

# The potential of prefabricated technologies for rental housing

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**Abstract.** The aim of the paper is to highlight the benefits of lean prefabricated and modular construction for the construction of rental housing by considering financial and time savings. In the current turbulent development of prices of building materials as well as banking products and availability of housing, Slovakia is facing significant problems with housing shortage, which is also addressed by foreign countries in the form of rental housing. According to Eurostat data for 2021, the ratio of rental housing in Slovakia to the total number of dwellings is the second lowest in the European Union at 7.1%, while this is mainly rental housing in properties owned by private landlords. The Act on State Support for Rental Housing sets maximum rent levels for individual regions of Slovakia, which directly affect the costs associated with construction. The paper shows that there is great potential of volumetric modular construction to solve increasing demand for rental housing. This article analyses the current state of adoption of modular construction abroad and in Slovakia by the good practice review and literature research resources review.

## 1 Introduction

The biggest challenges in the construction industry that are creating pressure to increase construction efficiency are the shortage of labour, but also the increased demand for quality, speed, cost, and increased safety [1]. These challenges are well reflected by industrialization, especially in the form of prefabrication and modularization in the construction industry [2].

Prefabrication is the off-site construction method in which precast components are produced off-site in a factory and then moved and assembled on-site [2, 3]. Off-site construction is defined by The National Institute of Buildings Sciences established by the United States Congress and Off-Site Construction Council [4] as the planning, design, fabrication, and assembly of building elements at a location other than their final installed location to support the rapid and efficient construction of a permanent structure. Off-site construction is characterized by an integrated planning and supply chain optimization strategy.

In prefabricated method of construction, the use of conventional construction management is problematic due to its approach of work on site, but the use of lean principles

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are highly compatible and are reflecting the needs to bring more effective approach in construction management to cut waste and shorten the duration of construction projects [1].

According to Tamar et al [5], most construction projects lack deeper construction analysis due the way of design by architects and without in-depth execution design to rationalize the construction. Behind those lack of analyses is traditional way of designing construction projects by architects with installation technicians with the focus on typology, technical norms, and legal regulations which can lead to incoherent construction and is the one of the main barriers to promote prefabricated and modular construction methods. Incoherent construction occurs when industrialized technologies and materials are combined with traditional design or techniques. Coherent building system is when design, project and execution are deeply integrated which leads to better application of Lean methods and overall construction improvements.

Commonly presented use cases of Lean practices are applied to specific types of industrial production and are more difficult to standardize for common practice in the construction industry [6]. Lean construction is the construction management practice which leads to reduction of production costs, waste, and time consumption [7]. McKinsey has found [8] that application of lean principles into large-scale construction projects can achieve 10 to 30 percent reductions in expected completion time and cost savings of 10 to 25 percent. D. Itodo and O. Olalekan [9] found that currently, the most mentioned factors that support the implementation of lean off-site construction in housing delivery are early involvement of the supply chain and simulation to visualise the production process and standardisation of the process.

Industrial building systems are structures based on prefabrication and standardisation, the main pillars of lean production, which allow to better optimise the use of building materials and labour in the construction sector. One of the most complex lean methods of off-site construction is modular construction, where most of the work is done off-site and then transported and assembled modules on site to form a building [10]. 3D volumetric modules are most suitable for buildings with high repetition of modules like hotels, hostels, or affordable housing [11]. According to McKinsey's research [11, 12, 13], modular construction can reduce construction costs by up to 20% and speed up the construction process of building projects by 20 to 50% using.

Thai et al. [2], who in 2020 called modular construction a "disruptive technology", describe the main advantages of modularity for use in high-rise buildings as speed of construction, safer production, lower impact on the environment, and better-quality control. On the other hand, several barriers prevent the wider use of modular construction. Organizations involved in prefabrication in the U.S. [4, 13, 14] states the following challenges of modularization for overcoming barriers: Need of increased coordination, Earlier owners' capital in the project, local regulations and technical limitations like size limits, lack of transparency in project costs, flexibility in usage stage. Some of the challenges in modular construction are also a result of a lack of knowledge and understanding how modular processes work and its benefits by different construction practitioners and the public. One of the barriers in the promotion of modular construction is also high-risk capital and the mismatch between constant production and volatile demand in the construction industry [1].

