Krzysztof Zima, Maria John
Structure and Environment 2025, vol. 17, (4), pp. 165-174, Article number: el 016
https://doi.org/10.30540/sae-2025-016

Structure and Environment
ISSN 2081-1500
e-ISSN 2657-6902
https://content.sciendo.com/sae
https://sae.tu.kielce.pl

Kielce University of Technology

DOI: 10.30540/sae-2025-016

COMPARISON OF TRADITIONAL AND MODULAR CONSTRUCTION IN TERMS OF TECHNOLOGY, TIME AND COST

PORÓWNANIE BUDOWNICTWA TRADYCYJNEGO I MODUŁOWEGO POD WZGLĘDEM TECHNOLOGII, CZASU I KOSZTÓW

Krzysztof Zima*, Maria John
Cracow University of Technology, Poland

Abstract

Modular construction is a rapidly growing sector of the construction industry in recent years. This paper presents information on modular construction technology, including its characteristic features and the positive aspects resulting from its use. It discusses the scope of application, completion time, quality of workmanship and ways to minimise losses during the module production process, along with the possibility of reusing both the modules and the materials from which they are made. The comparative analysis covered technological and economic aspects as well as completion time, using the example of a single-family residential building for two technological variants: modular and traditional construction. Both technologies were discussed in detail. The economic analysis was based on market research of offers from companies specialising in the construction of buildings using the technology in question. The cost estimate for traditional construction was prepared using the BIMestiMate programme. A comparative analysis of the construction time for buildings using both technologies was also carried out.

Keywords: comparative analysis, modular construction, traditional construction

Streszczenie

Budownictwo modułowe to sektor branży budowlanej, który w ostatnich latach szybko się rozwija. Niniejszy artykuł przedstawia informacje na temat technologii budownictwa modułowego, w tym charakterystyczne cechy oraz korzyści wynikające ze stosowania tej technologii. Omówiono w nim zakres zastosowań, czas realizacji, jakość wykonania oraz sposoby minimalizacji strat podczas procesu produkcji modułów, a także możliwość ponownego wykorzystania zarówno samych modułów, jak i materiałów, z których są one wykonane. Analiza porównawcza objęła aspekty technologiczne i ekonomiczne, a także czas realizacji, na przykładzie budynku mieszkalnego jednorodzinnego dla dwóch wariantów technologicznych: konstrukcji modułowej i tradycyjnej. Obie technologie zostały szczegółowo omówione. Analiza ekonomiczna opierała się na badaniach rynkowych ofert firm specjalizujących się w budowie budynków z wykorzystaniem danej technologii. Kosztorys dla konstrukcji tradycyjnej został przygotowany przy użyciu programu BIMestiMate. Przeprowadzono również analizę porównawczą czasu budowy budynków przy użyciu obu technologii.

Słowa kluczowe: analiza porównawcza, konstrukcja modułowa, konstrukcja tradycyjna

1. INTRODUCTION

Modular construction is a dynamically developing sector that has gained popularity in recent years. It allows for a significant reduction in project completion times without compromising on quality. What is more, the use of modern technologies in modular construction often leads to improved quality, which makes this method even more attractive.

*Cracow University of Technology, Poland, e-mail: krzysztof.zima@pk.edu.pl

The construction process is strongly linked to environmental protection, with consideration given at the design stage to minimising the negative impact on the environment during the construction of the modules and throughout the entire life of the building. Modular construction technology offers a new perspective on the construction process, while also streamlining it. It is used in various areas, such as hotels, commercial and service buildings, student residences, multi-family residential buildings and single-family homes.

At present, modular construction is undergoing extensive development and offers significant advantages in a number of areas. The key to further progress is to streamline the design process, shorten the development cycle and increase competitiveness. Consequently, it is imperative to establish and optimise the design process for modular buildings. For instance, [1] proffers modular construction as a response to contemporary challenges, including the ongoing global pandemic, the war in Ukraine, population migration, military relocations, natural disasters and housing shortages in European markets.

2. MODULAR CONSTRUCTION

2.1. Sustainable design

Modular construction is a process in which a building is constructed off-site, in controlled factory conditions, using the same materials and designs that meet the same norms and standards as conventionally built structures – but in half the time [2].

