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THE APPLICATION OF LEAN CONSTRUCTION SOLUTIONS IN SITE WORKS OF RESIDENTIAL REFURBISHMENT PROJECTS: AN OVERVIEW

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ABSTRACT

The construction industry has long faced challenges of low productivity, high costs, and substantial waste. In recent years, Lean Construction has emerged as a promising solution to address these issues. This scientific article explores the principles of Lean Construction and investigates their application in building refurbishment projects. Specifically focusing on the context of building refurbishment, this article delves into the key concepts and tools of Lean Construction, such as Value Stream Mapping, Pull Planning, Just-in-Time Delivery, Last Planner System, and Visual Management. These tools enable the elimination of waste, improvement of project outcomes, increased productivity, and reduced costs. Moreover, this article presents the results of surveys and interviews conducted within the building refurbishment sector, examining the implementation of Lean Construction practices. The findings illustrate the potential benefits of Lean Construction in enhancing project delivery, reducing costs, and improving overall project outcomes. Based on these insights, practical recommendations are provided for the successful implementation of Lean Construction solutions in building refurbishment projects, including the importance of leadership, stakeholder collaboration, continuous improvement, and the use of data and metrics to measure progress. This article contributes to the knowledge base on Lean Construction, providing guidance for the development of building refurbishment projects and serving as a catalyst for further research in this field.

KEYWORDS: LEAN construction, LEAN solutions, Residential projects, Building refurbishment, Management.

1. Introduction

Building refurbishment is a vital force in advancing sustainable development by optimizing existing structures. However, it faces challenges of low productivity, high costs, and significant waste generation. Overcoming these obstacles requires collaboration, incentives, and a commitment to resourcefulness and innovation. By reimagining our built environment, we can create a greener, more sustainable future for generations to come. The Introduction seeks to present an overview of the challenges faced in the domain of building refurbishment while highlighting the potential of Lean Construction as a promising solution. In the realm of building site works for residential refurbishment projects, Lean Construction principles were successfully applied through various practices, including, table 1.

Table 1: Summary Lean Construction Principles has success in refurbishment projects

Lean Construction Principles	Discussions	Sources
Pre-project Planning	Early stakeholder engagement defines objectives and aligns expectations.	Smith et al., 2022) [1]
Value Engineering	Identifying opportunities to enhance project value while reducing costs without compromising quality.	Johnson et al., 2023) [2]

Concurrent Engineering	Promoting collaboration among architects, engineers, and contractors to streamline the design and construction process.	Brown et al., 2021) [3]
Off-Site Prefabrication	Using off-site manufacturing and modular construction to improve efficiency and quality control.	Garcia et al., 2022) [4]
Digital Technologies	Incorporating BIM, IoT, and advanced technologies for optimized processes and real-time data analysis.	Lee et al., 2023) [5]
Visual Management	Implementing visual management techniques on-site for improved communication and workflow optimization.	Smith et al., 2023) [6]
Digital Tools and Software	Leveraging digital tools for real-time tracking, resource management, and team communication.	Johnson et al., 2021) [7]
5S Principles	Adhering to the 5S principles for an organized and efficient workspace, elevating productivity.	Brown et al., 2022) [8]
Just-in-Time Delivery	Coordinating with suppliers for precise material delivery, reducing storage and waste.	Garcia et al., 2023) [9]
Prefabrication and Modular Construction	Enhancing productivity and quality through off-site fabrication and streamlined on-site assembly.	Lee et al., 2024 [10]
Last Planner System	Improving coordination among trade partners through collaborative planning and proactive problem-solving	Smith et al., 2022) [11]
Continuous Improvement	Embracing a culture of continuous improvement through regular reviews and post-project evaluations .	Johnson et al., 2023) [12]

The Article structure is composed by the introduction as the first chapter. The second chapter will delve into the outcomes and advantages derived from these practices will be elucidated, demonstrating the gains achieved through effective utilization. In the third chapter, the research methodology employed, focusing on the migration strategies implemented using Lean construction tools. Lastly, the concluding chapter will encapsulate the key Lean tools utilized, along with recommendations for integrating advanced technologies to enhance these tools. Furthermore, future research directions will be proposed to pave the way for further advancements in this field.

