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Research paper

Analysis of technology, time and costs of three methods of building a single-family house: traditional brick, reinforced concrete prefabrication, timber frame

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Abstract: The article presents a comprehensive analysis of technology, time and costs of three methods of building a single-family house; traditional brick, reinforced concrete prefabrication and timber frame. The goal of this study was to determine if prefabricated and timber frame building methods and materials have the potential to replace traditional method of construction in the context of cost and time. For this purpose, a qualitative analysis was performed, including a list of benefits of each of the analysed construction technologies and a quantitative analysis in which the cost of finished houses per 1 m^2 of usable area was compared. The analyses were conducted for two single-family houses with similar characteristics using scheduling and cost estimation software. The conducted analyses have shown that the shortest time to build a house is in the prefabricated reinforced concrete technology. The used construction technology from ready-made prefabricated elements affects the time of building house and thus, the costs of its construction. The construction time for the house in case of a timber frame structure and made of ready-made reinforced concrete prefabricated elements is similar but the cost of a timber frame structure is much higher. It takes longest time to build a house in traditional brick technology and requires the involvement of the largest financial resources from all three analysed construction technologies. Despite this, traditional brick technology is the most used in construction in Poland and other Central and Easter Europe countries. This is due to the widespread belief of investors about the durability of a building made in this technology and the habits of investors resulting from a long-standing tradition of construction. However, the study's results in the world showed that a change in build technology is a step in addressing the concerns of poor quality and reduce construction costs and time, increasing the construction sector's productivity and sustainability.

Keywords: single-family house, traditionally brick house, prefabricated reinforced concrete house, timber frame house, construction time, construction cost

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1. Introduction

Nowadays, there are many technologies of building single-family houses and they differ, among others, in materials used for construction. The basic material is brick, but in recent years prefabricated reinforced concrete elements and timber frame structures gain popularity [1–3]. All of the above-mentioned materials meet basic requirements for houses, i.e., durability and safety, which guarantee their long use. The choice of material and technology of building a house affects time of investment implementation and costs incurred by an investor which translates into the costs of labour, hiring workers' teams, machinery and equipment. In Central and East Europe, including Poland, most investors still prefer to build houses by means of traditional methods, using materials such as cellular concrete, sand-lime or expanded clay blocks. The reason behind such a choice is a long history of building houses in this technology and the conviction of investors about the durability of the structure.

A single-family brick house consists of foundations, walls made of small elements such as blocks or bricks, and a traditional concreted ceiling. The materials that build walls are joined with the use of appropriate binders. Brick walls are both a load-bearing and heat-insulating elements. The use of small elements for the construction of walls allows to freely form the body of the building without major restrictions in building designs. The construction in traditional brick technology consists of the following stages:

– making a slab or a strip footing,
– building foundation walls up to a height of 30–50 cm above the ground level,
– erecting walls with the use of small elements: bricks or blocks. They are connected by the use of appropriate binders,
– building rib-and-slab or monolithic (reinforced concrete) ceilings,
– building a roof truss,
– building internal installations.

A prefabricated single-family house consists of foundations, mostly a gable roof, prefabricated external and internal walls, prefabricated or monolithic ceilings, prefabricated or concreted stairs in a traditional way [4–8]. The construction of a single-family house by the use of prefabricated concrete elements consists of the following stages:

– making a slab or a strip footing and execution of foundation walls,
– positioning prefabricated external and internal walls of the house with a crane on the insulated foundation walls on the assembly binder, anchoring them in concrete and immobilizing them until the binder binds. Adjacent walls are joined with each other by means of stainless-steel fasteners placed in a gap filled with liquid and high-strength assembly adhesive or concrete,
– setting, using a crane, prefabricated ceiling slabs, which are stabilized on the walls by being screwed into load-bearing walls with anchors. The corners of a house are fastened along their entire height with a rod with a diameter of $d = 12$ mm, ensuring the stability of the structure,
– installation of stairs,

- assembly of end walls,
- installation of a traditional roof truss or made of wooden prefabricated roof girders constituting a plane for suspending the ceiling (in the case of flat roofs, a solution in the form of full flat roofs is used),
- bricklaying the chimney,
- laying an insulation layer, mineral wool or polystyrene on the walls,
- plastering external and internal walls,
- assembly of windows and doors,
- interior finishing.

