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Enhancing Productivity and Quality in Korean Modular Housing through Smart Factory Integration

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Abstract

Purpose: Korea's construction industry has faced declining productivity and quality issues due to labor-intensive onsite construction and variables like weather, material price fluctuations, and labor shortages. The modular housing industry, introduced in Korea in 2003, offered benefits like reduced construction time and enhanced productivity through offsite manufacturing. However, its adoption remains limited due to high costs, quality concerns, and low consumer acceptance**. Research Design, Data, and Methodology:** This study explores the feasibility and impact of implementing smart factory technologies in the modular housing industry to overcome these barriers. Using survey data from 179 construction industry experts, the study employs frequency and regression analysis to identify key factors influencing the adoption of modular housing and the effectiveness of smart factories. Findings suggest that government-led educational programs and strong policy support are essential for successful implementation, enhancing productivity, reducing costs, and improving quality. **Conclusions:** The study emphasizes the need for standardization of modular housing, deregulation of relevant laws, and increased public awareness to stimulate market growth and innovation. Policy recommendations include financial support for modular manufacturers transitioning to smart factories, ensuring stable supply volumes, and promoting the benefits of modular housing to consumers. Integrating smart factory technologies can lead to significant advancements in the modular housing industry, contributing to the sustainable development and modernization of Korea's construction sector.

Keywords: Modular Housing, Smart Factory, Construction Industry, Producitvity Improvement, Policy Support

JEL Classification Code : R30, R31, R32, R38

1. Introduction

Over the past decade, the Korean construction industry has faced significant declines in productivity and quality. The primary issue with onsite construction is its inherently low productivity (Eastman & Sacks, 2008). Since most construction processes occur outdoors, unforeseen variables such as inclement weather, material price surges, and limitations on the influx of foreign labor, particularly due to the COVID-19 pandemic, have adversely impacted productivity and quality. Additionally, the harsh working conditions, compared to other manufacturing industries, have led to a continuous decline in the influx of young skilled workers (from 38% to 16%), while the existing workforce is aging. The proportion of foreign workers in

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construction is significantly increasing, underscoring the industry's reliance on this labor segment. Moreover, the construction industry is classified as the slowest among secondary industries to adopt automation due to its project-based and outdoor nature. Consequently, construction activities heavily rely on manual labor and require a large workforce (Kisi et al., 2017).

To address these challenges, the modular housing industry, a segment of Off-Site Construction (OSC), was introduced in Korea in 2003. Modular housing allows for simultaneous site work, such as excavation and foundation, and factory production of housing units, leading to reduced construction time (Lawson et al., 2012). By conducting construction tasks both onsite and in the factory concurrently, modular housing can reduce the construction period by approximately 20-50% compared to traditional construction methods (Boyd et al., 2013). In terms of productivity, while traditional construction is temporary and environmentally vulnerable, modular housing can lower labor dependency through automation and standardization in factory production, resulting in an estimated 60% improvement in productivity (Bertram et al., 2019).

Despite these advantages, the adoption of modular housing in Korea remains limited to public rental housing projects and pilot projects for dormitories and military accommodations by private companies. The government, academia, and the modular industry have analyzed various barriers to the adoption of modular housing and have made several attempts to address them. Efforts include analyzing and reducing the high implementation costs of modular housing, overcoming technical limitations such as vibration and noise, developing moisture-proofing technologies, and improving assembly techniques. Additionally, research has been conducted on applying Building Information Modeling (BIM) to increase productivity in factory operations. The psychological mechanisms of customers and technicians have also been analyzed using the Technology Acceptance Model (TAM) (Sin et al., 2022), revealing insights into their attitudes and acceptance levels.

Nevertheless, modular housing in South Korea is still overlooked by customers and technicians compared to traditional construction methods in terms of cost, technology, and quality. Even with the recent rise in domestic construction costs, making it difficult for construction companies to start projects, modular housing is not considered an alternative to the existing wet construction methods. This study seeks to understand and analyze the fundamental issues preventing the activation of modular housing by identifying the level of awareness among experts. Therefore, this study aims to analyze the factors hindering the widespread adoption of modular housing in South Korea through a survey of construction industry experts, contributing to the development of future activation strategies.

2. Literature Review and Distinction

2.1. Literature Review

Recent studies on modular housing include numerous papers that have thoroughly examined various aspects of the modular construction method. Each study focuses on specific topics such as efficiency, safety, productivity, residential satisfaction, and the promotion of modular construction.

2.1.1. Process Studies

Lee Hyun-Jung et al. (2020): This study identified safety risk factors in the factory production process of modular construction and evaluated their importance, providing foundational data to enhance safety in factory production stages. Jung Jin-Hak et al. (2020): This research identified risk factors at each stage of modular construction and analyzed their importance, suggesting ways to manage risks efficiently at each stage. Nam Seong-Hoon et al. (2019): This study selected the optimal factory production process for modular buildings to enhance efficiency. Lee Joo-Sung et al. (2017): Developed a BIM-based simulation framework to meticulously plan and manage the design and construction processes of modular methods. Kim Jung-Kyung et al. (2014): Improved the factory production process of residential buildings' modular systems, analyzing problems in existing processes and proposing efficient improvements.

Kim Tae-Yoon et al. (2013): Optimized the factory production process of modular units using the Design Structure Matrix (DSM), minimizing interdependencies between processes and maximizing efficiency. Lee Kwang-Bok et al. (2011): Proposed an overall process including factory production, transportation, and installation to ensure the efficiency of unit modular methods, aiming for integrated management of the entire process.

2.1.2. Productivity Studies

Ma Jong-Hyun et al. (2023): Analyzed factors hindering productivity in modular production and proposed measures for improvement, providing specific directions for productivity enhancement. Kwon Jae-Hwan et al. (2023): Conducted a study on applying BIM (Building Information Modeling) to modular construction, exploring ways to improve design and construction efficiency.