The focus of modular construction technology is on sustainable design, self-sufficiency and environmental compatibility. The following modern technologies are utilised: solar panels, geothermal systems, and energy-efficient glass. The latter allows for effective heat accumulation during the winter months and reflects sunlight in the summer months, thereby maintaining an optimal temperature indoors. Additionally, a mechanical ventilation system with a recuperator is employed, which enables the recovery of heat from the ventilated room. As asserted by [3], modular construction is regarded as one of the most sustainable building solutions for mitigating environmental degradation during the operational phase of a building. A growing number of investors are opting for the construction of small houses, drawn to these structures by their simplicity, cost-effectiveness and rapid assembly.

In the context of the construction of modular buildings, it is imperative to prioritise the minimisation of waste, which is defined as the amount of materials utilised. In the nascent stages of construction, the amount of construction waste is a pertinent consideration. The fabrication process entails the utilisation of precise machinery to meticulously execute the cutting of repeatable elements to the precise dimensional parameters delineated in the design specifications. The potential exists for a 90% reduction in waste. The consumption of natural resources is also subject to limitations imposed by the utilisation of inter-module connections. These connections facilitate the straightforward disassembly and subsequent reuse of modules in alternative locations, thereby reducing the environmental impact. The elements from which the modules are made, or the entire modular structure, can be dismantled, and the materials used can be reused to create a new modular structure or recycled for use in other types of structures, not necessarily modular. The modules can be relocated to an alternative location or expanded in a variety of ways on site. The potential for reuse significantly reduces the requirement for further raw materials in the construction of new elements, thereby reducing energy consumption.

2.2. Development of modular construction

The expanding global population signifies a shared challenge confronting both developing and developed countries, namely the provision of adequate urban and industrial space. The construction sector must dedicate itself to continuous improvement and the pursuit of innovative solutions to facilitate the construction process. Modular construction offers the possibility of significantly reducing the time needed to complete buildings, thanks to advanced technology that involves prefabricating larger elements off-site.

Modular construction is a field that is undergoing constant development on the global market. Projections indicate the likelihood of sustained growth in this construction sector during the period from 2023 to 2030. A recent analysis by Data Bridge Market Research [4] has revealed that the average growth rate between 2015 and 2030 is projected to be 6.4%, with the value of the global modular market anticipated to reach USD 93.42 billion by 2030. In order to enhance the intricacy of the analysis, the modular construction market was segmented into regions, with local factors affecting the market being

Table 1. An examination of developmental trends across diverse geographical regions worldwide

Region	Key trends
 North America	The objective of sustainable urban development is twofold: firstly, to consider the quality of construction, and secondly, to ensure safety and comfort during work.
 Europe	The potential for reducing the construction time of a building facilitates accelerated urban development.
 Asia-Pacific	The design is uncomplicated, allowing for straightforward dismantling, expansion, or repositioning of the completed structure.
 South America	The construction of healthcare facilities can be accomplished expeditiously.
 Middle East and Africa	The propensity to invest is positively correlated with income level, and is further facilitated by convenient access to financial resources and loan opportunities.

Source: [4].

taken into account, including trends, trade routes and changes in building regulations. The analysis presented in Table 1 also takes into account potential investors and competition in the local and national markets, as well as technological developments. The report is based on three main criteria: the type of modules (PMC – Permanent Modular Construction and RC – Relocatable Construction), the materials used (wood, concrete, steel) and the building's purpose (hospitals, education, housing, hotels).

According to forecasts, China is set to assume a particularly prominent role in the field of modular construction in the forthcoming years, given its substantial impact on the construction sector. The country has the largest construction market in the world, accounting for approximately 20% of all global investments. China is a country undergoing significant population growth and improved living standards, which are increasing the demand for housing. This indicates that modular construction can grow rapidly to meet the needs of a growing population. This is particularly evident during the critical period of the 2020-2022 COVID-19 pandemic, when numerous hospital shelters were constructed rapidly across China, including the Wuhan Huoshen Mountain Hospital. This rapid construction is a testament to the significant benefits of modular construction. Nevertheless, a considerable proportion of modular buildings continue to exhibit substandard quality. Many manufacturers of modular buildings utilise rudimentary equipment and employ low-level assembly techniques. They have not established a comprehensive research and development and production system, which hinders the assurance of the quality of the buildings [5]. Figure 1 illustrates the global levels of development of modular construction.