A single-family house with a timber frame structure consists of foundations, a wooden load-bearing structure, wooden or slab ceilings, a double or hipped roof. The structure of the building is based on a large number of wooden beams and boards of various dimensions, supported by joists and connected with boards which create a wooden frame of a house, which is attached to the foundations with steel anchors. Boards are used as the basic construction material, usually 38 mm thick (1.5 inches of nominal thickness) and a width depending on the strength needs. For internal walls, boards with a width of 89 mm are used, while for external walls, boards with a width of 140 mm due to thermal insulation. The load-bearing wall of a timber frame house consists of vertical structural pillars spaced every 30, 40 or 60 cm, anchored in the foundation from below, and attached to the ceiling structure from above. The skeleton of the house is upholstered with plasterboards, which are the inner part of the wall. The next layers are a vapour barrier foil, insulation material, e.g., mineral wool, wood wool or polyurethane foam, fibreboard, windproof foil, facade wool and a layer of mineral plaster. The construction of a single-family house in a timber frame structure consists of the following stages:

- making slab or strip footing and foundation walls. In the case of building a light frame house, the foundations can be simplified,
- assembly of a foundation made of pressure-impregnated timber, separated from the foundations with a layer of thick insulation felt,
- assembly of the bottom panel and anchoring the whole to the foundation,
- assembly of external walls with openings for doors and windows,
- assembly of partition walls and ceiling,
- wall sheathing and roof sheathing assembly. The whole structure is sheathed with a moisture-resistant OSB / 3 board,
- filling the space between the beams in the roof structure with glass or mineral wool,
- external protection of the wall and roof structures with a windproof membrane,
- covering the facade with hard glass or mineral wool,
- making/building the facade of structural plaster or facade wood,
- roofing,
- installation of windows and doors,
- installation assembly,
- finishing of internal walls with vapour barrier layers and plasterboards.

According to European Commission, the construction industry is very important to the EU economy, because provides 18 million direct jobs and contributes to about 9% of the EU's GDP. However, this sector of industry has to become more competitive, resource efficient and sustainable [9]. In Europe approximately a 70% of buildings are residential, where 50% are single-family houses, with the remaining 20% are multi-family houses [3]. However, buildings are account for more than 30% of CO_2 emissions and waste generated, 40% of energy consumption, and 50% of materials extraction [10]. The European Union (EU) indicated that reduction of residential building effects is one of the main goals to meet the Paris agreement targets and improvement towards a circular economy [3]. In the several studies of comparison conventional and prefabricated buildings, were demonstrated that prefabrication reduces 5–40% of negative impacts on the environment like (i.e. reduction of GHG emissions, energy use, depletion of natural resources and environmental degradation) [1, 2, 11–13]. Moreover, prefabricated construction can decrease total cost for approximately 30% than traditional construction, during reducing embodied and operational carbon [12, 14]. On the other hand, modern wood-based construction systems also have many advantages, including workmanship quality improvement, reduction of significant negative impact on the environment and productivity increase in in terms of shortening the construction work process [15–17]. Modern wood-based construction methods are able to provide excellent thermal performance and durability. As well as, prefabrication they are dry methods (wet processes during construction are minimize), thus they reduce implementation time and accelerate the use of building. However, the main advantages of wood-based construction is use the wood as renewable natural resource and contribute to sustainability and protection of the environment [16].

Taking the above into account, the aim of this article was to determine if prefabricated and timber frame building methods and materials have the potential to replace traditional method of construction in the context of cost and time. The subject of this studies/research was the analyses the technology, time and costs of the three methods of building a single-family house: traditional brick, reinforced concrete prefabrication and timber frame. For this purpose, a qualitative analysis was performed, including a list of benefits of each of the analysed construction technologies, and a quantitative analysis, in which the cost of finished houses per 1 m^2 of usable area was compared. The analyses were conducted for two case studies of single-family house designs with similar characteristics. The results of our work may be helpful in investment decision-making of selecting the appropriate technology for the construction of single-family houses in the context of time, costs and sustainability.

2. Analysed houses

The study analysed two single-family houses according to individual projects. House no. 1 is one-story building without a basement, with a building area of 109.08 m^2, and house no. 2 with usable area of 70.00 m^2. The specific feature of selected buildings, including usable and building areas and scheme of elevations are shown in Table 1.