Lee Won-Bae et al. (2021): Conducted research to shorten the production period during the factory production stage of modular construction, proposing measures to increase production speed and reduce costs. Kim Sang-Cheol et al.

(2024): Analyzed the issues of the Prefabricated Prefinished Volumetric Construction (PPVC) method and proposed measures for improvement, suggesting specific solutions to enhance the applicability of the PPVC method.

2.1.3. Safety Studies

Jeon Jong-Bae et al. (2024): conducted a comprehensive study focusing on the improvement of building safety through the implementation of modular construction techniques. Their research delved into a variety of technical and managerial measures designed to elevate safety standards within the construction industry. The study systematically explored the potential of modular construction to not only streamline building processes but also enhance safety outcomes by reducing the risks associated with traditional construction methods.

The team outlined specific technical strategies that include the use of advanced materials and prefabrication methods that ensure better quality control and consistency in construction elements. They also highlighted the importance of integrating safety protocols right from the design phase, ensuring that modular components are engineered with safety as a paramount consideration.

2.1.4. Residential Satisfaction Studies

An Jeong-Wook et al. (2023): Analysed factors influencing the residential satisfaction of modular housing occupants through two studies and proposed measures for improvement, deriving specific methods to enhance the living environment of modular housing. This type of research is critical as it not only addresses the immediate needs of modular housing occupants but also contributes to the broader goals of sustainability and efficiency in the construction industry. It provides valuable insights for manufacturers, designers, and urban planners involved in the development and deployment of modular housing solutions. By understanding and improving the factors that affect residential satisfaction, stakeholders can ensure that these homes are not only efficient and sustainable but also desirable places to live.

2.1.5. Activation Studies

Bae Ju-Heon et al. (2023): analysed the economic feasibility of the steel modular method through life cycle cost analysis, proving the long-term economic benefits of the steel modular method. Shin Ji-Woong et al. (2022): Analysed the acceptance mechanisms of modular construction in Korea, seeking ways for modular construction to be more actively accepted in the domestic market. Jeong Hye-Jin et al. (2020): Studied ways to activate the application of modular methods to small public buildings, suggesting ways to increase the applicability of modular methods in the public sector. Yoon Hong-Min et al. (2021): Conducted a comparative study on procurement methods for activating public modular housing, analysing the pros and cons of different procurement methods to enhance the efficiency of public modular housing projects.
Kim Ji-Hoon et al. (2017): analysed and proposed improvements to waterproofing methods for container-type modular housing in Korea, seeking ways to enhance the durability and living convenience of modular housing.

2.1.6. Comprehensive Analysis of Research Contributions

These studies have provided a solid foundational research base for the modular housing industry in Korea. To improve productivity, they optimized factory processes and applied advanced technologies such as BIM to enhance production efficiency. For economic improvements, they analyzed the costs of modular construction to identify issues and aimed to create a safer and more reliable construction environment. Additionally, they studied the needs of modular housing residents to improve residential satisfaction. To invigorate the modular market, they conducted economic analyses and aimed to provide strategic insights.

2.2. Distinction

This study focuses on analyzing the necessity and impact of adopting smart factory technologies to revitalize the Korean modular housing industry. The distinctiveness of this study compared to existing research lies in several key areas.

First, while previous studies have primarily concentrated on specific aspects such as productivity, cost reduction, and quality improvement, this study comprehensively analyzes the impact of smart factory adoption on the modular housing industry. This comprehensive analysis includes evaluations of productivity, quality, and cost from multiple perspectives.

Second, the study conducts quantitative analysis through expert surveys. By gathering data from professionals currently working in the Korean construction industry, this study reflects the real opinions of field experts, providing insights not only from theoretical analysis but also from practical perspectives.

Third, the research identifies barriers to the activation of the modular housing industry and explores various technical and economic solutions to overcome these obstacles. This approach offers multifaceted strategies for the sustainable development of the modular housing industry.

Through an integrated and comprehensive approach, this study aims to analyze the necessity and effects of adopting smart factory technologies and provide specific policy recommendations. By doing so, it seeks to contribute to the revitalization and sustainable development of the Korean modular housing industry. The distinctiveness of this study ensures that it provides significant foundational data for practical policy formulation and stands out from existing research in the field.

3. Framework of Analysis

3.1. Research Methodology

The dataset used in this study was meticulously compiled through a survey conducted among experts in the construction industry. This dataset serves as the foundation for comprehensive quantitative analysis. The analytical approach includes frequency analysis, which investigates the distribution and prevalence of various responses within the data. Next, ANOVA (Analysis of Variance) and Bonferroni post-hoc tests are employed to analyze the perception differences between groups based on their experience in the construction industry.

These multifaceted analytical techniques collectively contribute to a comprehensive understanding of the fundamental patterns and insights summarized in the expert responses. By employing a diverse array of methodologies, the analysis can capture a wide spectrum of perspectives, ensuring that no single aspect of the data is overlooked. This integrative approach allows for a more nuanced interpretation, enabling experts to identify key trends and underlying principles with greater accuracy. Consequently, the synthesized insights derived from this thorough examination provide a robust foundation for informed decision-making and strategic planning, reflecting the depth and breadth of the expert analysis.

3.2. Overview of the Survey

The expert survey on construction conducted in this study was carried out as follows. The survey aimed to gather expert opinions to promote the modular housing industry through the introduction of smart factories in the country. The survey comprised seven sections, each covering understanding of modular housing, the necessity for activation, the need for smart factory introduction, expected benefits and potential issues, and policy support matters. Additionally, to encourage respondents to clearly express their positions and facilitate easy data analysis by eliminating neutral responses, a 4-point Likert scale was used. The survey targeted experts currently working in the construction industry. The questions were designed using Google Forms and the survey was conducted online with 188 professional participants. The primary goal of this survey is to identify and develop effective strategies to promote the adoption of modular housing in the domestic housing market. Considering the focus of this study, it was deemed essential to obtain directly relevant data from individuals engaged in various capacities within the current national construction sector.

