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PROSPECTS OF IMPLEMENTING STEEL FRAMES IN MULTIFAMILY RESIDENTIAL CONSTRUCTION

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Abstract. This study investigates the potential of steel frame structures for residential construction in Ukraine, focusing on sustainability and rapid building techniques for affordable housing. By tracing steel's evolution from early projects like the Ditherington Flax Mill and Crystal Palace to modern modular structures such as Pacific Park Brooklyn, the research illustrates how steel frames support cost-efficient, high-quality housing. A novel concept introduced – the metamorphic structure and building envelope – enables flexible design and easy maintenance, tailored to meet Ukrainian context. This method emphasizes a steel frame core with a dynamic facade that adapts to changing functional and aesthetic needs while maximizing recyclability.

***Purpose**. This study assesses steel frames' feasibility for affordable and sustainable residential housing in Ukraine.*

***Methodology**. Through literature review and case studies, including historical and modern steel-frame projects, the study analyzes steel's adaptability in modular construction and examines local regulatory challenges.*

***Results.** Findings suggest that steel frames offer quick assembly, cost savings, and adaptability, with the metamorphic envelope concept utilizing steel's flexibility to a higher extent.*

***Scientific novelty.** This research advances sustainable construction by presenting the metamorphic structure and envelope as a new model for adaptable steel housing in Ukraine.*

***Practical relevance**. The study offers a framework for using steel frames in affordable housing, benefiting Ukraine's market and sustainable development goals.*

Keywords: sustainable architecture, steel structure, steel frame, residential construction, affordable housing, metamorphic structure, metamorphic building envelope, prefabricated structure, recycled content.

INTRODUCTION

Throughout the history of the construction industry, residential construction has undergone numerous transformations — from the use of practically raw materials to complex artificial composites and 3D printing [7]. Stone and wooden structures remained irreplaceable for a long time. Meanwhile, metals

in construction for many centuries primarily served as small functional elements, such as nails, door hinges, and the like, or, when made from soft precious metals, as decorative features [15]. The Industrial Revolution marked the starting point for the use of ferrous metals as independent building materials, driven by advances in extraction and processing technology, which became increasingly efficient over time. The first building in the world constructed with a steel frame is considered to be the Ditherington Flax Mill, built in the English suburb of Shrewsbury in 1797. This industrial facility is also called the «grandfather of skyscrapers» due to its innovative structural approach [11]. One of the most outstanding early structures featuring metal was the Crystal Palace, built for the Great Exhibition in 1851 to showcase the achievements of that era. Its construction used cast iron, glass, and wood. Decades of metallurgical advances led to new alloys being created with improved structural characteristics. Research in chemistry enabled higher melting temperatures for steel, enhancing its fire resistance. In the United States, steel frames were initially used for the construction of skyscrapers. By the 20th century, steel structures were increasingly used in industrial and civil construction.

In Ukraine today, structural steel is mainly used in industrial structures, shopping centers, and public buildings. The advantages of this material go far beyond only structural benefits. Steel structures enable quick assembly on-site, as they are usually pre-manufactured in factories. This minimizes time spent on the construction site, reducing the overall project timeline. The project timeline can look as follows [5]: design and permit approval, earthworks and foundation; parallel production of structures, structure assembly, building occupancy. Simultaneously executing two stages of construction significantly reduces the time needed to complete them. The speed of erecting load-bearing structures when using steel can significantly exceed that of reinforced concrete buildings. Pre-manufactured frames with bolted connections allow for rapid assembly, as demonstrated by a 30-story hotel in China that was constructed in an impressive 15 days [12]. In the current state of things, this advantage can benefit industry in two main ways: promptly reconstructing damaged structures or radically reducing time needed for new residential construction. Several steel mills operate in Ukraine to meet market demands, and the vast availability of local raw materials helps reduce transportation costs. Steel is one of the most recyclable materials, helping to reduce the environmental impact of construction waste and contributing to the sustainable development of the construction industry. The use of steel helps reduce overall construction costs due to its relatively low price compared to other materials. Additionally, the quick construction reduces labor and equipment rental costs. When compared to partially recycled concrete, steel, being fully recyclable, is at least 10% more affordable[3]. Steel provides operation and maintenance flexibility, allowing for adaptation to various functional needs. The ease of reconstruction and rearrangement enhances the functional versatility of structures. When exposed to risk of external threats with structural damage as a result, steel framework structural elements can be quickly replaced with minimal upfront costs.