Modular construction has biggest barriers in logistic management [15]. The transport and assembly of the modules is carried out using the just-in-time construction method, which makes the construction of modular buildings very fast and efficient. However, this method of construction also poses logistical risks, both on the part of the module transporter and on the part of the manufacturer, the builder, and the material supplier. Therefore, in off-site construction methods, it is advisable to use pull techniques to plan the supply chain, resulting in a 12.6% reduction in construction time and an 80% reduction in component idle time.

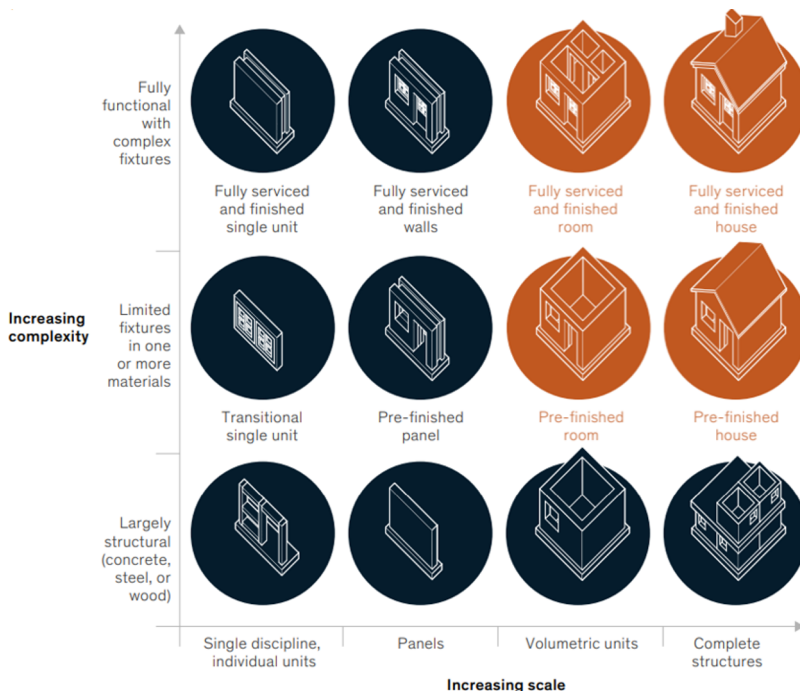
The construction industry is also under a lot of pressure due to low housing affordability and much slower construction of new housing than the demand in the housing market. Eurostat statistics suggest that problems in building new rental housing may also be causing a multiplication of the costs of building new housing compared to average prices in rental housing, with the difference in builders' costs compared to rentals increasing by 20% in the eurozone and 37% in Slovakia between 2015 and 2022.

Many of the research papers are reporting not only a slow progress in prefabricated and modular construction, but also many gaps in the industry through all areas from theoretical research to practical applications. Gaps are mainly due to very segmented and traditionally oriented construction industry with a lack of broader point of view from perspective of work in research, design, construction, logistics, and production.

## 2 Subject of research

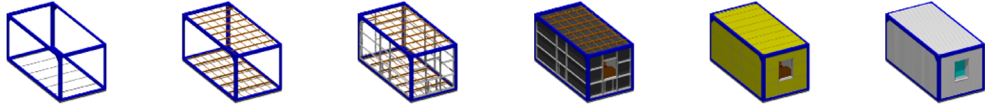
The subject of the research is an investigation of the feasibility and applicability of volumetric modular construction techniques specifically adapted to rental housing. This study aims to explore the distinctive characteristics, various types, advantages, and potential disadvantages of volumetric modular construction in the context of rental housing in the world and in Slovakia.

Volumetric modular construction is a modern construction method that involves the fabrication of entire building modules in controlled factory environments [16, 17]. In the highest degree of complexity, these modules also include installation wiring, accessories, and surface finishes. Modular construction methods cover a range of different approaches and systems with various degrees of prefabrication [12] (Fig. 1). To gain the most benefits of the off-site construction methods, the subject of research is focused on volumetric modular constructions. This approach offers benefits such as increased cost efficiency, improved quality, and reduced construction time with resource waste elimination [12, 18, 19, 20].



**Fig. 1.** Degree of prefabrication based on complexity and scale of modular construction [12].

From structural-material aspect, we divide types of space modules into lightweight and heavyweight volumetric modules by material of framework (Fig. 2).



**Fig. 2.** Degree of volumetric modules complexity from load-bearing structure to fully finished module [21].

Volumetric modules based on timber are lightweight types of modules which are very popular in practise mainly used in small constructions. Load-bearing structures are made of wood covered by OSB, or SDK boards and filled with thermal insulation that is diffusely open or closed supplemented by installation holes or even distribution. From exterior side, they are usually insulated with contact or non-contact thermal insulation systems. The advantages are better thermo-technical parameters and lower environmental impact directly at the construction site [22].