Details of the survey are listed in Table 2 under the title 'Expert Survey.' This survey aimed to gather insights from a broad sample of 188 experts directly involved in the construction industry. The survey period was set from July 3, 2024, to July 15, 2024, chosen to provide respondents ample time to thoughtfully complete the survey.

3.3. Research Hypotheses

This study evaluates the perception and recognition of issues related to the application of modular housing among different career groups, based on hypotheses set to analyze the impact of smart factory adoption on the activation of modular housing. Unlike traditional construction methods, modular housing involves assembling pre-manufactured modules at the site, offering several advantages such as reduced construction time, cost savings, and ease of quality control. Emphasizing the need for smart factory adoption to fully utilize these benefits of modular housing.

A smart factory aims to optimize production processes and maximize efficiency through digital technologies and automated systems, creating an innovative manufacturing environment. Introducing a smart factory in the production of modular housing can result in improved quality, increased production efficiency, and cost savings. However, there is insufficient research on how the introduction of such innovative technology impacts the perception differences among construction experts based on their career groups.

Therefore, this study sets two main hypotheses:

H1: There are differences in perceptions among experienced groups regarding the application of smart factories in modular housing.

H1-1. Producing high-quality modulars through smart factory adoption will help restore consumer confidence.

H1-2. When constructing large-scale, mid-rise modular housing, there will be a significant reduction in actual construction time.

H1-3. Enhancing production efficiency of modular housing through smart factory application will help activate the modular industry.

H1-4. Reducing production costs of modular housing through smart factory application will help activate the modular industry.

H1-5. The quality of modular housing will be improved through smart factory application.

H2: There will be differences in recognizing the anticipated issues of applying smart factories to the modular housing industry among different career groups.

H2-1. Applying smart factories will incur excessive initial investment costs.
H2-2. Establishing a smart factory for the modular industry may result in losses due to low initial operational rates.
H2-3. Smart factory application may show low efficiency due to lack of operational experience.
H2-4. It will be challenging to secure stable volumes until the domestic modular industry grows.

4. Results and Discussion

4.1. The Characteristics of a Respondent

This section provides an in-depth analysis of the demographic characteristics of the construction industry experts who participated in the survey, categorized by gender, age, residence area, occupation, and experience.

Table 1 : Frequency Analysis of Respondents

Category	Classification	The number of People	Proportion (%)
Gender	Male	162	86.2
	Female	26	13.8
Age	20s to 40s	16	8.5
	40s to 50s	40	21.3
	50s to 60s	106	56.4
	Over 60	26	13.8
Residence Area	Seoul	64	34
	Gyeonggi + Incheon	105	55.9
	Non-metropolitan	19	10.1
Occupation	Public Agent	134	71.3
	Construction Manager	50	26.6
	Academia	4	2.1
Experience	Less than 1-10 years	34	18.1
	Less than 10-20 years	35	18.6
	Less than 20-30 years	64	34
	Over 30 years	55	29.3

This descriptive analysis categorizes the demographic characteristics of construction industry experts who responded to the survey, based on gender, age, residence area, occupation, and experience.

- **Gender:** Reflecting the nature of the construction industry, most survey respondents are male, accounting for 86.2% (162 individuals), while females make up 13.8% (26 individuals).
- **Age:** Most respondents are in their 50s to 60s (56.4%), indicating a significant proportion of experts with over 20 years of experience in the construction industry. Those in their 40s to 50s constitute 21.3%, individuals over 60 years account for 13.8%, and those in their 20s to 40s represent the smallest group at 8.5%.
- **Residence Area:** Most respondents reside in Gyeonggi and Incheon (55.9%), with 34% living in Seoul and 10.1% in non-metropolitan areas.
- **Occupation:** Most respondents work in public institutions or are public officials (71.3%), followed by construction managers (26.6%), and a small percentage are in academia (2.1%).
- **Experience:** The largest group has 20 to 30 years of experience (34%), followed by those with over 30 years (29.3%), 10 to 20 years (18.6%), and 1 to 10 years (18.1%).

This demographic analysis highlights a predominantly male, experienced population residing mainly in metropolitan areas, primarily employed as public officials.

Table 2: Frequency Analysis: Smart Factory in Modular Housing

Category	(1) Very negative	(2) Negative	(3) Positive	(4) Very Positive
Ensure Consumer Trust High Quality Modular	4	4	98	82
	2%	2%	52%	44%
Effect Reducing Construction Time	6	8	107	67
	3%	4%	57%	36%
Increased Production Efficiency	4	10	114	60
	2%	5%	61%	32%
Cost Reduction	4	23	108	53
	2%	12%	57%	28%
Improved Quality Control	6	24	108	50
	3%	13%	57%	27%
Excessive Initial Investment Cost	2	11	106	69
	1%	6%	56%	37%
Loss Due to Low Initial Factory Utilization	3	9	102	74
	2%	5%	54%	39%
Low Efficiency Due to Lack of Smart Factory Experience	1	17	125	45
	1%	9%	66%	24%
Difficulty Securing Stable Volume	2	7	95	84
	1%	4%	51%	45%
Stable Order Support Until Activation Stage	3	13	103	69
	2%	7%	55%	37%
Government Led Training of Modular Specialists	5	40	98	45
	3%	21%	52%	24%
Standardization of Modular Housing	2	13	100	73
	1%	7%	53%	39%
Deregulation of Modular Housing	2	8	107	71
	1%	4%	57%	38%
Public Promotion of Modular Housing	5	18	113	52
	3%	10%	60%	28%
Total	49	205	1484	894
	2%	8%	56%	34%

Frequency analysis was conducted to measure the occurrence of values within the dataset and understand the distribution of data. Respondents rated various items on a scale from 1 to 4 to gauge their perceptions of modular housing.