ANALYSIS OF RECENT RESEARCH

Undoubtedly, Ukraine faces unprecedented challenges in the field of new construction and reconstruction. The current situation can be considered similar to the increased housing demand in the middle-end of XX century, which was solved during the 1950s-1970s with the large-panel residential buildings constructed using industrial methods, based on the first mass-production designs. These buildings exhibit substantial architectural and structural limitations and fail to meet current sanitary, hygienic, thermal, and durability standards for enclosures in operation [19]. To prevent the creation and implementation of temporary, yet lasting solutions to the housing demand that may lead to complex, problematic outcomes in the future, it is essential to examine the persistent example of the 80% of Ukrainian residential housing [20]. Even though large-panel buildings are considered prefabricated and manufactured, they lack the option of in-occupancy maintenance. Sustainability, as a complex paradigm, may have multiple implementations and extrapolation even in a narrow-purpose research. Therefore it is crucial to emphasize that a manufactured building assembly or a structure as a whole is not always sustainable [4]. For instance, if it does not provide baseline thermal efficiency. While reinforced concrete is an industry standard for residential construction, there are studies that show significant differences in the sustainable performance of concrete as opposed to steel. For instance, Life Cycle Assessment (LCA) is a quantitative comparative analysis and assessment of the environmental impacts of product

systems considering the determined functional unit [13]. One of the recent researches that took place in Iran shows some particularly interesting results. This study compares two multi-story residential buildings in Tehran with similar functions: one built with a steel frame and the other with a concrete frame. Through a life cycle assessment, it analyzed each stage of the buildings' lifespans, from material sourcing to demolition and waste recycling. The environmental impacts examined included global warming potential over 100 years, acidification, eutrophication, human toxicity (cancer and non-cancer effects), resource depletion (water and minerals), climate change, fossil fuel use, air acidification, and biotoxicity. Results showed that the concrete frame generated approximately 219,000 tonnes more pollution across the eleven impact categories than the steel frame. Additionally, the concrete frame underperformed in all but one environmental category. The findings also highlighted that CO_2 was the largest contributor to global warming among non-organic emissions, while methane led the organic emissions. These results advocate for steel frames to mitigate environmental harm in the building industry [10; 13].