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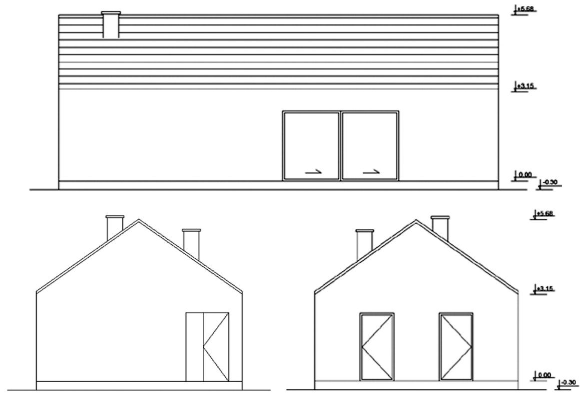
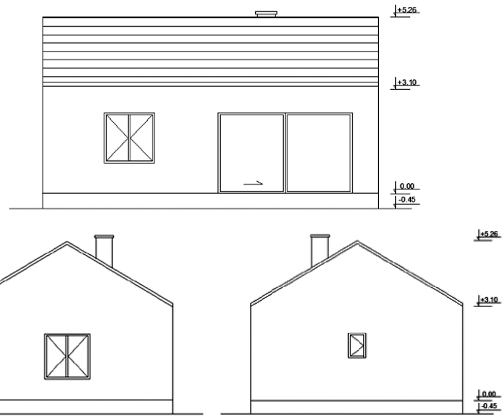
Table 1. Properties/features of analysed houses

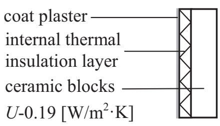
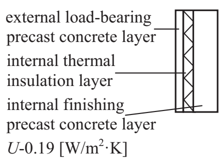
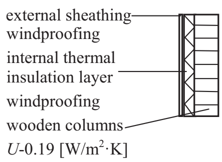
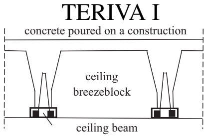
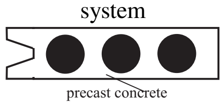
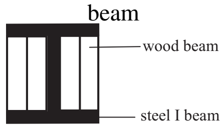
House no. 1 – building area 109,53 m^2 – usable area 95.04 m^2	
House no. 2 – building area 70,00 m^2 – usable area 51.82 m^2	

3. Subject and methodology of research

3.1. Construction technologies of analysed houses

Three construction technologies of the single-family houses were analysed. I technology – house constructed using traditional brick technology, II technology – house constructed using reinforced concrete prefabrication and III technology using timber frame structures. Regardless of the technology of building the house, earthworks, foundation works, installation works, doors installation, windows installation and roof construction are carried out in the same way in all three variants. The differences concern the construction of walls and ceilings as well as finishing works. Table 2 presents a comparison of the construction of analysed single-family houses made in the analysed construction technologies.

Table 2. Construction technologies of analysed single-family houses: traditional brick, reinforced concrete prefabrication, timber frame

Construction stages		Construction technology		
		Traditional brick	Reinforced concrete prefabrication	Timber frame
Earth works		Excavation with transport on the plot		
		The use of concrete crusher in the excavation		
		The use of sand with compaction in the excavation		
Foundation slab		10 cm thick made of lean concrete C12/15		
		Reinforcement, concreting and insulation of the foundation slab		
Rough stage	Walls	Masonry construction  Internal walls made of ceramic blocks	Prefabricated single-layer inner wall 	Wooden columns, external sheathing, windproofing 
	Ceiling	TERIVA I 	Prefabricated DX ceiling system 	Wooden beams, steel beam 
	Roof	Wooden rafters	Wooden rafters	Wooden rafters
	Chimneys and ventilation pipes	Ceramic blocks	Ceramic blocks	Ceramic blocks
Fit-off stage	Windows and doors	PVC balcony doors Steel entrance door	PVC balcony doors Steel entrance door	PVC balcony doors Steel entrance door
	Elevation	–	–	Facade wool 10 mm thick, thin-layer plaster
	Roof	Roof membrane, roof battens, coated tile sheet, coated sheet flashings, PVC gutters	Roof membrane, roof battens, coated tile sheet, coated sheet flashings, PVC gutters	Roof membrane, roof battens, coated tile sheet, coated sheet flashings, PVC gutters