- **General Perceptions:** Most responses for each category fall within the "positive" or "very positive" ratings, indicating a generally favorable perception of modular housing among construction industry professionals. The combined positive and very positive responses typically exceed 80%, suggesting strong support for modular housing concepts.
- **High Quality Modular:** An impressive 96% of respondents (52% positive, 44% very positive) believe that high-quality modular housing ensures consumer trust. This high level of agreement underscores the importance of quality assurance in modular housing acceptance.
- **Reduction in Construction Time:** Most respondents (93%) view the reduction in construction time positively, highlighting one of the key advantages of modular housing. This aligns with the industry's need for faster project completion.
- **Production Efficiency:** Increased production efficiency is also seen positively by 93% of respondents, indicating recognition of the efficiency gains possible through modular construction.
- **Cost Reduction:** While 85% of respondents see cost reduction as a positive aspect of modular housing, a notable 12% rate it negatively, suggesting some skepticism about the cost-saving potential.
- **Initial Investment:** Despite the high support for modular housing benefits, 56% of respondents acknowledge the issue of excessive initial investment costs, which could be a significant barrier to broader adoption.

Table 3: Expected benefits of applying smart factory technology to modular housing

Category	The number of people	Percent	Valid Percent	Cumulative Percent
Cost reduction	13	6.9	6.9	6.9
Increased Quality	11	5.9	5.9	12.8
Reducing construction time	122	64.9	64.9	77.7
Saving Labor	42	22.3	22.3	100.0
Total	188	100.0	100.0	

- **Key Benefits:** The most anticipated benefit of applying smart factory technology to modular housing is reducing construction time (64.9%), followed by saving labor 22.3%). This highlights the industry's focus on efficiency and labor optimization.

industry experts. The results of this analysis show that construction industry professionals have a positive perception of modular housing.

The most anticipated benefit of modular housing is the reduction in construction time, followed by labor savings,

- **Quality and Cost:** Despite the emphasis on time and labor savings, only a small proportion of respondents see cost reduction (6.9%) and increased quality (5.9%) as primary benefits, suggesting that these factors, while important, are secondary to efficiency improvements.

Table 4 : Stage Modular Housing Market

Category	The number of people	Percent	Valid Percent	Cumulative Percent
Growth Stage	29	15.4	15.4	15.4
Introduction Stage	154	81.9	81.9	97.3
Maturity Stage	4	2.1	2.1	99.5
Saturation Stage	1	0.5	0.5	100.0
Total	188	100.0	100.0	

- **Market Stage:** A vast most of respondents (81.9%) believe that modular housing is still in the introduction stage, indicating that the market is relatively new but has significant growth potential. Only a small fraction sees it in the growth (15.4%), maturity (2.1%), or saturation stages (0.5%).

Table 5: Main Obstacles Activating Modular Housing

Category	The number of people	Percent	Valid Percent	Cumulative Percent
Concerns About Quality and Reliability	64	34.0	34.0	34.0
Economic Barriers	53	28.2	28.2	62.2
Industry and Cultural Resistance	40	21.3	21.3	83.5
Legal and Regulatory Barriers	31	16.5	16.5	100.0
Total	188	100.0	100.0	

- **Primary Barriers:** The primary obstacles to the activation of modular housing are concerns about quality and reliability (34%), economic barriers (28.2%), and industry and cultural resistance (21.3%). Legal and regulatory barriers are considered less significant (16.5%) but still relevant.
- **Quality Concerns:** The high proportion of respondents concerned about quality and reliability suggests that addressing these issues is critical for broader acceptance of modular housing.

The survey data on modular housing was analyzed to understand the distribution and general perceptions among cost reduction, and quality improvement. Most respondents believe that modular housing is still in the introductory stage, indicating that it is relatively new in the market but has significant growth potential.

The main obstacles to the activation of modular housing are concerns about quality and reliability, economic challenges, resistance to new technologies, and legal regulations. The survey results, analyzed through frequency analysis, can be used to improve modular housing, identify and address these concerns, and develop strategies to promote market activation.

4.3. ANOVA Analysis

This study utilized one-way analysis of variance to analyze the perception difference regarding the activation of modular housing based on career differences among a group of construction industry professionals. ANOVA was used to analyze the perception differences regarding the activation of modular housing based on career differences among construction industry professionals. Levene's test results showed homogeneous variances among all groups ($p > 0.05$).

Table 6: Levene Statistic

Category		Levene Statistic
Effects	Ensure Consumer Trust High Quality Modular	2.011
	Effect Reducing Construction Time	0.059
	Increased Production Efficiency	0.316
	Cost Reduction	1.172
	Improved Quality Control	0.778
Problems	Excessive Initial Investment Cost	0.020
	Loss Due to Low Initial Factory Utilization	1.677
	Low Efficiency Due to Lack of Smart Factory Experience	1.155
	Difficulty Securing Stable Volume	0.878

The analysis revealed significant differences among career groups regarding several key factors in the construction industry. These key factors include productivity, operational efficiency, and the adoption rate of advanced technologies. The post hoc test results highlight how professionals with different career backgrounds and experiences perceive and benefit from smart factory implementations in diverse ways. This detailed analysis helps to identify specific areas where smart factory effects may vary significantly, offering valuable insights for targeted improvements and strategic decision-making.