The steel frame structure is a versatile platform for flexible volume- and space-planning decisions [14]. It allows more modularity and adaptivity than other construction methods and technologies. In the history of residential construction there are multiple instances of mid XX century single-family houses that featured open planning and steel frame as a structure. One of them is Farnsworth House [17], designed and constructed by Ludwig Mies van der Rohe [9]. This existing single-family house incorporates steel columns, concrete slabs and large-pane glass for facades. On such a scale that would seem impractical, when assuming a building is located on the ground level and even more impractical if it's located in an urban context. But when considering a large multistory residential building, especially with elevated levels of residences, the issue of privacy does not pose any inconvenience. Of course, the steel framework does not require a fully glazed facade. Moreover, when considering affordable housing, modular and prefabricated building assemblies of different types and looks can contribute to the overall occupancy performance in a good way. Pacific Park Brooklyn (Atlantic Yards) is one of the vivid examples of using steel framework as the structural core with modular dwelling units [3]. The 32 story tower is composed of three main volumes, each with their own unique facade articulation. The red and gray paneled volume along Flatbush Avenue has approximately reached its half way mark in height, while the second volume of light gray panels along Dean Street has seen the installation of 4 out of 18 floors of modules. The third volume of the tower will rise above the lower two. When completed, the 346,000 square foot tower will bring 363 rental apartments to the area, half of which will fall under the affordable housing program [8]. It is the tallest Modular Building in the World and is designed to achieve LEED Silver certification. This example demonstrates that steel frame residential construction has the potential to be implemented in a sustainable manner. For the context of the lot in New York city that is a profitable and a cost-effective solution. In the Ukrainian context a conceptual steel frame residential building was designed and has started the construction. As for now, the process is on hold indefinitely, but the idea of the Steel House in Mariupol itself is a solid proof of concept [21]. Even though this pilot project has been started, there are still building code limitations that prevent such concepts from emerging and evolving. The main limitation is the fire rating and fire resistance of the building. With fully steel structure, a building can be a IIIa-fire rated one. While in some countries structural steel frame is a main building technology approach for skyscrapers, the mentioned group of fire rating allows structures to be only 1 story in height, according to the residential code fire rating regulations [18]. Further discussion on this topic can include the following: fire rating III allows 5-story high residential buildings to incorporate wooden elements as part of the slab structure, e.g. beams, while wood being a combustible material, as opposed to steel, an incombustible material. That means it is literally impossible to implement the steel framework concept in residential construction without changes to the regulations. And in order for that process to be started, a new proof of concept needs to be developed.

PURPOSE

The purpose of this study is to reconsider residential space as a whole, leading to opening new ways of creating sustainable and lasting structures that are ergonomic and comfortable for inhabitants [16]. The current legislation and construction regulation in Ukraine set specific limitations for residential buildings. This study also concentrates on these limitations in the context of steel structure

implementation and discovers ways of compliance with the building code, while trying to outline an adaptation of the innovative approach that can be seen in the recent achievements of multifamily residential construction. Adhering to common engineering sense is considered a major milestone for this research, as it is still only a hypothetical assumption at an early stage of development in the local context. Despite its hypothetical nature, this study aims to lay a solid foundation for future discussion and research in the possibility of implementing steel frames in residential multifamily buildings. There are a number of positive examples in the realm of the study from throughout the world [3] and one conceptual pilot project in Ukraine whose execution has been unfortunately postponed indefinitely due to the circumstances in the region [21].

RESULTS AND DISCUSSION

As a result of this study, the concept of a steel frame core with a metamorphic building envelope was developed. In Ukraine this approach can be used to construct cost-effective and future-proof affordable housing with available local steel materials. This concept can be denoted as constructing a lasting, easy-maintained steel frame and designing metamorphic buildings, or metamorphic facades. That would mean even if structural parts fail, they can be replaced on site with the exact same manufactured counterpart, while building envelope can be reshaped, enhanced if needed or replaced. Just like in biological context, such metamorphic structural and architectural concepts can allow residential spaces and volumes to be shaped with time and need, while still being affordable solutions. However, the metamorphic building envelope concept should not be mistaken for metamorphic architecture, which means just mimicking the analogue from nature. Rather it is a concept within dynamic architecture that allows interactable occupancy for the built environment with respect to the demands of the interior and exterior characteristics [6]. This approach will help to eliminate irregulated occupants' interference with the building envelope as it can be seen in mass-series residential buildings, yet allow them to be somewhat more independent with the interior planning. While this can be an advantage for occupants themselves, framework structure approach also allows to minimize interior work costs for the developer. Another question that can be addressed is the engineering networks layout. However, with the rapid development and availability of highly technological materials and engineering inventions, this may not be an issue at all, allowing dynamic approaches to be utilized to even higher extent [1].

