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A Review on Modular Construction Technique

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ABSTRACT: This review paper compares modular and traditional construction methods, focusing on cost, time efficiency, quality, and safety. Data from case studies, industry reports, and expert interviews highlight that modular construction, characterized by off-site fabrication, reduces construction time, ensures consistent quality, and minimizes on-site disruptions. However, it may struggle with complex designs and large-scale projects. Traditional construction, while slower and less efficient, offers greater design flexibility and adaptability, especially for custom and high-end projects. The paper concludes that project-specific requirements should guide the choice between methods, with a hybrid approach potentially offering the best balance. These insights aim to inform future construction practices, promoting more efficient and effective building strategies.

KEYWORDS: Modular construction, Traditional construction, Off-site fabrication, Construction efficiency, Quality control, Cost-effectiveness, Design flexibility

I. INTRODUCTION

The construction industry is at a pivotal juncture, driven by the need for innovation and efficiency in the face of increasing urbanization, labour shortages, and the demand for sustainable practices. Traditional construction methods, characterized by on-site assembly, have long dominated the industry. However, these methods are often fraught with challenges such as extended project timelines, weather-related delays, high labor costs, and significant material waste. In response to these challenges, modular construction has emerged as a promising alternative that could potentially transform the way buildings are constructed.

Modular construction involves the off-site fabrication of building components in a controlled factory environment. These prefabricated modules are then transported to the construction site for rapid assembly. This technique offers numerous advantages over traditional methods, including reduced construction time, enhanced quality control, and cost savings. By allowing for simultaneous site preparation and module fabrication, modular construction significantly accelerates project completion times. The controlled factory environment ensures consistent quality and reduces the likelihood of construction defects, while also minimizing material waste and labor costs. Despite these benefits, modular construction is not without its limitations. One of the primary challenges is its limited flexibility in accommodating complex architectural designs and bespoke project requirements. Traditional construction methods offer greater adaptability, which is particularly important for custom and high-end projects that demand unique architectural features. Additionally, while modular construction is efficient for smaller to medium-sized projects, it may face scalability issues when applied to larger, more complex developments. The initial setup costs for factories and transportation can also be high, posing a barrier to widespread adoption.

This review paper aims to provide a comprehensive analysis of modular construction by examining its advantages, challenges, and economic implications. It will draw on data from case studies, industry reports, and expert interviews to offer a holistic understanding of how modular construction compares to traditional methods. A key focus will be the economic aspects, including initial costs, lifecycle costs, and potential savings achieved through reduced construction time and improved quality. Furthermore, the paper will explore the practical application of modular construction through case studies, such as the RK International School project in Maharashtra, which demonstrate the method's efficiency and quality benefits. By highlighting the strengths and limitations of modular construction, this paper seeks to inform industry stakeholders about the potential of this innovative approach. The insights gained from this review could guide future construction practices and policies, promoting more efficient, sustainable, and high-quality building strategies.

II. LITERATURE REVIEW

Yi Yang,Wei Pan,Mi Pan : Manufacturing of modular buildings: a literature review (November 2017).

Manufacturing of modular buildings: a literature review(November 2017):This paper aims to provide a systematic review of existing academic perspectives and suggest future research directions to improve module manufacturing systems. The review explores critical research issues from five aspects: process and activities, organization and people, factory configuration, technology, and information and control system. Outlined suggestions for research opportunities include (1) increased utilisation of digital manufacturing, (2) more exploration of strategies for the adoption of automated technologies, (3) development of holistic and practical approaches to supporting DfMA methodology, (4) well-defined information management systems through BIM. The findings should contribute to a more comprehensive understanding of the practices, challenges and the state-of-the-art research in the manufacturing of modular buildings. [1]

Viacheslav Shirokov, T E Gordeeva, A Yu Bocharov :Analytic method of structural analysis of modular buildings(April 2020).