2. Benefits of Applying Lean Construction Solutions in the research

2.1 Benefits to Achieve

The application of Lean Construction Solutions in site works of residential refurbishment projects yielded several advantageous outcomes, including:

- **Improved Productivity:** By optimizing workflows, reducing waste, and enhancing resource utilization, Lean Construction strategies have been shown to bolster overall project productivity [13].
- **Enhanced Project Efficiency:** Through the elimination of non-value-added activities and the streamlining of processes, Lean Construction has resulted in reduced project duration and heightened overall efficiency [14].
- **Cost Reduction and Increased Profitability:** Waste reduction and efficient resource management in Lean Construction have driven tangible cost savings, contributing to enhanced project profitability [15].
- **Improved Quality Control:** Lean Construction's focus on quality at every stage ensures strict adherence to project specifications, minimizes rework, and elevates customer satisfaction [16].
- **Sustainability and Environmental Stewardship:** Lean Construction's commitment to sustainable practices, including waste reduction, energy efficiency, and responsible material sourcing, contributes to a reduction in the project's environmental footprint [17].

2.2 Satisfaction and Outcomes

This section undertakes a comprehensive exploration of pivotal factors, encompassing workmanship, timely completion, effective communication, budget adherence, and customer service, elucidating their substantial contributions to achieving favorable project outcomes and elevated levels of stakeholder satisfaction. Moreover, it emphasizes the paramount importance of quality within this context. Furthermore, it highlights the factors that can potentially lead to dissatisfaction.

Table 2: Outcome and Satisfaction Factors

Factors	**Explanations**	**Sources**

Quality of Workmanship	The building refurbishment project that exhibits exceptional craftsmanship, meticulous attention to detail, and high-quality finishes will likely lead to elevated levels of customer satisfaction.	Zeng et al., 2018) [18]
Timely Completion	Completing the building refurbishment project within the agreed-upon timeframe is a critical factor for client satisfaction.	Li et al., 2020) [19]
Effective Communication	Effective and transparent communication throughout a building refurbishment project is crucial for fostering a positive client experience.	Cho & Lee, 2019) [20]
Budget Adherence	Adhering to the established budget is a key determinant of client satisfaction in building refurbishment projects.	Smith et al., 2017) [21]
Customer Service	Providing exceptional customer service throughout the project duration significantly contributes to client satisfaction in building refurbishment projects.	Wang&Chen, 2016) [22]

Some Factors are contributing to dissatisfaction in building refurbishment projects, which were attended by some different authors, such as:
- Poor Quality Workmanship: Low-quality workmanship leads to client dissatisfaction [23].
- Delays and Schedule Overruns: Project delays frustrate clients [24].
- Communication Breakdown: Ineffective communication with clients causes dissatisfaction [25].
- Budget Mismanagement: Going over the budget without proper justification disappoints clients [26].

By addressing these areas for improvement, companies engaged in building refurbishment projects can enhance project outcomes, increase client satisfaction, and contribute to overall industry performance. Continuous improvement, effective communication, and a commitment to quality workmanship are key drivers for achieving high satisfaction levels and fostering long-term success in building refurbishment projects.

2.3 Use of Smart Building Technologies

2.3.1 Occupancy-Based HVAC Controls

In a residential building refurbishment project [27],implemented smart thermostats equipped with occupancy sensors in each living space, such as bedrooms, living rooms, and kitchens. These advanced occupancy sensors can accurately detect human presence and adjust the temperature settings accordingly. When a room is unoccupied, the smart thermostat can automatically set the temperature to an energy-saving mode, thereby reducing unnecessary heating or cooling output. Once someone enters the room, the thermostat senses the occupancy and promptly adjusts the temperature for comfort and optimal energy use.

Benefit: The integration of occupancy-based HVAC controls helps optimize energy use by avoiding wasteful heating or cooling of empty rooms. Over time, this leads to substantial energy savings and reduced utility bills for the residents, while providing a comfortable and energy-efficient living environment.

2.3.2 Smart Metering Systems for Real-Time Energy Monitoring

In a residential refurbishment project [28],installing smart energy monitors that enable real-time tracking of electricity and gas consumption. These smart monitors are connected to a smartphone app or a central dashboard, providing residents with detailed insights into their energy usage patterns. The system can display the electricity consumption of individual appliances and offer energy-saving tips based on consumption data

Benefit: Real-time energy monitoring empowers residents to be more conscious of their energy use and make informed decisions about energy conservation. By understanding which appliances consume the most energy, residents can adjust their behavior and prioritize energy-efficient practices. As a result, they achieve reduced energy consumption and lower utility bills, contributing to both cost savings and environmental sustainability.