Steel/Aluminium volumetric modules have mostly a supporting structure of galvanized steel C-profiles. The walls embedded in the steel frame are filled with an insulating core from mineral wool, ESP, or PIR foam, to which building boards are installed on the sides, mainly plasterboard, gypsum fibreboard, OSB or metal sheets. They are also insulated externally with various External Thermal Insulation Composite Systems. The advantage of 3D steel modules is ability to produce long-span modules [23, 24].

Volumetric modules based on concrete are heavyweight types of modules for modular construction made of either parts of high strength precast concrete or lightweight concrete walls or combination with other types of materials. In concrete modules, tensile strength is carried out by fibre and steel reinforcement. Its biggest advantages are high strength and seismic resistance [23].

Modules are limited by transport dimensions and therefore, their maximum overall length is generally 13 m, and the total possible module width is 4.2 m. In practice, from typological point of view, the typical dimensions of modular units are based on the purpose of their use (Table 1) [24].

**Table 1.** Typical dimensions of volumetric modular units [24].

Application	Internal wall height (mm)	Internal module width (mm)	Internal module length (m)	Ceiling-floor zone (typical) (mm)
Study bedrooms	2400	2500 – 2700	5.4 to 6	300
Apartments	2400	3300 – 3600	6 to 9	450
Hotels	2400 – 2700	3300 – 3600	5.4 to 7.5	450
Schools	2700 – 3000	3000 – 3600	9 to 12	600
Offices	2700 – 3000	3000 – 3600	6 to 12	600 – 750
Health sector	2700 – 3000	3000 – 3600	9 to 12	600 – 750

For high-rise buildings, weight is a major constraint in building design. Therefore, smaller modular units may be the solution, but then reduce the overall benefit of modular construction. A characteristic feature of high-rise buildings is the grouping of modules around a core of reinforced concrete.

Each modular manufacturer has its own system of design, production, assembly, and marketing. Some module manufacturers also have their own design offices, assembly crews or offer construction delivery with all finishes [25].

### 3 Methodology

The purpose of the research is to analyse the current state of adoption of modular construction abroad and at home by two research methods: the good practice review and literature research resources review.

In good practise review, the scientific databases, expert journals, and books were used to show best examples in practise.

In the literature research review, quantitative research was used through Web of Science database based on the topic of interest which included title, abstract and keywords. Several different searches were conducted to obtain an effective number of publications for the analysis of topics focused on modular buildings.

#### 3.1 Good practise review

Examples of good practice from abroad point to the fact that very tall buildings can be constructed from volumetric modules, which can be built very quickly and can be more cost-effective in terms of area. These buildings are mostly used for long-term or short-term housing purposes, which also creates conditions for use in the rental housing segment. Table 2 shows examples of modular buildings from around the world, arranged by number of storeys. These are constructions built since 2014, i.e. after the global economic crisis (2007-2008), but also include constructions built during the covid crisis. An example is the tallest building in Table 2, which was built during the pandemic. This also points to one of the benefits of modular buildings, that many workers are not needed during their construction, while a well-controlled environment can be created in the factory itself, in terms of health and safety.

**Table 2.** Examples of volumetric modular buildings in the world.

Project	Storey	Year	Location	Material
Avenue South Residence [26]	56	2023	Singapore	Concrete
Croydon Tower [27, 27]	44	2020	London, UK	Steel
Clement Canopy [27]	40	2019	Singapore	Concrete
B2 Tower [27]	32	2016	New York, USA	Steel
Apex House [27]	29	2017	London, UK	Steel
SOHO Tower [27]	29	2014	Darwin, Australia	Steel
Kvarteret Jylland [29]	14	2021	Krista, Sweden	Steel
Solidarity Hotel on Seine [30]	4	2020	Paris, France	Steel

From the mentioned good practice examples, the tallest building built from volumetric modules is Avenue South Residence and is situated along Silat Avenue at Bukit Merah, near downtown Singapore. The twin tower is 192 meters tall with 56-storey is the highest residential tower in the world. It has 1074 living units and was built using over 3000

prefabricated prefinished volumetric modules [26], series of 3 to 6-sided boxes cast from concrete with 80 percent off-site completion [31]. Thanks to the modular construction and used ecological type of concrete, there was 50 percent reduced carbon emission and 40 percent boost in productivity. With precise planning, the construction project was able to overcome most of the supply disruptions during pandemic period (Fig. 3a).