Analytic method of structural analysis of modular buildings(April 2020):The paper presents an analytical method of modular buildings calculation. It focuses upon basic design assumptions that are accepted for modular buildings calculation. The authors introduce their classification of loads and impacts, which are basic for modular buildings. They also describe a method of determining inertial forces from seismic action designed on the basis of a cantilever analytical model. Analytical and numerical methods for determining the forces in the elements of modular units are further compared. It is revealed that the analytical method strongly agrees with FEM (that is the finite elements method) with the error being 2-6%. The analytical method is sufficiently accurate for engineering calculations.[2]

Gauchel,Hovestadt, Van Wyk, S.and Bhat:Modular Building Models (January 1993) :

Current research suggests that to model real-world complexity, one must trade centralized control for autonomy. In this paper we develop a modular approach to building modelling that is based on object-oriented autonomy and makes it possible to define these models in a distributed concurrent manner. Such a modular and autonomous implementation brings inherent uncertainty and conflict which cannot be determined a priori. Steel modular building structures are being increasingly adopted for a variety of building applications since their method of construction, despite being relatively new, offers many benefits over conventional constructional methods. Even though their behaviour under gravity (dead and live) loads is generally well understood, their response to lateral dynamic loads such as seismic and wind loads, is relatively less known. Due to their unique structural detailing, their structural response and failure patterns under lateral dynamic loading can vary considerably from that exhibited by conventional structures. Limited research has shown that under lateral loading, modular structures tend to fail at the columns which are critical members whose failure can lead to partial or total collapse of the structure.[3]

Mc Guire Modular building block(November 2020):

This patent describes a modular building block comprising an enclosure defined by end walls, side walls, a top wall and a bottom wall in an assembled relationship. The top wall includes a pattern of fastener slots and the bottom wall includes fastener tabs selectively slid able into a co operable locking relationship in both vertical and horizontal directions with fastener slots in the top wall of another enclosure there below. Certain of the fastener slots in the top wall are disposed parallel to the longitudinal axis and along opposite edges thereof adjacent each of the side walls of the enclosure and other of the fastener slots are normal to the longitudinal axis at the mid region of the enclosure and along an edge thereof adjacent each of the end walls of the enclosure. The fastener tabs each include a cut-out portion overlaid by the top wall of another enclosure at an assembled condition. [4]

Shaham Asadi, Ataollah Beigzade. Cheap and High Quality Housing with Emphasis on Modular Building(September 2017):

Housing as one of the most basic needs of human being has received much attention. As a physical shelter, it is a fundamental need in each family. The need to housing has been increased based on the population increase in cities and its high density and it is a big problem in cities. High price of housing and lack of quality including construction materials to form and cultural quality is one of the greatest concerns of most of families. The study to create methods or types of design is necessary to provide comfort and many suitable housing indices and quality indices. Quality issue in housing increases the price. To reduce construction time and improvement of construction operation, modular building is used in the world. This method is a good model in construction for housing mass production. It should be considered that housing as living place of human being should be mostly regarding cultural issues than a symbol for the life and survival of human being. The study design is descriptive-analytic. The data is collected via existing articles and

resources to present a strategy to eliminate the problem of cheap housing. The problem of cheap housing gives some feedback regarding the materials or climatic and cultural patterns of society and also it creates problems in society and people as low-income class. The present study aimed to approach two paradoxes of cheap price and quality (including materials and culture). [5]

J. Zhang, Y. Lu, G. Li Structural Analysis on Mechanical Properties of 3D Steel Structure Modular Buildings (August 2015):

Modular building is a highly prefabricated construction system, and most structural members are made in the factory. There are many successful modular system construction cases abroad. However, the research on modular structure starts relatively late in China, and the research outcome is still limited. The cold-forming thin-walled steel joist system is a widely used modular system. Based on the force transferring mechanism, this modular system has two types: column-bearing system and wall-bearing system. Considering the influence of the story, opening and depth, the mechanical characteristics of these two systems, structural performance, and steel consumption are evaluated using finite element method. Finally, reasonable application scope and designing methods are proposed based on the comparison of analysis results. This paper provides a good reference for modular system construction in China. © 2015, Progress in Steel Building Structures All right reserved. [6]

Tharaka Gunawardena, Tuan Duc Ngo, Priyan Mendis Behaviour of Multi-Storey Prefabricated Modular Buildings under seismic loads (December 2016):

