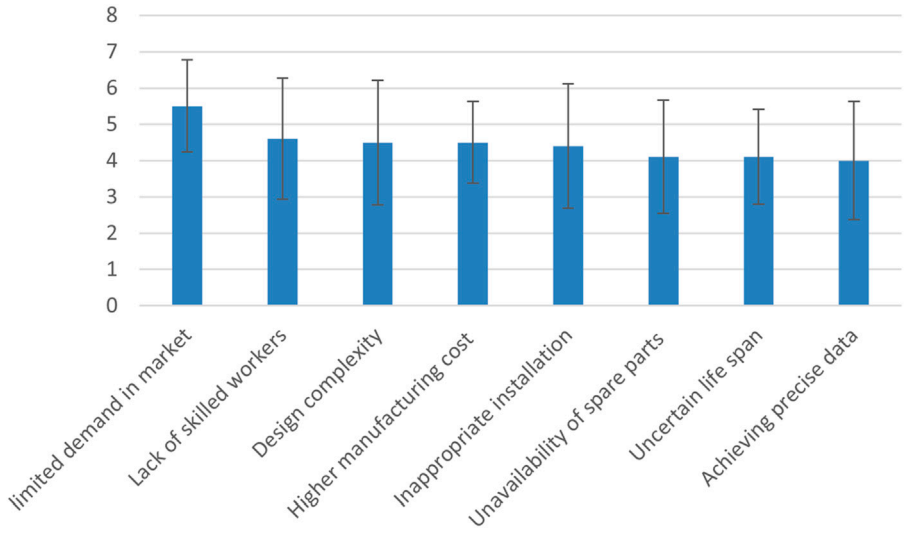

FIGURE 3
Ranking of product-level barriers based on mean and standard deviation values.

important enablers and barriers that must be considered in a renovation project. In the questionnaire survey form, the participants were asked to rank each factor on a seven-point Likert scale ranging from 7 ('very important') to 1 ('not important at all'). Then, we calculated Mean and Standard Deviation for collected data using Microsoft excel. The average score ranking was applied to compare the importance levels of the identified factors.

Based on our participants' responses, the top five most common project-level barriers were as follows: the immutability of heritage buildings, the tolerances of buildings, insufficient spaces, insufficient information about the solutions and lack of coordination (Figure 2), with the corresponding average values of 5.3, 5.1, 5.0, 4.8 and 4.6. Accordingly, the respondents' opinions on the lack of understanding by end users showed great variation with a standard deviation (SD) of 1.9. The responses regarding failure to learn from a successful project showed the least variation (SD = 1.2).

Similarly, the participants' responses regarding product-level barriers are presented in Figure 3. The results showed that the most common product-level barriers were as follows: limited demand in the market, lack of skilled workers, design complexity, higher manufacturing cost and inappropriate installation, with average values of 5.5, 4.6, 4.5, 4.5 and 4.4, respectively. The respondents' opinions on the lack of skilled workers showed great variation, with an SD value of 1.7. Their opinions on higher manufacturing costs showed the least variation (SD = 1.1).

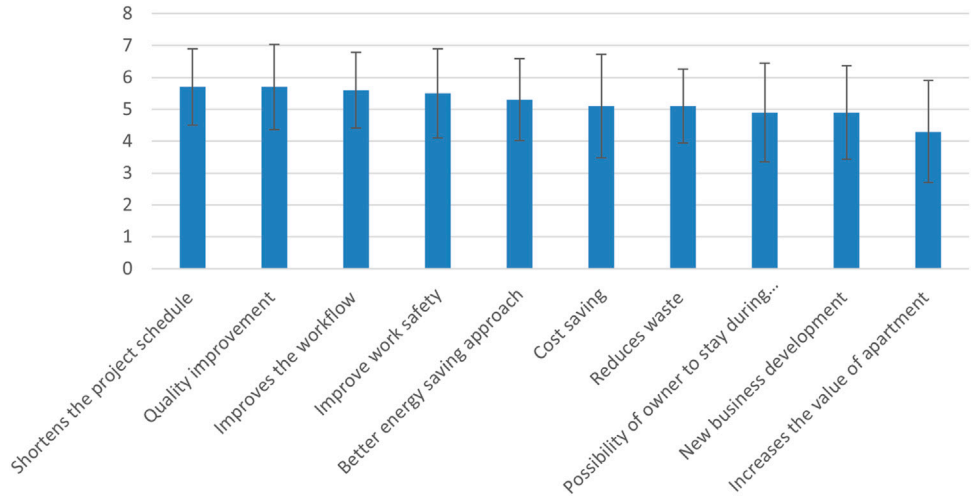

FIGURE 4
Ranking of the importance of enablers based on mean and standard deviation values.

The identified enablers of industrial solutions and our participants' responses are presented in Figure 4. From the survey responses, the most common enablers were as follows: shortened project schedule, quality improvement, improved work safety and better energy savings approach with average values of 5.7, 5.7, 5.6, 5.5 and 5.3, respectively. The respondents' opinions on cost savings mostly varied (SD = 1.6), while their responses regarding project schedule showed the least variation (SD = 1.2).

6 Discussion

The implementation of industrial solutions provides various monetary and non-monetary enablers to construction projects. Several studies have analysed and documented the enablers of these solutions (e.g., Attouri et al., 2022; Hwang et al., 2018). However, studies on the implementation of solutions in renovation construction projects remain unsatisfactory (e.g., Attouri et al., 2022). Although several studies have identified the barriers and enablers of using industrial solutions (e.g., Zhang et al., 2022; Naaranoja and Uden, 2007), these have mostly focused on new building construction.