Firstly, significant differences were found in the reduction in construction time among career groups ($p = 0.000$). Post hoc analysis indicated that professionals with over 30 years of experience had a more positive perception of reduced construction time compared to those with 1-10 years and 20-30 years of experience.

Similarly, increased production efficiency also displayed significant differences ($p = 0.000$). The over 30 years career group held a more favorable view of production efficiency than all other groups.

Regarding cost reduction, significant differences were found ($p = 0.000$). Professionals with over 30 years of experience viewed cost reduction more positively compared to those with 1-10 years and 20-30 years of experience.

In terms of improved quality control, significant differences were identified ($p = 0.000$). The over 30 years career group had a more positive view of improved quality control compared to those with 1-10 years and 20-30 years of experience.

Lastly, significant differences were found regarding the perception of low efficiency due to a lack of smart factory experience ($p = 0.006$). The analysis indicates that individuals with over 30 years of experience in the construction industry viewed the lack of smart factory experience more negatively compared to those with 1-10 years of experience. This finding suggests that seasoned professionals may perceive greater challenges and inefficiencies associated with the adoption of smart factory technologies, likely due to their extensive background and familiarity with traditional methods. In contrast, those with less experience may be more adaptable and less critical of the learning curve involved in implementing new technologies. Understanding these perceptions is crucial for designing effective training programs and support systems tailored to different experience levels, ultimately facilitating a smoother transition to smart factory practices across the industry.

Table 7 provides a detailed explanation of the post hoc test conducted to analyze the differences in the effects of smart factories among different groups. This table aims to illustrate the statistical significance and the extent of the variations observed between the groups in the context of smart factory implementations. By examining these differences, the post hoc test helps to identify specific areas where smart factory effects may vary significantly, thus offering valuable insights for targeted improvements and strategic decision-making.

Table 7: Post hoc test for group differences in smart factory effects

Dependent Variable	(I) Career	(J) Career	Mean Difference(I-J)	Std. Error	Significance	95% Confidence Interval	
						Lower Bound	Upper Bound
Ensure Consumer Trust High Quality Modular	1-10 years	10-20 years	0.043	0.152	1.000	-0.362	0.447
		20-30 years	0.078	0.134	1.000	-0.278	0.435
		Over 30 years	0.318	0.137	0.130	-0.048	0.685
	10-20 years	1-10 years	-0.043	0.152	1.000	-0.447	0.362
		20-30 years	0.035	0.132	1.000	-0.318	0.388
		Over 30 years	0.275	0.136	0.268	-0.088	0.639
	20-30 years	1-10 years	-0.078	0.134	1.000	-0.435	0.278
		10-20 years	-0.035	0.132	1.000	-0.388	0.318
		Over 30 years	0.240	0.116	0.237	-0.069	0.549
	Over 30 years	1-10 years	-0.318	0.137	0.130	-0.685	0.048
		10-20 years	-0.275	0.136	0.268	-0.639	0.088
		20-30 years	-0.240	0.116	0.237	-0.549	0.069
Effect Reducing Construction Time	1-10 years	10-20 years	0.244	0.157	0.732	-0.175	0.662
		20-30 years	0.170	0.138	1.000	-0.199	0.539
		Over 30 years	.602*	0.142	0.000	0.223	0.981
	10-20 years	1-10 years	-0.244	0.157	0.732	-0.662	0.175
		20-30 years	-0.074	0.137	1.000	-0.439	0.292
		Over 30 years	0.358	0.141	0.070	-0.017	0.734
	20-30 years	1-10 years	-0.170	0.138	1.000	-0.539	0.199
		10-20 years	0.074	0.137	1.000	-0.292	0.439
		Over 30 years	.432*	0.120	0.002	0.113	0.752
	Over 30 years	1-10 years	-.602*	0.142	0.000	-0.981	-0.223
		10-20 years	-0.358	0.141	0.070	-0.734	0.017
		20-30 years	-.432*	0.120	0.002	-0.752	-0.113
Increased Production Efficiency	1-10 years	10-20 years	0.155	0.146	1.000	-0.234	0.545
		20-30 years	0.082	0.129	1.000	-0.261	0.425
		Over 30 years	.550*	0.132	0.000	0.198	0.903
	10-20 years	1-10 years	-0.155	0.146	1.000	-0.545	0.234
		20-30 years	-0.074	0.127	1.000	-0.414	0.266
		Over 30 years	.395*	0.131	0.018	0.045	0.744
	20-30 years	1-10 years	-0.082	0.129	1.000	-0.425	0.261
		10-20 years	0.074	0.127	1.000	-0.266	0.414
		Over 30 years	.468*	0.111	0.000	0.171	0.766
	Over 30 years	1-10 years	-.550*	0.132	0.000	-0.903	-0.198
		10-20 years	-.395*	0.131	0.018	-0.744	-0.045
		20-30 years	-.468*	0.111	0.000	-0.766	-0.171
Cost Reduction	1-10 years	10-20 years	0.151	0.159	1.000	-0.272	0.575
		20-30 years	-0.003	0.140	1.000	-0.376	0.371
		Over 30 years	.512*	0.144	0.003	0.128	0.896
	10-20 years	1-10 years	-0.151	0.159	1.000	-0.575	0.272
		20-30 years	-0.154	0.139	1.000	-0.524	0.216
		Over 30 years	0.361	0.143	0.073	-0.019	0.742
	20-30 years	1-10 years	0.003	0.140	1.000	-0.371	0.376
		10-20 years	0.154	0.139	1.000	-0.216	0.524
		Over 30 years	.515*	0.121	0.000	0.192	0.839
	Over 30 years	1-10 years	-.512*	0.144	0.003	-0.896	-0.128
		10-20 years	-0.361	0.143	0.073	-0.742	0.019
		20-30 years	-.515*	0.121	0.000	-0.839	-0.192