From the smallest building mentioned in good practise examples, Solidarity Hotel on Seine is the project initiated by Aurora, serves as a shelter for homeless people, facilitating their reintegration into society. The hotel is designed to accommodate up to 308 people, the to provide living space for those who are in needs. The hotel consists of 226 spacious modules supplied by Czech company KOMA MODULAR, which is active in Slovak market as well. The hotel has four floors and features modules measuring 11 × 2.5 meters, with a total area of 5,160 square meters. The facade features white polycarbonate panels, complemented by heat-treated wood cladding and irregularly painted sheet metal elements [30] (Fig. 3b).



**Fig. 3.** a) Avenue South Residence [26], b) Hotel on Seine [30].

Examples of good practice from abroad related to modular constructions point to the suitability of this method of construction for rental housing and for buildings with a larger number of floors. This is also one of the main reasons why modular construction for rental housing can only be used to a limited extent in Slovakia, due to the regulated limit on the number of floors of modular timber-based buildings, up to a maximum of 4 to 5 floors [22, 32]. Although steel-based modular construction can also be used for multi-storey buildings, modules for lower floors, but would have to be structurally more robust and therefore more costly. Therefore, even good practice examples from Slovakia present only buildings with a maximum of three storeys.

The technology of modular buildings in Slovakia has a history mainly in the segment of temporary buildings used on construction sites. At present, they are mainly used for the construction of family houses or recreational buildings. As individual modules they are also used for points of sale or for administrative purposes. The examples of good practice in Slovakia (Table 3) show that they are also used for the housing and education segments, but mainly in regions that can be considered less economically developed regions.

**Table 3.** Examples of volumetric modular buildings in Slovakia.

Project	Storey	Year	Supplier, Producer	Material
Sport center of the police, Bratislava [33]	2	2023	KOMA	Steel
Hotel: Björnson Tree Houses, Jasná [34]	1	2019	Ark Shelter	Wood
Elementary school, Podhorany [21]	3	2014	Rikostav	Steel
Container school, Podhorany [21]	3	2013	Rikostav	Steel
Rental apartments, Malá Domaša [21]	3	2011	Rikostav	Steel
Administrative building, Košice [33]	2	2011	KOMA	Steel
Rental apartment, Malá Domaša [21]	3	2010	Rikostav	Steel

Examples of good practice, show that modular construction is also usable for administrative purposes, but also for the background of sports buildings. However, there is a clear difference in the number of storeys compared to examples from around the world, as commented above, particularly for fire safety reasons [32]. It is obvious that the buildings built in Slovakia have not even used the potential of the possible four storeys so far (Fig. 4). The cost per living unit would be lower if four storeys were built compared to three or two storeys.



**Fig. 4.** a) Sport center of the police, Bratislava [33], b) Rental apartment, Malá Domaša [21].

From the chosen high building with at least three storeys, it is obvious that in Slovakia, modular buildings for housing were built only in years 2010-2011, even as experimental buildings. Since then, there has been no recorded construction of any modular housing, which is in sharp contradiction to the government's intention in rental housing development, which was after 2020 also part of the program statement. Agency for state-supported rental housing stated [35] that more than 80% of the population aged 17-45 years calls for construction of rental apartments.

### 3.2 Literature research review

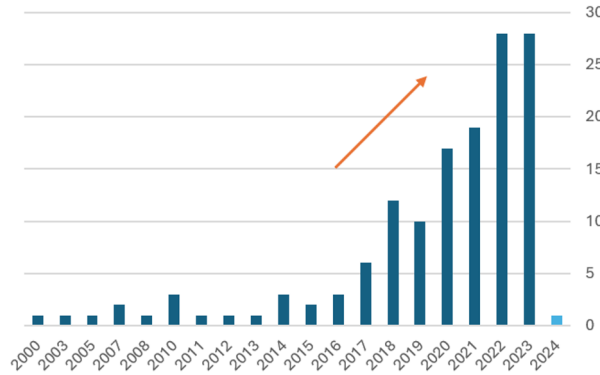
The second approach to research the potential of modular constructions was based on the search for contributions and topics related to modular construction in the environment of scientific publications. The bibliometric analysis was performed in the Web of Science database through the analysis of article titles, abstracts, and keywords.