This paper will therefore present the nonlinear time history analysis of a multi-storey modular building against several ground motion records. The critical elements that need special attention in designing a modular building in similar seismic conditions is discussed with a deeper explanation of the behaviour of the overall system. Prefabricated Modular Buildings are increasingly becoming popular in the construction industry as a method to achieve financially economical buildings in a very short construction time. This increasing demand for modular construction has expanded into multi-storey applications where the effect of lateral loads such as seismic loads becomes critical. However, there is a lack of detailed scientific research that has explored the behaviour of modular buildings and their connection systems against seismic loads. [7]

Sukhi Sendanayake, David P. Thambiratnam, Nimal Jayantha Perera, Tommy Chan. Seismic mitigation of steel modular building structures through innovative inter-modular connections (November 2019):

This paper aims to mitigate this by shifting the failure away from the columns to inter-modular connections which can be allowed to deform in a ductile manner. Towards this end, this paper proposes two innovative inter-modular connections and investigates their performance under monotonic and cyclic lateral loading using comprehensive validated numerical techniques. The proposed connections have an additional steel plate and resilient layers to provide increased ductility and dissipation of seismic energy with desired ductile failure mechanisms. Three-dimensional numerical models of the proposed connections are developed in ABAQUS software considering geometric and material non linearities, as well as contact formulations to accurately capture their response to the lateral loads and failure propagation. The numerical model is verified based on experimental results in the literature and used for extensive parametric studies. Seismic reliance of the proposed connections in terms of ductility, failure patterns, and energy absorption are compared with those of a standard inter-modular connection currently used in modular buildings. The outcome of this study demonstrates that the proposed connections have superior dynamic performances compared to the standard inter-modular connections in use today. New information generated through this study will enable to improve life safety and dynamic performance of modular building structures under typical gravity loads as well as under seismic loading. : Civil engineering; Construction engineering; Structural analysis; Structural engineering; Structural mechanics; Failure mechanism; Innovative inter-modular connection; Lateral loading; Seismic mitigation; Steel modular structures Keywords: Civil engineering, Construction engineering, Structural analysis, Structural engineering, Structural mechanics, Failure mechanism, Innovative inter-modular connection, Lateral loading, Seismic mitigation, Steel modular structures. [8]

Andrew Lacey, Wensu Chen, Hong Hao, Kaiming Bi. eview of Bolted Inter-Module Connections in Modular :

In current practice, the force-displacement and moment-rotation behaviours of inter-module connections for modular steel buildings are established by a combination of theoretical, experimental, and numerical analyses. The simplified connection behaviour is then incorporated into a numerical model of the overall structure for analysis and design. For engineering design analysis, it is desirable to estimate the inter-module connection stiffness by means of simplified calculations. Methods for estimation of the stiffness of traditional steel connections are available in the literature, however, their application to inter-module connections (also known as inter-connections) remains to be investigated.

This paper summaries existing interconnection details, including their purpose and associated design methods and models. The inter-connections selected from the literature provide details of the typical force-displacement and moment-rotation behaviors. For the selected inter-connections, the numerical and experimental results are compared with the calculated theoretical results predicted by existing theoretical models. The existing theoretical models are compared, and their limitations are outlined. [9]

Wahid Ferdous, Yu Bai, Tuan Duc Ngo New advancements, challenges and opportunities of multistorey modular buildings-A state-of-the-art review(January 2019):

This paper critically reviews the recent developments, performances, challenges and future opportunities of modular buildings. Modular constructions are extensively used for low-rise buildings and further attracts strong interest for multi-storey building structures. Prefabricated modules demonstrated satisfactory performance under static, dynamic impact, cyclic, seismic, blast, fire and long-term sustained loading, and offer environmental, economic and social benefits. The acceptance and application of modular construction will further spread with the development of design guidelines, more skilled workers, addressing handling and transportation difficulties, and the development of novel interlocking connections between modules. Recently, composite materials demonstrated high potential to manufacture prefabricated building modules. In Australia, it is expected that modular construction will increase from the current stage of 3% to 5-10% by year 2030. [10]

Yisu Chen, Chao Hou, Jiahao Peng Stability study on tenon-connected SHS and CFST columns in modular construction(January 2019):