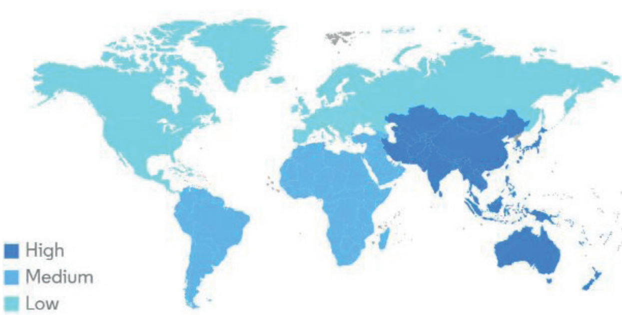

Fig. 1. Areas of development in modular construction
Source: [6]

3. COMPARATIVE ANALYSIS OF MODULAR AND TRADITIONAL CONSTRUCTION

3.1. Analysis of manufacturing technology

A comparative analysis was conducted on two single-family residential buildings, each with a usable area of approximately 90 m², constructed using both modular and traditional technologies. The fundamental distinction between the two technologies pertained to the load-bearing structure of the edifice. In traditional construction methods, ceramic hollow brick walls were utilised, whereas in the context of modular technology, these walls were composed of a steel frame. This single-family residential building, constructed using modular building technology, consists of three modules based on a steel frame structure; it is a two-story building. Two modules make up the ground floor, which has a usable area of 61.48 m², while the first floor consists of one module with a usable area of 30.62 m² and a terrace located on one of the ground floor modules. The building's interior includes an entryway, a utility room, hallways, a living room with a kitchenette, 3 bedrooms, and 2 bathrooms. The total usable area is 92.35 m², and the building footprint is 83.03 m². The base modules (Module I and Module II) are set on a foundation-foundation footings-which the investor must construct on their own before proceeding with the installation of the modules.

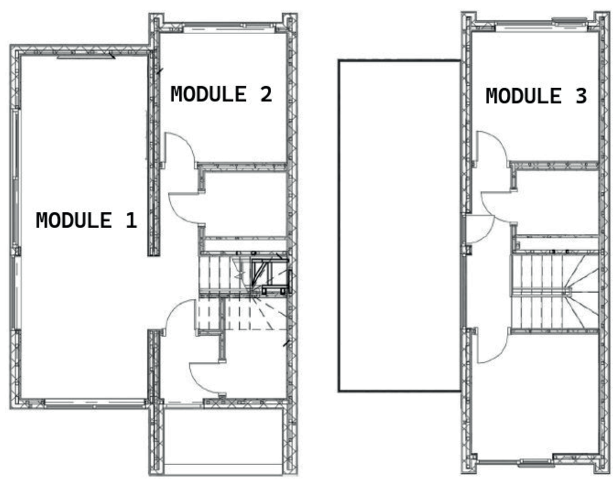

Fig. 2. Floor plan of the modular building-ground floor and first floor-including the assigned module numbers

Modules I and II have a simple cuboid structure, while the module on the second story has a gable roof covered with standing seam aluminum sheet metal. Dimensions of the modules used: Module I – 3.35 m × 3.60 m × 9.7 m, Module II – 3.35 m × 3.60 m × 12.30 m, and Module III – 3.85 m × 3.60 m × 12.30 m. The

Figure 2 shows the floor plans for the ground floor and first floor of the proposed modular building.

It is evident that both structures satisfy the criteria for ensuring adequate load-bearing capacity of the building and those relating to the heat transfer coefficient, in accordance with WT. As illustrated in Table 2, the heat transfer coefficient Uc for individual partitions was utilised as the fundamental metric for evaluating the quality of these elements. The U_c coefficient is a pivotal parameter in the assessment of the quality of building partitions. It is evident that a reduction in the value of the partition results in enhanced thermal properties, leading to diminished heat losses within the building and subsequent reduction in operating costs. The analysis indicates that partitions constructed using modular construction technology exhibit superior parameters in comparison to those produced by traditional methods.