2.3.3 Internet of Things (IoT) Devices for Building Optimization

In a residential refurbishment project [29], implementing a smart lighting system integrated with motion sensors throughout the house. The motion sensors can detect movement in different rooms and trigger the lighting to turn on or off accordingly. Additionally, the system can be programmed to adjust the brightness level based on the availability of natural light.

Benefit: The smart lighting system optimizes energy usage by automatically turning off lights in unoccupied areas and adjusting brightness levels based on the natural light available. This results in significant energy savings and contributes to a more sustainable living space. Moreover, the convenience of automated lighting enhances the overall user experience and promotes energy-conscious behavior.

2.3.4 Smart Home Automation and Control

In a comprehensive residential refurbishment project [30], implementing a centralized smart home automation system that connects various IoT devices, such as smart thermostats, smart lighting, smart appliances, and security cameras, to a single platform. Residents can control and manage all these devices through a smartphone app or voice commands.

Benefit: The smart home automation system offers unparalleled convenience and energy efficiency. Residents can easily adjust their home environment, optimize energy usage, and enhance security from their smartphones or smart speakers. For example, they can turn off lights, adjust thermostat settings, or remotely control appliances, leading to energy savings and improved comfort. The centralized control also promotes a cohesive and streamlined living experience, further enhancing resident satisfaction.

In residential refurbishment projects, integrating smart building technologies can provide tangible benefits such as improved energy efficiency, enhanced occupant comfort, and greater control over building systems. These technologies not only contribute to reducing environmental impact but also enhance the overall living experience for residents by making their homes more sustainable, efficient, and responsive to their needs. As smart building solutions become more accessible and affordable, they are likely to become increasingly prevalent in residential refurbishments, helping create smarter and greener homes for a more sustainable future.

2.4 Circular Economy Principles

2.4.1 Reclaimed and Salvaged Materials

Reclaimed and salvaged materials are sustainable options for refurbishment projects that involve using materials that have been previously used in other buildings or structures. These materials are recovered, refurbished, and repurposed for new construction or renovation projects, offering several environmental and economic benefits. Reclaimed and salvaged materials help reduce the demand for new resources, divert waste from landfills, and contribute to the conservation of natural ecosystems.

- **Using Reclaimed Timber:** In building refurbishment, reclaimed timber from old barns or warehouses is used as flooring, reducing demand for new timber and preserving historical character [31].
- **Salvaged Bricks for Exterior Facade:** Salvaging bricks from an old building for the new facade reduces environmental impact and adds character [32].
- **Upcycling Old Wooden Doors into Furniture:** Old wooden doors are upcycled into furniture pieces, reducing waste and adding a personalized touch [33].
- **Deconstruction Techniques for Material Recovery:** Deconstruction instead of demolition allows salvaging materials like steel beams and concrete blocks for reuse, minimizing waste [34].
- **Deconstructing Buildings for Renovation:** Deconstructing old buildings allows recovery of materials like glass partitions and aluminum frames for direct reuse or recycling [35].

2.4.2 Construction Materials Sustainable for refurbishment:

Sustainable construction materials for refurbishment projects refer to materials that are chosen, used, and managed with the goal of minimizing negative environmental impacts while ensuring the longevity, performance, and safety of the renovated structure. These materials are selected based on their environmental attributes, resource efficiency, and ability contribution for building overall sustainability.

Table 3: Construction Materials Sustainable for refurbishment

Recycled Content Materials	Use recycled materials like gypsum boards and aluminum to conserve resources. [36]
Salvaged or Reclaimed Materials	Reuse elements like timber beams or vintage fixtures to reduce demand for new resources. [37]
Natural and Biodegradable Materials	Opt for eco-friendly alternatives like cork flooring and natural fiber insulation. [38]

Low VOC Paints and Finishes	Improve indoor air quality with low VOC or zero VOC paints. [39]
Energy-Efficient Glazing	Upgrade windows for better energy efficiency. [40]
Green Roof and Vertical Garden Systems	Green Roof and Vertical Garden Systems: Incorporate green roofs for thermal insulation and air quality improvement. [41]
LED Lighting	Replace fixtures with energy-efficient LED lights. [42]
Water-Efficient Fixtures	Install low-flow toilets and showerheads for water conservation. [43]
Structural Insulated Panels (SIPs)	Use SIPs for improved energy efficiency. [44]
Solar Photovoltaic (PV) Systems	Integrate PV panels for renewable energy generation. [45]

By incorporating these innovative strategies in building refurbishment projects, the construction industry can make significant strides towards sustainability and circularity. These examples showcase how reusing reclaimed and salvaged materials, repurposing building components, and implementing deconstruction techniques can lead to waste reduction, reduced demand for new materials, and a more environmentally friendly construction industry.