Thus, the current research investigated the barriers and enablers of implementing industrial solutions in renovation projects. Based on a literature review, semi-structured interviews and a survey, we analysed 27 major barriers and 10 enablers. Some new barriers were identified, such as the tolerances of buildings and the immutability of old/heritage buildings, which were not previously reported in past studies. New enablers were also discussed, such as new business development in the construction ecosystem with renovation-specific solutions.

These identified barriers and enablers are specific to renovation projects and have not been discussed in previous studies in the renovation project domain (e.g., Kemmer, 2018; Hassanien, 2007; Naaranoja and Uden, 2007). In analysing the content of the semi-structed interviews, we found that the interviewees emphasised the necessity of having better awareness of the enablers of industrial solutions in renovation projects. Overall, renovation project professionals were concerned about the affordability of the industrial solutions offered. According to Bansal et al. (2017), in making decisions regarding the implementation of industrial solutions in a project, personal preferences, anecdotal evidence or direct cost-based evaluations were preferred rather than holistic and sustainable performance metrics. Along the same lines, our informants mentioned that there was no practice of adopting suitable methods to decide whether adopting industrial solutions would be beneficial for a project.

Furthermore, the interviewees emphasised the need for new marketing strategies for existing industrial solutions. A detailed systematic investigation of industrial solutions and their corresponding enablers should be adopted. To date, no study has been conducted to develop marketing strategies for industrial solutions. A recent study (Chauhan et al., 2022a) presented a prefabrication impact measurement method based on which the authors evaluated a few industrial solutions. Their results clearly presented the overall cost of industrial solutions, which was much lower than that of the traditional method of construction. For example, their results could be adopted for marketing purposes.

Additionally, the feedback from interviewees suggests that decision-making processes in renovation projects often rely on direct cost evaluations rather than holistic performance metrics. This indicates a gap in the current decision-making frameworks that could be addressed by developing comprehensive evaluation methods that consider both short-term and long-term enablers of industrial solutions.

While the findings of this study provide valuable insights, the small number of survey responses is a limitation that should be addressed in future research. Expanding the sample size and conducting more extensive surveys would enhance the reliability and generalizability of the results. Moreover, investigating digital marketing strategies and other innovative approaches could further support the adoption of industrial solutions in renovation projects.

7 Conclusion

This research analysed the barriers and enablers of industrial solutions implemented in renovation projects using a mixed methods approach featuring a literature review, semi-structured interviews and a questionnaire survey. The implementation of solutions in renovation projects is more complex than in new construction projects. Although previous studies (e.g., Junnonen, 2012) have investigated the enablers and barriers of implementing industrial solutions in the context of the Finnish construction industry, they have failed to reflect recent changes in the industry. In addition, previous studies have documented multiple enablers and barriers, but they did not identify the most important barriers and enablers for construction professional planning in relation to the implementation of industrial solutions.

This study identified 27 barriers that can be categorised at the project level (appearing at the management level) and at the product level (mostly appearing during the installation and technical part of the solutions). Among the identified barriers, the most severe was the limited demand for industrial solutions in the market. This is mainly due to a lack of awareness of the enablers of implementing industrial solutions in renovation projects. The immutability of heritage buildings is identified as a second major challenge. Similarly, the tolerances of old buildings, which prevented the installation of industrial solutions, and the insufficient spaces to ensure construction work safety and damage prevention were identified as the third and fourth major barriers. In general, the findings indicated that the most important barriers were at the project level rather than at the product level.

Accordingly, this study identified 10 enablers of industrial solutions. The major enablers were shortened project schedule, quality improvement, work safety improvement, energy savings and cost savings. In renovation projects, shorter project schedules can have a significant impact on a building's occupants. It can help minimise the evacuation time for existing building users, which is particularly important for hospitals, schools and other buildings where people spend a great deal of time. Additionally, shorter project schedules allow individuals to use the building during construction, which can be a significant advantage for businesses or organisations that cannot afford to shut down completely during renovation projects.

The enablers related to quality improvement and work safety improvement are highly similar to those in new construction projects. However, our research findings can help identify specific areas of concern in older buildings that must be addressed to further improve quality and safety. For example, our findings could be useful in identifying materials or systems that must be replaced due to safety concerns or those that can help improve building performance. Similarly, the issue of energy savings could be particularly relevant in renovation projects because older buildings are typically less energy-efficient than newer buildings. Our findings can help identify products and solutions that can be easily installed to improve a building's energy efficiency. For example, replacing outdated HVAC systems or adding insulation can significantly reduce energy consumption and lower energy costs.

In conclusion, this study provides new perspective in renovation project by analyzing the barriers and enablers that impact industrial solutions. These enablers in renovation projects, including shorter project schedules, quality improvement, work safety improvement and energy savings provide actionable insights for policymakers, designers, and contractors, offering guiding principles to enhance decision-making processes and create viable solutions for the obstacles encountered in renovation projects. By focusing on the unique context of renovation projects and employing a robust mixed-method approach, this study represents a vital step towards the efficient and effective implementation of industrial solutions in these projects. This, in turn, contributes to more sustainable and cost-effective outcomes, advancing the field towards better practices in renovation using industrialized methods.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

KC: Writing–original draft. AP: Writing–review and editing. RL: Writing–review and editing. OS: Writing–review and editing.

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Conflict of interest

Author RL was employed by VTT Technical Research Centre of Finland.

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Publisher's note

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