Table 2. A comparison of the heat transfer coefficients for a selection of partitions

Thickness [cm]	Traditional technology	Heat transfer coefficient U_c [W/m²K]	Thickness [cm]	Modular technology	Heat transfer coefficient U_c [W/m²K]
	External walls above ground level	**0.19**		**External walls above ground level**	**0.16**
1.5	Ceresit CT36 thin-layer façade		0.30	Quartz sintered facade panel	
18.0	Termo Organika polystyrene foam		3.70	Ventilation layer	
28.8	Max 220 ceramic block		10.00	Ventirock Super rock wool with veil	
1.0	Cement-lime plaster		1.20	Duripanel B1 cement-bonded particle board	
			11.00	Rockton Super rock wool	
			-	Vapour barrier membrane	
			1.25	Nida Cicha plasterboard	
			1.25	Nida Ogień+ plasterboard	
	Monolithic reinforced concrete ceiling with unidirectional reinforcement	**0.30**		**Modular ceiling – module II (ceiling) and module III (floor)**	**0.10**
5.0	Concrete screed		1.50	Finishing layer	
-	Polyethylene foil		1.80	Brio 18 gypsum fibreboard	
10.0	EPS polystyrene foam		2.50	EPS 300 polystyrene board	
12.0	Reinforced concrete slab		2.20	Duripanel B1 cement-bonded particleboard	
2.7	Steel grating		-	Vapour barrier membrane	
1.3	Plasterboard		20.00	Rockton Super rock wool	
1.0	Cement-lime plaster		0.06	Galvanised steel sheet	
			8.00	Ventilation layer	
			-	Vapour-permeable membrane	
			0.06	Galvanised steel sheet	
			12.00	Rockton Super rock wool	
			8.00	Ventilation layer	
			-	Vapour barrier membrane	
			1.25	Nida Cicha plasterboard	
			1.25	Nida Ogień+ plasterboard	
	Floor on the ground	**0.28**		**Floor on the ground**	**0.13**
5.0	Concrete screed		1.50	Finishing layer	
-	PE foil		1.80	Brio 18 gypsum fibreboard	
10.0	XPS polystyrene foam		2.50	EPS 300 polystyrene board	
15.0	Concrete slab		2.20	Duripanel B1 cement-bonded particleboard	
-	KMB compound		-	Vapour barrier membrane	
10.0	B-10 concrete		16.00	Rockton Super rock wool	
20.0	Gravel (compacted)		7.00	Purteco PSC35 closed-cell foam	
			0.06	Galvanised steel sheet	

Source: own

3.2. Economic analysis

A cost estimate for the single-family residential building under analysis was prepared using the BIMestiMate programme, with the aim of facilitating a comprehensive and detailed calculation of the construction costs. The estimated price of the facility incorporates both direct and indirect costs, in addition to profit and VAT. The unit prices were adopted in accordance with the Sekocenbud price list for the fourth quarter of 2025. The construction of the building was estimated to cost PLN 480.000 gross. The roofing and external wall cladding had the greatest impact on the cost of construction using traditional technology for the analysed building.

The estimated cost of constructing the building using modular technology amounted to approximately PLN 460.000 gross, a figure derived from a tender conducted among companies involved in construction using the technology in question. As illustrated in Figure 3, the diagrammatic representation provides a visual representation of the percentage distribution of costs for a specified phase of construction, utilising both modular and traditional methodologies.

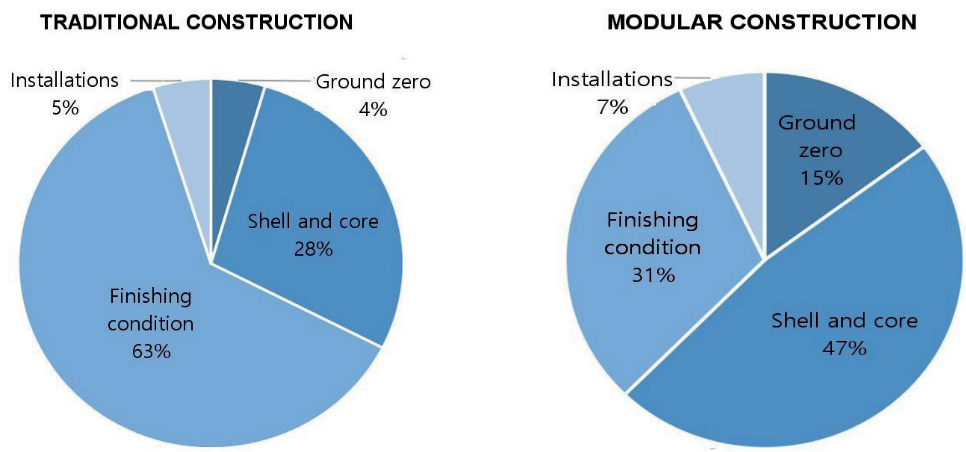

Fig. 3. Diagrams showing the percentage share of modular and traditional construction stages in economic terms
Source: own study