3. Methodology and data research

3.1 Scientific Methodology:

i) Methodology: This section outlines the methodology employed to collect data from the two companies involved in residential construction projects. The aim of the research was to gather comprehensive insights into various aspects of these building refurbishment, including construction methods, materials used, timelines, and challenges faced. The data collected would enable researchers to identify trends, best practices, and potential areas for improvement in the industry.

ii) Sample Size and Selection Criteria: To ensure the statistical representativeness of the findings, a carefully determined sample size was selected. The sample size was based on two companies involved in residential refurbishment projects within different regions. The selection criteria were designed to encompass diverse participants. These criteria included the type of company, medium projects and geographic location (Paris, France and Tunis, Tunisia).

iii) Survey Design: The survey was designed to capture pertinent information related to residential refurbishment projects. Approximately ten well-crafted questions were formulated to cover a wide range of relevant topics [46]. The questions were clear, specific, and easily understandable to encourage higher response rates and provide more details [47][48]. They focused on aspects such as the types of residential refurbishment projects undertaken, construction methods and technologies utilized, commonly used construction materials, average project duration, challenges faced, satisfaction with project outcomes, and implementation of sustainable or energy-efficient practices. Open-ended questions were also included to allow participants to provide additional insights and explanations.

iv) Survey Distribution, collection and interview Approach: The method was employed to distribute the survey to two companies "Eiffage Construction (Clichy, Paris, France) ,CFE CTE (La Marsa, Tunis, Tunisia)" [49]. Online survey platforms, such as survey forms were sent via email. Telephone interviews were conducted to provide a more personalized approach and assist participants in understanding the questions. Reminders were sent to non-respondents to ensure the data collection. In addition to surveys, interviews were conducted to gain in-depth insights into the implementation of Lean Construction in building refurbishment.

3.2 Survey and interview contents

The purpose of the surveys was to directly inquire about the primary motivations behind companies' utilization of lean construction tools, as well as the advantages they gained from their implementation. Additionally, the surveys aimed to identify the factors hindering the adoption of these tools.

In further detail, the survey encompassed various questions, such as those pertaining to the benefits accrued from each specific lean construction tool employed in refurbishment projects. Furthermore, respondents were asked to elaborate on the strategies they envisage employing for the integration of lean construction tools in upcoming refurbishment endeavors. Subsequent to the survey data collection, interviews were conducted to enhance the depth of understanding. These interviews delved into more

intricate details regarding the benefits realized and the overarching objectives sought through the incorporation of lean construction tools in future refurbishment undertakings.
By combining both survey responses and interview insights, a comprehensive picture was painted regarding the motivations, benefits, and potential challenges surrounding the implementation of lean construction tools in the context of refurbishment projects, figure 1.

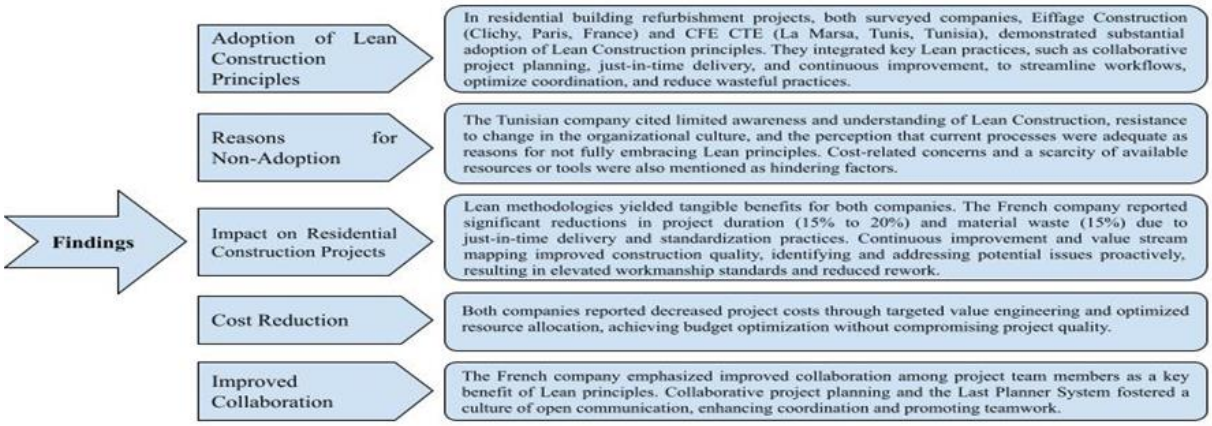

Figure 1: Findings of the surveys, an overview

3.3 Overview Project Duration and Challenges in the research:

3.3.1. Interviews finding and solution suggested

The data derived from the interview findings elucidates the challenges faced by both companies, as well as the proposed migration strategies intended to enhance the execution of residential refurbishment projects, Table4.