CONCLUSIONS

Steel frames hold significant promise for residential construction in Ukraine, offering speed, affordability, and sustainability due to steel's recyclability and local availability. This research introduces a metamorphic structure and building envelope concept, allowing flexible, adaptable structures that accommodate both functional and aesthetic changes over time. Global examples, like Pacific Park Brooklyn, highlight the benefits of steel in modular, high-rise housing, showing it as a viable option for Ukraine's housing needs. While local building codes present challenges, adapting steel-frame construction to meet these requirements could yield future-proof, cost-effective housing solutions, setting a strong foundation for expanded use of steel in residential construction. Historical and Global Context: Steel structures have proven efficient, adaptable, and resilient, making them suitable for both affordable and high-rise housing. Global case studies illustrate steel's economic and environmental benefits in modular construction. Advantages of Steel in Residential Construction: Steel frames allow rapid, cost-effective assembly, reducing labor and equipment expenses. Their prefabricated nature enables construction in challenging conditions, as demonstrated by a 30-story hotel in China built in just 15 days. Metamorphic Building Envelope: A steel frame with a metamorphic building envelope allows flexibility in design, supporting future-proofing through dynamic, adaptable facades and customizable interiors. Ukrainian Context and Potential Barriers: While strict building codes in Ukraine pose challenges, steel's sustainability and local availability can make it a cost-effective solution. A Mariupol pilot project highlights its feasibility in Ukrainian housing. Prospects and Future Research: Further adaptation to Ukrainian standards could enable a new generation of sustainable, affordable housing with dynamic architectural potential, providing a foundation for steel frame use in residential construction across Ukraine.

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АНОТАЦІЯ

Костюченко М., Шевченко О. Перспективи впровадження сталевих каркасів у багатоквартирному житловому будівництві

Це дослідження вивчає потенціал сталевих каркасних конструкцій для житлового будівництва в Україні, зосереджуючись на сталості та швидких методах будівництва для доступного житла. Відстежуючи еволюцію сталі від ранніх проектів, таких як Дітерінгтонський лляний завод і Кришталевий палац, до сучасних модульних конструкцій, таких як Pacific Park Brooklyn, дослідження ілюструє, як сталеві каркаси підтримують економічно ефективне, високоякісне житло. Проводиться паралель із ситуацією потреб житла у середині XX століття та аналіз наслідків наведеної ситуації з точки зору сьогодення. Новою концепцією, яку було представлено, є метаморфна конструкція та будівельна оболонка, що дозволяє гнучке проектування та легке обслуговування, адаптоване до українського контексту. Цей метод полягає у застосуванні сталевого каркасу з динамічним фасадом, який може адаптуватися до змінних функціональних та естетичних потреб у майбутньому.

Мета. *Дослідження оцінює здійсненність сталевих каркасів для доступного та сталого житлового будівництва в Україні.*

Методологія. *У ході дослідження застосовувались огляд літератури та аналіз вітчизняного та закордонного досвіду, що включає історичні та сучасні проекти зі сталевими каркасами, дослідження аналізує адаптивність сталі в модульному будівництві та вивчає місцеві нормативні виклики та обмеження.*

Результати. *Висновки свідчать про те, що сталеві каркаси забезпечують швидку збірку, економію коштів та адаптивність, а концепція метаморфної оболонки використовує гнучкість сталі на більш високому рівні.*

Костюченко М., Шевченко О. Перспективи впровадження сталевих каркасів у багатоквартирному житловому будівництві. *Теорія та практика дизайну. Архітектура та будівництво.* К.: КАІ, 2024. Вип. 4(34). С. 22–28.
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Наукова новизна. *Дослідження представляє концепцію метаморфної конструкції та оболонки як нову модель адаптивного сталевого житла в Україні.*

Практична значущість. *Дане дослідження пропонує застосування для сталевих каркасів в доступному житлі, що сприяє розвитку українського ринку в сфері будівництва та досягненню цілей сталого розвитку.*

Ключові слова: стала архітектура, сталеві конструкції, сталевий каркас, житлове будівництво, доступне житло, метаморфна конструкція, метаморфна будівельна оболонка, модульна структура, перероблений вміст.

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