3.3. Analysis of construction time

Construction time is a key determinant of project efficiency, cost control, and client satisfaction. The method of construction-traditional or modular-has a significant impact on overall project duration. This section analyzes the differences in construction time between traditional construction and modular construction, highlighting the stages, influencing factors, and empirical data from relevant studies.

A detailed analysis of the construction time for a modular building, which averages 120 days, demonstrates that the construction time for a single-family house using modular technology is 30%-50% shorter (Fig. 4). This finding is consistent with the claim of a 50% reduction in construction time presented in [2] and cited in the introduction.

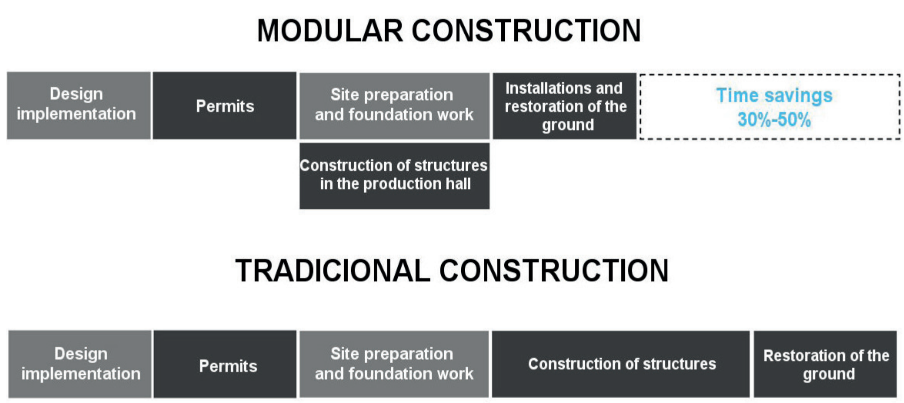

Fig. 4. Cost diagrams for individual stages in modular and traditional construction
Source: [7]

Table 3. Overview of Construction Processes – a differences between tradicional and modular construction

Stage	Traditional Construction	Modular Construction
Design Phase	Sequential – detailed design completed before construction begins.	Parallel – design and module manufacturing can overlap.
Site Preparation	Conducted before structural work begins; delays affect the schedule.	Can occur simultaneously with off-site module fabrication.
Structural Construction	On-site, weather-dependent, often labor-intensive.	Off-site, in factory-controlled conditions, faster and less weather-dependent.
Installation & Finishing	Occurs after structure completion.	Modules are installed rapidly; only final connections and finishes done on-site.

The construction time for a modular building is significantly shorter, mainly due to the repeatability of partition construction and the technology used to connect individual layers. The work is carried out in a closed production hall, which means that weather conditions do not cause delays due to forced interruptions to ongoing work. The MS Project programme was used to create a schedule for the construction of a single-family house using traditional technology, for which the construction time was set at 205 days.

The Table 3 provides a synopsis of the primary phases of the construction process in both traditional and modular terms, highlighting the fundamental discrepancies in the implementation of individual phases.

In the context of traditional construction methodologies, the process is characterised by its sequential nature, whereby each stage of construction commences only upon the completion of the preceding one. For instance, design work must be fully completed before construction can begin on site, and earthworks and foundation work must be completed before the structure can be erected. This arrangement frequently results in an increase in the overall project completion time and an elevated risk of delays due to meteorological conditions, material logistics or the coordination of construction teams.

Conversely, modular construction is distinguished by concurrent processes. In practice, this signifies that design work, prefabrication of modules in the factory and preparation of the construction site can be undertaken concurrently. The modules are manufactured in controlled factory conditions, regardless of weather and construction site constraints, which significantly reduces completion time. Subsequent to the completion of prefabrication, the finished elements are transported to the site and assembled expeditiously, with only finishing work and installation connections remaining on site.