This study aims to explore the theoretical and numerical stability analysis of a tenon connected square hollow section (SHS) steel column to address the tying and stability issue in modular construction. Due to the excellent performance of composite structures in fire resistance and buckling prevention, concrete-filled steel tube (CFST) columns are also taken into account in the analysis to evaluate the feasibility of adopting composite sections in modular buildings. Characteristic equations with three variables, i.e., the length ratio, the bending stiffness ratio and the rotational stiffness ratio, are generated from the fourth order governing differential equations. The rotational stiffness ratio is recognized as the most significant factor, with interval analysis conducted for its mechanical significance and domain. Numerical analysis using ABAQUS is conducted for validation of characteristic equations. Recommendations and instructions in predicting the buckling performance of both SHS and CFST columns are then proposed. [11]

Jianfei Zhang, Lin Peng, Yijian Shi, Baoguang Chen Finite element analysis of double-layer box type modular building (December 2019):

Box - type modular building with advantages of quick installation, good comfort, beautiful appearance and convenient turnover, is widely used in construction of temporary construction, business services, holiday villas and other projects. In this paper, a single span double - layer box - type modular building in Shenzhen was taken as an example, using modular building system with a special shaped corner column and cold-formed thin-walled beam. The finite element software ANSYS was used to calculate the overall structural strength and stiffness, and the stress and displacement calculation results under the control of vertical load and horizontal wind load were respectively given. The results show that under the snow load, the maximum stress of the whole structure is 163.14MPa, which appears in the middle of the second layer top frame purlin. Under the horizontal wind load, the maximum stress of the whole structure appears at the beam-to-column connection panel, and the stress of the first story is more unfavourable than that of the second one. The maximum displacement in the horizontal direction is 10.37mm. The maximum displacement angle between layers is 1/278. The above calculation results all meet the requirements of "Standard for design of steel structures" (GB50017-2017), which can ensure the safety and reliability during normal use. Furthermore, it can provide reference for the design and optimization of multi-storey box Building. [12]

Elena M. Generalova, Viktor P. Generalov, Anna A. Kuznetsova, Modular Buildings in Modern Construction(December 2016):

The article considers temporary methods of using modular units in construction. The advanced world experience in the construction of modular buildings is analyzed. It is emphasized that modular construction has the potential to shorten project design and engineering time, reduce costs and improve construction productivity. The installation of modular buildings is cost-efficient, safe and eco-friendly. Modern modular systems are based on using not only large elements such as «block rooms» but various small 3D building elements. The analysis result of Russian developments in the construction of modular buildings proves that Russia has great experience in the development of 3D reinforced concrete modules. As the research results the article shows promise for developing of modern modular construction systems in order to provide the population with affordable, comfortable and eco-friendly housing. The paper describes

the prospects and relevance of introducing modular prefabricated units not only into low-rise but into multi-storey and high-rise construction as well. [13]

III. CONCLUSION

The analysis of modular versus traditional construction techniques reveals distinct advantages and challenges associated with each method. Modular construction, characterized by off-site fabrication, offers significant benefits in terms of reduced construction time, enhanced quality control, and cost efficiency. This method is particularly advantageous for projects requiring rapid completion and high precision, such as low-cost school buildings. By assembling components in a controlled factory environment, modular construction minimizes waste and ensures consistent quality, which is crucial for large-scale and repetitive projects. However, modular construction also faces limitations, especially when dealing with complex designs and large-scale projects. The initial setup costs and the need for specialized skills can pose challenges, and the method's applicability might be constrained by these factors. Traditional construction, on the other hand, provides greater flexibility for bespoke designs and allows for adjustments during the building process. This makes it suitable for high-end and custom projects where design intricacies and on-site modifications are essential.

The theoretical comparison between modular and traditional methods further emphasizes the potential savings in time and cost with modular construction, albeit with considerations for specific project requirements and complexities. In conclusion, the choice between modular and traditional construction should be guided by project-specific needs. While modular construction offers significant advantages in terms of efficiency and quality, traditional methods provide necessary flexibility for complex and custom projects. A hybrid approach, combining elements of both techniques, may often yield optimal results, promoting more efficient building strategies and improving project outcomes.

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