Improved Quality Control	1-10 years	10-20 years	0.035	0.167	1.000	-0.410	0.481
		20-30 years	0.032	0.147	1.000	-0.360	0.425
		Over 30 years	.490*	0.151	0.009	0.086	0.893
	10-20 years	1-10 years	-0.035	0.167	1.000	-0.481	0.410
		20-30 years	-0.003	0.146	1.000	-0.392	0.386
		Over 30 years	.455*	0.150	0.017	0.055	0.855
	20-30 years	1-10 years	-0.032	0.147	1.000	-0.425	0.360
		10-20 years	0.003	0.146	1.000	-0.386	0.392
		Over 30 years	.458*	0.128	0.003	0.118	0.798
	Over 30 years	1-10 years	-.490*	0.151	0.009	-0.893	-0.086
		10-20 years	-.455*	0.150	0.017	-0.855	-0.055
		20-30 years	-.458*	0.128	0.003	-0.798	-0.118

Hypothesis 1: Differences in perceptions of modular housing

The analysis of consumer trust, reduction in construction time, increased production efficiency, cost reduction, and improved quality control revealed distinct perceptions among different career groups.

Firstly, concerning consumer trust, the ANOVA results indicated no significant differences among career groups regarding the impact of high-quality modular housing (p = 0.062). This finding suggests a consensus across all career groups that high-quality modular housing positively influences consumer trust. Additionally, post hoc tests confirmed no significant differences in pairwise comparisons for consumer trust, as all p-values exceeded 0.05.

In contrast, significant differences emerged concerning the reduction in construction time. The ANOVA results (p = 0.000) highlighted those professionals with over 30 years of experience had a significantly more positive perception of reduced construction time compared to those with 1-10 years (Mean Difference = 0.602, p = 0.000) and those with 20-30 years of experience (Mean Difference = 0.432, p = 0.002).

Similarly, the perception of increased production efficiency varied significantly among career groups, as evidenced by ANOVA results (p = 0.000). Post hoc tests revealed that the over 30 years career group held a more favorable view on production efficiency than all other groups: 1-10 years (Mean Difference = 0.550, p = 0.000), 11-20 years (Mean Difference = 0.395, p = 0.018), and 20-30 years (Mean Difference = 0.468, p = 0.000).

Regarding cost reduction, the ANOVA results indicated significant differences among career groups (p = 0.000). Specifically, professionals with over 30 years of experience viewed cost reduction more positively than those with 1-10 years (Mean Difference = 0.512, p = 0.003) and the 20-30 years group (Mean Difference = 0.515, p = 0.000). No significant differences were found between other groups, as all p-values exceeded 0.05.

Lastly, significant differences were also observed in the perception of improved quality control (p = 0.000). Post hoc tests showed that professionals with over 30 years of experience had a more positive view of improved quality control compared to those with 1-10 years (Mean Difference = 0.490, p = 0.009) and those with 20-30 years of experience (Mean Difference = 0.458, p = 0.003). Again, no significant differences were noted between other groups, as all p-values were greater than 0.05.

Table 9: Post hoc test for group differences in smart factory Problems

Dependent Variable	(I) Career	(J) Career	Mean Difference(I-J)	Std. Error	Significance	95% Confidence Interval	
						Lower Bound	Upper Bound
Excessive Initial Investment Cost	1-10 years	10-20 years	-0.018	0.148	1.000	-0.413	0.378
		20-30 years	0.054	0.131	1.000	-0.295	0.403
		Over 30 years	0.273	0.134	0.261	-0.085	0.632
	10-20 years	1-10 years	0.018	0.148	1.000	-0.378	0.413
		20-30 years	0.072	0.130	1.000	-0.274	0.417
		Over 30 years	0.291	0.133	0.182	-0.064	0.646
	20-30 years	1-10 years	-0.054	0.131	1.000	-0.403	0.295
		10-20 years	-0.072	0.130	1.000	-0.417	0.274
		Over 30 years	0.219	0.113	0.329	-0.083	0.521
	Over 30 years	1-10 years	-0.273	0.134	0.261	-0.632	0.085

		10-20 years	-0.291	0.133	0.182	-0.646	0.064
		20-30 years	-0.219	0.113	0.329	-0.521	0.083
Loss Due to Low Initial Factory Utilization	1-10 years	10-20 years	0.014	0.152	1.000	-0.390	0.419
		20-30 years	0.266	0.134	0.290	-0.091	0.622
		Over 30 years	0.318	0.137	0.130	-0.048	0.684
	10-20 years	1-10 years	-0.014	0.152	1.000	-0.419	0.390
		20-30 years	0.251	0.132	0.355	-0.102	0.604
		Over 30 years	0.304	0.136	0.161	-0.059	0.667
	20-30 years	1-10 years	-0.266	0.134	0.290	-0.622	0.091
		10-20 years	-0.251	0.132	0.355	-0.604	0.102
		Over 30 years	0.053	0.116	1.000	-0.256	0.361
	Over 30 years	1-10 years	-0.318	0.137	0.130	-0.684	0.048
		10-20 years	-0.304	0.136	0.161	-0.667	0.059
		20-30 years	-0.053	0.116	1.000	-0.361	0.256
Low Efficiency Due to Lack of Smart Factory Experience	1-10 years	10-20 years	0.211	0.136	0.728	-0.151	0.572
		20-30 years	0.226	0.119	0.359	-0.092	0.545
		Over 30 years	.437*	0.123	0.003	0.109	0.764
	10-20 years	1-10 years	-0.211	0.136	0.728	-0.572	0.151
		20-30 years	0.015	0.118	1.000	-0.300	0.331
		Over 30 years	0.226	0.122	0.389	-0.099	0.551
	20-30 years	1-10 years	-0.226	0.119	0.359	-0.545	0.092
		10-20 years	-0.015	0.118	1.000	-0.331	0.300
		Over 30 years	0.211	0.103	0.258	-0.065	0.487
	Over 30 years	1-10 years	-.437*	0.123	0.003	-0.764	-0.109
		10-20 years	-0.226	0.122	0.389	-0.551	0.099
		20-30 years	-0.211	0.103	0.258	-0.487	0.065
Difficulty Securing Stable Volume	1-10 years	10-20 years	0.129	0.146	1.000	-0.260	0.519
		20-30 years	0.061	0.129	1.000	-0.282	0.404
		Over 30 years	0.329	0.132	0.082	-0.023	0.682
	10-20 years	1-10 years	-0.129	0.146	1.000	-0.519	0.260
		20-30 years	-0.069	0.127	1.000	-0.409	0.271
		Over 30 years	0.200	0.131	0.772	-0.150	0.550
	20-30 years	1-10 years	-0.061	0.129	1.000	-0.404	0.282
		10-20 years	0.069	0.127	1.000	-0.271	0.409
		Over 30 years	0.269	0.111	0.101	-0.029	0.566
	Over 30 years	1-10 years	-0.329	0.132	0.082	-0.682	0.023
		10-20 years	-0.200	0.131	0.772	-0.550	0.150
		20-30 years	-0.269	0.111	0.101	-0.566	0.029