Consequently, the implementation of modular technology in construction processes leads to enhanced integration, reproducibility, and temporal efficiency. In contrast, traditional methodologies are more prone to delays and external influences.

While modular construction significantly reduces on-site construction time, it requires more upfront planning and design coordination. Delays in manufacturing or transport can also affect schedules. However, once fabrication begins, the controlled factory environment enables consistent progress unaffected by external factors such as weather or site congestion. Traditional methods, although flexible for design changes, are slower due to sequential scheduling and dependency on multiple subcontractors.

4. DISCUSSION

The cost analyses are based on calculations and information obtained directly from companies, while the time analysis is based on frequently reproduced diagrams and analyses presented by various researchers. As illustrated in Table 4, a meta-analysis of select publications has been undertaken, with the objective of providing specific time-saving figures for comparisons between modular and traditional technologies.

As demonstrated in Table 4, an analysis of the data indicates that there is an average time saving of 28.9% when comparing modular and traditional technologies. It is evident from the publications cited that modular technology is significantly advantageous. With regard to the issue of cost comparisons, the mean cost saving was found to be 23.4%, whilst in one case, costs were identified as being 6.67% higher.

Table 4. A brief meta-analysis of differences in construction duration and costs between traditional and modular building methods

Type / scope of research	Time savings (modular vs traditional)	Cost savings (modular vs traditional)	Reliability assessment / type of methodology	Source
Industry-specific, analysis of numerous cases/clients	20–50% (the midpoint of **35%** was used in the calculations)	**≈20%**	Industry report, high practical relevance, but not peer-reviewed (weight: 1)	Bertram N., Fuchs S., Mischke J., Palter R., Strube G., Woetze J., Modular construction: From projects to products, McKinsey & Company, 2019.
17 PMC projects (empirical)	**45%** (averange)	**16%**	Empirical case studies (weight: 2)	https://www.enr.com/articles/16684-study-finds-modular-can-be-faster-safer-and-less-costly?utm_source=chatgpt.com
Case study / industrial buildings	**10.5%**	**39%**	Peer-reviewed (case study) (weight: 2)	Salih A., Wang C.C., Tian R., Mojtahedi M., A Case-Study-Based Comparative Analysis of Using Prefabricated Structures in Industrial Buildings. Buildings 2025, 15, 2416.
30 large-scale projects (residential, commercial, industrial)	**35%**	**22%**	Empirical quantitative (peer-reviewed/conference) (weight: 2)	Gómez M.F., Sánchez R.J., Impact of modular construction techniques on cost and time efficiency in large projects, International Journal of Civil Engineering and Construction 2024; 3(2): 43-47.
Single project (MS Project analysis)	**13%**	**-6.67%** (modular = 6.67% more expensive)	Empirical case; demonstrates variance (weight: 2)	Manjarekar A., Gadhave Y.A., Evaluating Modular Construction: Effects On Timelines, Costs, And Resource Efficiency Using MS Project. (2025). International Journal of Environmental Sciences, 95-104.
Systematic literature review	**35%** (often 20–50%)	**≈20%**	Systematic review (peer-reviewed) (weight: 1.5)	Zohourian M., Pamidimukkala A., Kermanshachi S., Almaskati D., Modular Construction: A Comprehensive Review. Buildings 2025, 15, 2020.

The cost analyses presented in the article by the authors did not reveal any significant differences in costs. In the case presented, the difference was 4.2% in favour of the modular technology.

In order to verify the duration time differences for the analysed building construction examples using both technologies, the authors prepared construction schedules. Simplified versions of these are presented in Figures 5 and 6.

The provided schedules demonstrate that the construction of a building under identical site conditions using modular technology required 153 days, in contrast to the 115 days required when traditional methods were employed. Nevertheless, the protracted construction period for the modular approach was primarily attributable to the time allotted for the fabrication of modules 1-3 within the production hall. The timeframe is primarily influenced by the waiting time for the materials required for construction, as well as their availability during a given period and the number of orders. When analysing the time period during which construction was conducted on-site, excluding the production of the modules in the factory, it can be concluded that the actual construction time was 63 days. This result indicates a 45% reduction in construction time using modular technology compared to traditional methods.