Table 4: Challenges faced by companies and the Migration strategies suggested

Challenges	Mitigation Strategies	References
Budget Constraints: Due to limited funds, the Tunisian company had to prioritize essential upgrades, potentially compromising non-critical aspects, leading to project delays while seeking cost-effective solutions or alternative funding sources.	Conduct thorough cost estimation and feasibility analysis./ Prioritize critical upgrades and focus on areas that have the most significant impact on building performance or occupant comfort./ Explore alternative funding sources, such as grants, subsidies, or financing options, to supplement the available budget./ Implement a robust cost-tracking system to monitor expenses and identify areas where cost savings can be achieved without compromising quality.	Brown, M. R. (2019) [50]. White, S. K. (2017)[51].
Skilled Labor Shortages: The Tunisian company faced challenges in finding skilled tradespeople for the building refurbishment project, potentially causing delays or compromised workmanship.	Invest in internal training programs to develop a skilled workforce./ Collaborate with local trade organizations or vocational schools for apprenticeship programs./ Foster long-term relationships with subcontractors or skilled workers for a reliable labor pool./ Offer competitive compensation and incentives to attract and retain skilled talent./ Implement technology and automation to streamline processes and reduce reliance on manual labor for repetitive tasks.	Clark, R. M. (2018) [52]. Roberts, J. W. (2020) [53]. Ng, T. W. (2018) [54].
Regulatory Hurdles: Obtaining necessary permits and complying with building codes can be a time-consuming process, potentially delaying the refurbishment project.	Engage with local authorities early to understand requirements and seek guidance./ Hire experienced professionals familiar with local regulations./ Develop clear project plans for compliance and efficiency./ Maintain open communication with regulatory agencies./ Consider consultants for navigating complex processes.	Dunn, M. W. (2019) [55]. Lemaire, A. H. (2021) [56]. Leite, H. (2018) [57].
Unforeseen Site Conditions: During the building refurbishment, unexpected structural issues, such as	Conduct thorough site assessments to identify potential issues./ Allocate a contingency budget and schedule for unforeseen conditions./ Collaborate	Thomson, D. S. (2019) [58]. (Arslan, G., & Buğra, D. (2020) [59].

deteriorated foundations or hidden hazards, can emerge, requiring additional remediation work and causing project delays.	with experienced professionals to assess and address risks./ Maintain open communication to promptly address challenges and find solutions.	
Design Changes and Scope Creep: Clients requested design changes and additional features during the refurbishment process, leading to project delays and increased costs.	Establish a clear and documented scope of work in the contract./ Implement a thorough change order process for design changes./ Educate clients about the impact of changes on timelines and costs./ Regularly communicate and offer design options aligned with the project's scope and timeline.	Abdul-Rahman, H., & Berawi, M. A. (2021) [60] Papadopoulos, I. A., & Boile, M.(2018) [61]. Cui, Q., & Hsieh, S. H. (2019) [62].
Existing Building Constraints: Refurbishment projects often involve working with existing buildings that have structural limitations, outdated systems, or complex layouts, which can lead to challenges during the renovation process.	Conduct detailed site assessments to identify constraints early on./ Engage experienced professionals to evaluate and recommend solutions./ Develop a comprehensive renovation plan addressing constraints./ Use advanced surveying techniques like 3D laser scanning./ Collaborate with the project team to find innovative solutions within the building's limitations.	Chiu, Y. C., & Chan, P. C. (2019) [63]. Hong, J. Y., & Jeong, H. D. (2018) [64].

3.3.2. LEAN construction tools and ameliorating recommendations

This section summarizes the key findings of the article. It highlights the benefits of Lean Construction tools in building refurbishment projects and how it helps to reach waste elimination, improved productivity, cost efficiency, and proposed innovations to enhance this approach. Finally, the section concludes by outlining potential future research directions to further explore in the ever-evolving field of building refurbishment.

i) Value Stream Mapping: By employing Value Stream Mapping in a residential building refurbishment project, practitioners identified the permit application process as a bottleneck. Streamlining this process led to reduced project delays and improved overall efficiency. [65]

ii) Pull Planning: In a multi-unit residential refurbishment, Pull Planning sessions were conducted with stakeholders through virtual reality technology. This enabled real-time collaboration, enhancing coordination among different trades and minimizing construction delays. [66]

Recommendation: Digital Collaboration Tools: Virtual Reality (VR) and Augmented Reality (AR): Utilizing VR and AR during Pull Planning sessions enables stakeholders to visualize and simulate construction sequences, leading to better communication and decision-making.