For research, there were carried out multiple searches of chosen keyword combinations (Table 4) entered in search engine of the database. The year of the first recorded source, 1955, testifies to the fact that modularity as such has been used in the construction industry for quite a long time. However, the next keyword "volumetric construction" already specifies the principle of modular construction, which started to appear in scientific articles from 1976, and there was obviously the lower number of articles in relation to this year. The combination of the previous two keywords "volumetric modular construction" with the assumption of the simultaneous appearance of both the words modular and volumetric, has already selected only 99 sources since 2003. Since the research is aimed at rental housing, another keyword focused on the building itself (with output of 115 sources). The final search combined the last two searches relevant to the subject of research and eliminated duplicate search sources in combination #3 and #4. All conducted searches were entered without exact matches.

**Table 4.** Results of topics from Web of science database search.

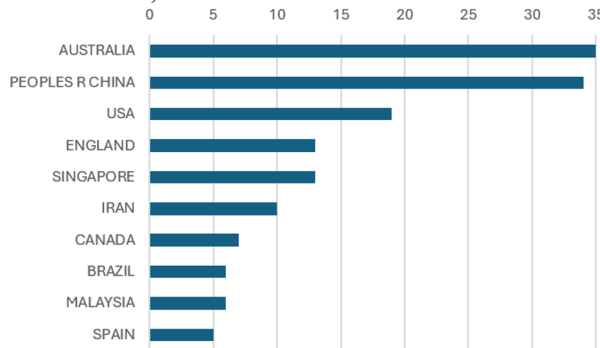
No.	Topic	Results	1st year of publication
1	modular construction	9884	1955
2	volumetric construction	2777	1976
3	volumetric modular construction	99	2003
4	volumetric modular building	115	2000
5	#3 OR #4	141	2000

Another evaluation was carried out on the obtained sample of 141 scientific papers. From the distribution of the number of publications in the time series from the year of first appearance (2000), it is obvious that while up to 2016 they were published in the order of three publications per year, from 2017 their number has a strong rising trend (Fig. 3). In the years 2022 and 2023 there were already by 28 published contributions per year (outside of the current year 2024).



**Fig. 4.** Number of publications in Web of Science database between 2000 and 2024.

Geographical distribution of abundance of publications shows that the most numerous research on volume modular construction is in Australia (35) and China (34), while only 19 articles are published in the USA, considered the cradle of modular construction (Fig. 4).



**Fig. 5.** Number of publications in Web of Science database by geographical distribution.

Publications of other countries shown in Fig. 5 are in the range of 5-13 entries, but only in two cases are European countries. No documents were found on volume modular construction/building published from Slovakia and Czech Republic. It follows from the above that there has been very few research on modularization, modular construction, or prefabrication in the European environment, which shows that research on this topic has still a lot of potential.

## 4 Conclusion

This research analyses the current state of volumetric modular construction from the point of view of good practice and an overview of previous research on this topic with the aim of finding future research direction in solving the insufficient supply of rental housing in Slovakia and abroad. The analysis shows that there is great potential in the given issue, either in practical construction or possible future research. The article also presents the basic types

of prefabricated and modular construction by describing the degree of prefabrication and volumetric modules in terms of material, structural and dimensional solutions. Examples show that modular construction has a positive effect on construction efficiency, but is also more environmentally friendly, not neglecting health and safety reasons.

The research shows that there are a whole series examples of good practice in the construction of high-rise buildings in the world from volumetric modular construction, which are built for the purpose of selling and renting apartments. This method of construction has a growing trend abroad, which is also related to the high demand for quick and cheap solutions to the lack of housing. This is also reflection of increasing builders' costs compared to rentals increasing in eurozone and in Slovakia in last years.

Examples of good practice in Slovakia show that the modular construction built so far have not used the potential of even the possible four floors. At the same time, it is obvious that the costs per residential unit would be lower, with a larger number of floors.

From the analysis of the literature review, carried out through the web of science database, a rapid increase in scientific publications was recorded since 2017, which reflects an increasing trend not only in the implementation of modular constructions, but also from the point of view of solving research questions. Australia and China are leading countries in the topic of volumetric modular construction research, while the USA, the cradle of volumetric construction, is behind them. From European countries England and Spain are leaders in this topic of research, while there are not any records from Slovakia and Czech Republic.

For the complexity of the topic, there is a need for bigger research and there is missing information about what is the real demand for volumetric modular construction and what challenges do companies face in this segment of construction in Slovakia.

The acknowledgement: This work was supported by project under the VEGA 1/0336/22 Research on the effects of Lean Production/Lean Construction methods on increasing the efficiency of on-site and off-site construction technologies.

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