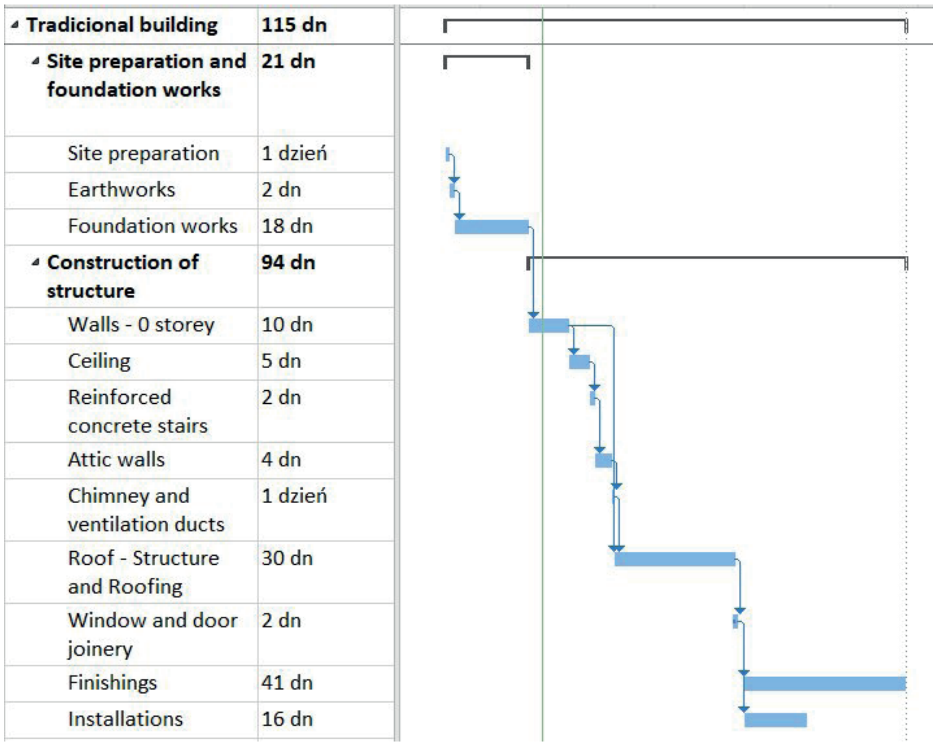

Fig. 5. Construction schedule for the construction of a sample building using traditional methods
Souce: own study