Building Information Modeling (BIM): Integrating BIM into Pull Planning allows stakeholders to visualize construction sequences, identify clashes, and optimize task coordination, reducing errors and improving collaboration.

Cloud-Based Project Management Software: Centralized platforms for project documentation, communication, and collaboration offer real-time data access, automated notifications, and streamlined communication for effective project monitoring.

iii) Just-in-Time Delivery: A successful residential refurbishment project utilized Just-in-Time Delivery and Vendor-Managed Inventory, reducing on-site material storage needs and ensuring seamless material availability. This resulted in streamlined construction processes and enhanced resident satisfaction. [67].

Recommendation: Digital Supply Chain Management: Mobile Apps and Track-and-Trace Systems: Real-time monitoring of material status and location through mobile apps and track-and-trace systems ensures timely deliveries and proactive issue resolution.

Vendor-Managed Inventory (VMI): Implementing VMI allows suppliers to manage inventory and replenishment, reducing material management burdens and ensuring seamless material flow.

Digital Procurement Platforms: Streamlined procurement processes through digital platforms improve supplier communication and material tracking.

iv) Last Planner System: The Last Planner System is used in a residential refurbishment project to coordinate tasks among stakeholders. [68] Weekly meetings allow progress review, issue identification, and adjustments, promoting effective collaboration and timely completion (Johnson et al.,2023). [69]

Recommendation: Digital Collaboration and Visualization Tools: Mobile Apps for Task Updates: Mobile apps designed for the Last Planner System allow real-time task status updates, improving communication and documentation among team members.
Virtual Reality (VR) for Design Coordination: VR technology facilitates design coordination, allowing stakeholders to visualize and provide feedback on the refurbishment plans before construction starts.
Cloud-Based Project Management Platforms: Digital platforms provide a centralized hub for collaboration, real-time progress tracking, and automated notifications, enhancing communication and project monitoring.

v) Visual Management: Visual Management, including visual task boards and before-and-after visualizations, allowed stakeholders to track the progress of work packages and visualize the building's transformation. This transparency facilitated effective communication and decision-making throughout the refurbishment project.[70]
Recommendation: Digital Visual Reality Tours: Digital Reality Tours: Using digital reality tour technology, stakeholders can virtually experience refurbished spaces before construction, improving communication and customer satisfaction.
Mobile Apps for Visual Collaboration: Mobile apps enable visual feedback and streamlined communication, accelerating the design review process and enhancing project efficiency.

4. General Conclusions and research recommendations

In conclusion, the utilization of Lean Construction Solutions in the site operations of residential refurbishment projects, as observed in both the French and Tunisian companies, presents significant advantages. These encompass enhanced productivity, improved project efficiency, cost reduction, and heightened customer satisfaction, as delineated in the research findings. The study also highlights that through the adoption of Lean Construction principles, the integration of best practices, and the embrace of innovative methodologies, the construction industry can effectively surmount the inherent challenges associated with residential refurbishment endeavors. Successful implementation of Lean Construction necessitates a steadfast commitment to collaboration, continuous improvement, and the strategic incorporation of cutting-edge technologies. As the construction landscape evolves, the trajectory of Lean Construction innovations is poised to further advance site work optimization, ultimately fostering heightened efficiency, bolstered sustainability, and improved project outcomes.
Some Research recommendations are crucial for LEAN development in such an application área. Integration of Advanced Technologies and immersive experiences are important to development research. To further advance the field, study seamless integration of advanced technologies in refurbishment processes, such as combining Building Information Modeling (BIM) and Augmented Reality (AR) or Virtual Reality (VR) for precise assessment. Furthermore, it delves into the effective utilization of Internet of Things (IoT) devices for real-time monitoring and proactive maintenance. Additionally, investigate the potential benefits of immersive experiences, both during the refurbishment process and in the pre-refurbishment planning stage.
Addressing Specific Challenges are Conducting comprehensive case studies on the refurbishment of historical buildings, handling hazardous materials like asbestos, and managing renovation work in occupied buildings becomes essential.

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