Hypothesis 2: Differences in perceptions of the application of modular housing

Firstly, regarding the excessive initial investment cost, the ANOVA results indicated no significant differences among career groups (p = 0.080). This suggests a common perception across all career groups that the initial investment cost is high. Additionally, post hoc tests confirmed no significant group comparisons for excessive initial investment cost.

In contrast, significant differences emerged concerning low initial utilization. The ANOVA results (p = 0.032) highlighted that career groups had differing perceptions of low initial utilization. However, post hoc tests did not find any specific group comparisons to be significant, as all p-values were greater than 0.05.

Regarding the low efficiency due to a lack of smart factory experience, significant differences were observed among career groups (p = 0.006). Post hoc tests revealed that professionals with over 30 years of experience viewed the lack of smart factory experience more negatively compared to those with 1-10 years of experience (Mean Difference = 0.437, p = 0.003).

Lastly, the analysis of the difficulty in securing a stable volume showed significant differences among career groups (p = 0.043). However, post hoc tests indicated no significant group comparisons, as all p-values were greater than 0.05.

This study indicates that professionals with over 30 years of experience have a more favorable view of adopting smart factory technologies for modular housing. They believe these technologies can reduce construction time, increase production efficiency, lower costs, and improve quality control. However, these experienced professionals also show greater concern about low efficiency due to insufficient familiarity with smart factory technology. This suggests that career-specific perceptions are crucial when implementing these technologies in the modular housing sector. For factors such as high initial investment costs and challenges in maintaining a stable volume, there were no significant differences among career groups, indicating a shared consensus on these challenges. Aligning this revised explanation with the data ensures an accurate interpretation of the ANOVA and post hoc test results.

5. Conclusions

5.1. Overview

Over the past decade, the Korean construction industry has experienced significant declines in productivity and quality. Onsite construction is inherently inefficient due to external factors such as climate change, recent increases in material prices, and labor shortages exacerbated by the COVID-19 pandemic, as well as internal factors like an aging workforce. These issues have led to a rapidly aging workforce, a decrease in young skilled labor, and an increase in foreign labor, resulting in decreased productivity and higher construction costs. The modular housing industry, introduced in Korea in 2003, offers a potential solution by allowing simultaneous site work and factory production, thereby reducing construction time and improving productivity. However, the application of modular housing in Korea has been mostly limited to public rental housing projects and pilot projects.

This study aimed to analyze the factors hindering the widespread adoption of modular housing in Korea and to gather and analyze construction industry experts' opinions on the diffusion of modular housing through the introduction of smart factories. A survey was conducted among construction industry experts to, first, analyze the distribution of responses regarding the benefits and obstacles to the activation of modular housing through frequency analysis, and second, to evaluate perception differences among various career groups using ANOVA and Bonferroni post-hoc tests.

The expert survey results indicate that most experts agree on the need for the diffusion of modular housing and the introduction of smart factories. The most anticipated benefits were reduced construction time and labor savings, while the primary concerns were related to quality and reliability.

ANOVA and Bonferroni post-hoc tests revealed significant perception differences among career groups. Experts with over 30 years of experience were more positive about the benefits of smart factory technologies, including reduced construction time, increased production efficiency, cost savings, and improved quality control. However, they also expressed greater concerns about low efficiency due to a lack of experience with smart factory technology compared to other career groups.

5.2. Practical and Policy Recommendations

To build consumer trust and address concerns about quality and reliability, it is essential to invest in continuous research and development and maintain strict quality control. Construction companies should focus on investing in quality control and R&D to enhance the reliability of modular housing products. Additionally, the government should introduce standardization and quality certification systems to ensure the quality of modular housing and increase trust among market participants and consumers.

To offset the high initial investment costs associated with modular housing and support stable factory operations, the government should offer economic incentives such as subsidies or tax breaks. Construction companies should leverage these economic incentives to explore ways to improve economic efficiency and quality.

Comprehensive education programs implemented through government and academic institutions can promote modular housing and help overcome resistance to new technologies among construction professionals. Additionally, simplifying laws and regulations related to modular housing is crucial to creating an environment conducive to its adoption and growth.

Public promotion campaigns should be conducted to raise awareness of the benefits of modular housing among consumers and construction industry stakeholders. Developing strategic promotion plans to highlight the advantages of modular housing can further increase consumer awareness. Furthermore, collaboration between public institutions and private companies to expand successful modular projects and actively promote these success stories will help build a positive perception of modular housing.