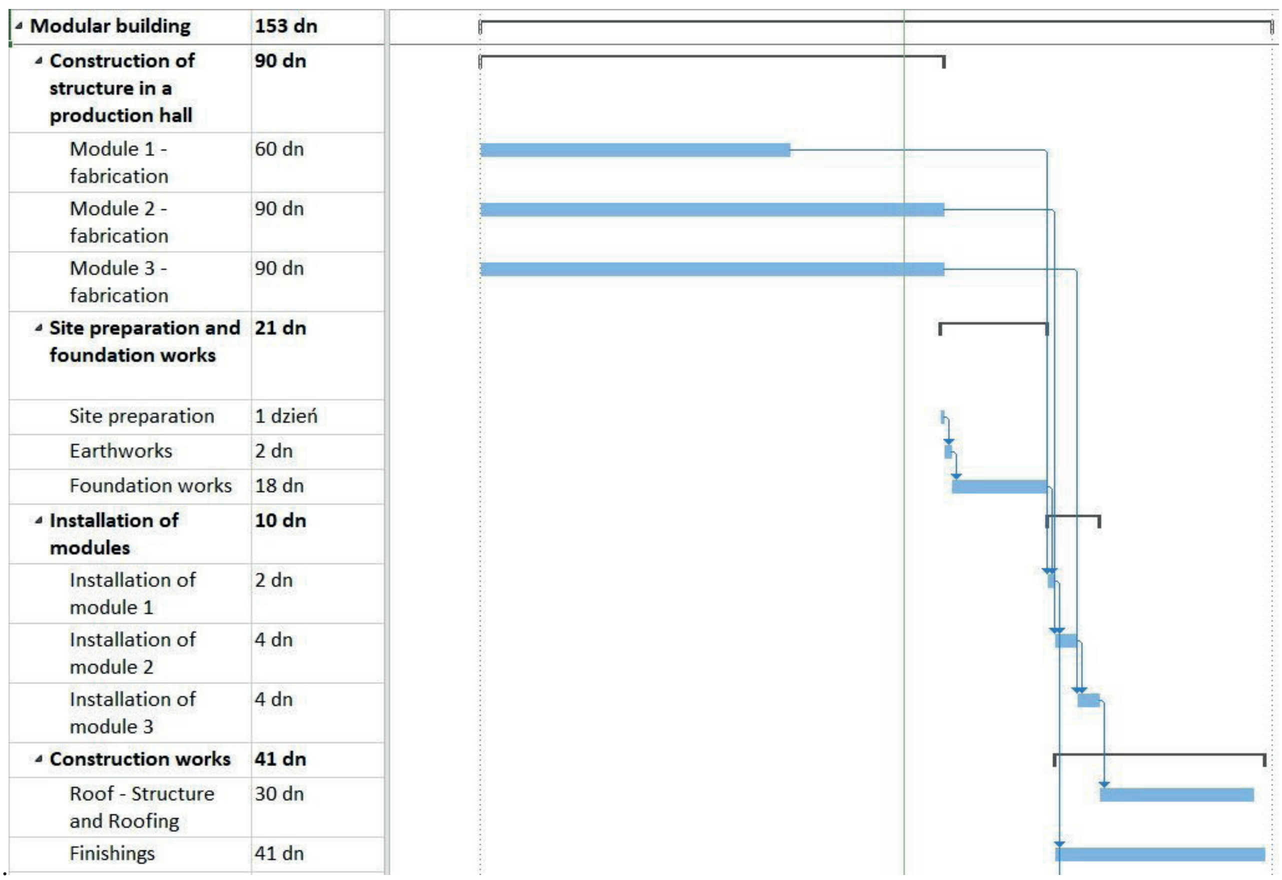

Fig. 6. Construction schedule for the construction of a sample building using modular technology
Souce: own study

5. CONCLUSIONS

Modular construction is an evolving field, with advances in technology and solutions being developed continually. This construction method introduces a novel approach to the building process, emphasising the optimisation of work and its independence from weather conditions, as the majority of the work is conducted within the controlled environment of a production hall. This methodology facilitates expedited construction without compromising quality, increasing costs or deteriorating the technical parameters of the building. The modular construction market is undergoing continuous development, which attests to the expanding potential of this technology. A growing number of investors are opting for modular construction, acknowledging its capacity to substantially reduce the time required to complete a project. The advantages of modular construction, particularly the reduced time needed for completion on site, the reduced impact on the environment and the reduced influence of weather conditions on the construction process itself, are well-documented. Consequently, its continued dynamic growth is to be expected.

REFERENCES

[1] Plis A., Prałat K.: Budownictwo modułowe jako odpowiedź na współczesne wyzwania. *Przegląd Budowlany*, (2023); 94(7-8):151-154. https://doi.org/10.5604/01.3001.0053.8513.
[2] Woźniak-Szpakiewicz E., Zhao S.: Modular construction industry growth and its impact on the built environment, *Technical Transactions* 12/2018 *Architecture and Urban Planning*, 43-52. DOI: 10.4467/2353737XCT.18.178.9666.
[3] Krysiak A.: The use of BIM technology in the design and construction of modular houses, Zeszyty Naukowe Politechniki Częstochowskiej, nr 29 (2023), 73-78. DOI: 10.17512/znb.2023.1.11.
[4] Data Bridge Market Research, Global Modular Construction Market – Industry Trends and Forecast to 2030, https://www.databridgemarketresearch.com/reports/global-modular-construction-market [access: 02.09.2024].
[5] Wang Y., Bian S., Dong L., Li H.: Multiresolution Modeling of a Modular Building Design Process Based on Design Structure Matrix. *Buildings* 2023, 13, 2330. https://doi.org/10.3390/buildings13092330.
[6] Mordor Intelligence, Modular Construction Market Size and Share Analysis - Growth Trends & Forecasts (2024 - 2029) Source: https://www.mordorintelligence.com/industry-reports/modular-construction-market [access: 10.09.2024].
[7] Prefabricated Volumetric Building Systems Market Report – UK 2018-2022, AMA Research, 29/03/2018.