Modular housing presents an appropriate alternative to address productivity and quality issues in the Korean construction industry. The introduction of smart factories has the potential to simultaneously solve economic and productivity challenges while improving the quality of modular housing. This study provides a practical basis for developing policies and strategies for the diffusion and development of modular housing in Korea by analyzing the perceptions of construction industry experts and identifying differences based on career groups.

5.3. Limitations

This study has several limitations. Firstly, the survey was conducted with a sample size of only 188 experts.

Secondly, it was primarily carried out among public institutions and government officials within the Seoul metropolitan area, which may affect the generalizability of the results.

Lastly, the study is based on data from a specific point in time, which may not capture changes over time.

Future research should address these limitations by using a larger sample size and employing various data collection methods. By implementing these recommendations and insights, productivity and quality issues in the Korean construction industry can be addressed, and the adoption of modular housing can be promoted, thereby contributing to sustainable development.

References

An, J. W., & Kim, J. H. (2023). A study on the improvement and activation through analysis of factors affecting residential satisfaction on modular housing. *The University of Han-Yang*. 2023.2.

Bertram, N., Fuchs, S., Mischke, J., Plater, R., Strube, G., & Woetzel, J. (2019). Modular construction: From projects to products. *McKinsey & Company: Capital Projects & Infrastructure*, 1-34.

Boyd, N., Khalfan, M. M., & Maqsood, T. (2013). Off-site construction of apartment buildings. *Journal of Architectural Engineering*, *19*(1), 51-57.

Choi, C. H., Kim D. H., Kim Y. S., Hong S. J., & Kim, H. S. (2014). Analysis of multi criteria decision making techniques on global trend. *Annual Conference of the Korean Society of Civil Engineers*, 1493-1494.

Choi, J. S., & Lee, J. S. (2018). A Study on Outsourcing application of MEP system for modular construction method. *Journal of Korea Inst. Build. Const.*, *18*(3), 277-283.

Choi, O. K., & Lee, H. S. (2018). Quantity management model for manufacturing and assembly of large-scale modular construction projects during construction phase. *Korean Construction Management Association*, 43-53.

Eastman, C. M., & Sacks, R. (2008). Relative productivity in the AEC industries in the United States for on-site and off-site activities. *Journal of Construction Engineering and Management*, *134*(7), 517-526.

Jeon, J. B., & Kim, W. C. (2024). A study on the safety plan of a building applying the modular construction method. *The University of Kyeonggi*. 2024.2.

Jung, C. W., & Jeon, M. H. (2022). A study on development of automation strategies for factory manufacturing process. *The Architectural Institute of Korea Fall Conference*, 706-707.

Jung, J. H., & An, Y. H. (2020). A study on risk management based on the risk identification and priority analysis of modular construction. *The University of Han-Yang*. 2020.2.

Kim, J. H., & Kim, Y. S. (2017). Economic feasibility study on the steel moment frame modular construction according to the life cycle cost analysis. *The University of Chung-Ang*. 2017.8.

Kim, T. Y. (2013). Work activity relation approach of modular factory production management using Dependency Structure Matrix (DSM). *Department of Architecture & Architectural Engineering, the Graduate School, Seoul National University*. 2013.8.

Kim, T. Y., Park, M. S., & Lee, H. S. (2013). Optimization methodology of modular unit factory production process using DSM. *Journal of the Architectural Institute of Korea*, *6*(296), 113-122.

Kim, T. Y., Park, M. S., & Lee, H. S. (2013). Optimization methodology of modular unit factory production process using DSM. *Journal of the Architectural Institute of Korea*, *6*(296), 113-122.

Kisi, K. P., Mani, N., Rojas, E. M., & Foster, E. T. (2017). Optimal productivity in labor-intensive construction operations: Pilot study. *Journal of Construction Engineering and Management*, *143*(3), 040161107.

Kwon, J. H., & Choi, S. G. (2023). A study on the application effect of modular method on BIM. *The University of Seoul*. 2023.2.

Lawson, R. M., Ogden, R. G., & Bergin, R. (2012). Application of modular construction in high-rise buildings. *Journal of Architectural Engineering*, *18*(2), 148-154.

Lee, H. J., & An, Y. H. (2020). A study on derivation of safety risk factors for factory by modular construction. *The University of Han-Yang*. 2020.2.

Lee, J. S., & Kim, J. J. (2017). BIM-based 4D simulation framework to improve module manufacturing productivity for modular construction projects. *The University of Han-Yang*. 2017.8.

Lee, K. B., & Kim, K. R. (2011). A proposal for optimizing unit modular system process to improve in Off-site manufacture, transportation and On-site installation. *The University of Aju*. 2011.

Ma, J. H., & An, Y. H. (2023). A study on analysis of modular manufacturing productivity inhibitor and improvement. *The University of Han-Yang*. 2023.2.

Min, S. H. (2018). Case studies and implications of smart factory implementation. *KDB Industrial Bank Monthly Report*, 2018.2, 747, 41-64.

Nam, S. H., & Kim, K. R. (2019). A decision support model for factory production process through prefabricated components in modular buildings. *The University of Aju*. 2019.

Seol, W. J., & Back, C. H. (2024). Investigation of factors affecting modular building factory population rate. *Korea Academia-Industrial Cooperation Society*, 860-861.

Endnotes:

1. Ministry of Land, Infrastructure and Transport, Korea Agency for Infrastructure Technology Advancement. (2024.03.20). Development of Optimization Technology for Modular.
2. Professional Construction Mutual Aid Association, Korea Construction Policy Institute. (2023, June 22). K-Modular Construction and Housing Industry Revitalization Strategy Seminar.