Continued on next page

Table 2 – *Continued from previous page*

Construction stages		Traditional brick	Reinforced concrete prefabrication	Timber frame
		Construction technology		
Enclosed stage	Elevation	Mineral wool boards, thin-layer plaster	–	–
Enclosed stage	Interior finishes	Insulation of the slab with the sub-floor layer. Gypsum plaster on the walls and ceilings	–	Walls – mineral wool filling, plasterboard sheathing Ceiling – mineral wool filling, vapor barrier, plasterboard sheathing
Enclosed stage	Installations	– mechanical ventilation, – heat recovery unit, – electricity, – water, – sewage systems, – underfloor heating, – gas boiler.	– mechanical ventilation, – heat recovery unit, – electricity, – water, – sewage systems, – underfloor heating, – gas boiler.	– mechanical ventilation, – heat recovery unit, – electricity, – water, – sewage systems, – underfloor heating, – gas boiler.

where: U – thermal transmittance value [W/m^2·K]

3.2. Methodology of environmental parameters assessment

In the purpose of estimate the energy standards the environmental characteristics of the embodied energy *EE*, global warming potential *GWP* and acidification potential *AP* of structural systems and/or construction materials of analysed single-family houses were calculated. The LCA methodology with the values of materials environmental characteristics of the Austrian Institute for Healthy and Ecological Building IBO database were used corresponding to Eq. (3.1), Eq. (3.2), Eq. (3.3) [16–18].

$$EE = \sum_{i=1}^{n} EE_i \cdot w_i \tag{3.1}$$

where: EE – embodied energy [MJ], EE_i – coefficient of embodied energy for ith material [MJ·kg^{-1}], w_i – weight of ith material [kg].

$$GWP = \sum_{i=1}^{n} ECO_{2i} \cdot w_i \tag{3.2}$$

where: GWP – global warming potential [kgCO$_{2eq}$], ECO_{2i} – coefficient of carbon dioxide equivalent for ith material [kgCO$_2$eq · kg^{-1}], w_i – weight of ith material [kg].

$$AP = \sum_{i=1}^{n} ESO_{2i} \cdot w_i \tag{3.3}$$

where: AP – acidification potential [$kgSO_{2eq}$], ESO_{2i} – coefficient of sulphur dioxide equivalent for ith material [$kgSO_2eq \cdot kg^{-1}$], w_i – weight of ith material [kg].

3.3. Methodology of cost and time

Assessing the economic parameters for the analysed variants of construction of a single-family house performed in three different construction technologies: traditional brick, reinforced concrete prefabrication and timber frame were performed in the Norma Pro software by Athenasoft, Poland. To prepare the bill of quantities, the available Polish Contractors Estimator (KNR) and own calculations were used. Calculation of construction works as offer cost estimates were performed according to Journal of Polish Laws of 2021, item 2458 [19] using simplified calculation method. The quantity take off was determined based on the design of the analysed houses.

For the analysis, the time schedules of construction were created using the software used in our conditions to evaluate construction in terms of the time of construction of MS Projects by Microsoft, USA. The time standards assigned to specific items in the Polish Contractors Estimator were used for the schedules. Time standards determine the time needed to perform one production unit in given technological and organizational conditions. Then, the efficiency norms were determined, defining the number of production units per time unit, i.e., in the analysed case the number of units that should be performed by one worker within one hour. Daily efficiency standards for the work schedules were determined assuming eight-hour working time. On the basis of the specific labour-consumption of a given work and taking into account its execution technology, the composition of the brigade that would perform a given work was determined. When executing work schedules, the level of general employment on the construction site as well as the date of completion of a given activity and all works at the facility were considered. The schedules are divided into the following construction stages: earthworks, foundation slab, rough stage, fit-off stage, enclosed stage.

4. Results

In this section, the results of comparative analysis of the selected construction variants single house building using the selected methodologies in terms of the energy, time and economic sustainability characteristics were presented. In order to better understanding and visible the difference, Tables 3 and 4 were created to summarize the conducted environmental parameters assessment analysis.

Because of the prepared schedules of construction works, it was found that the construction of the analysed single-family house no. 1 in the traditional brick technology takes 173 days, with the use of prefabricated reinforced concrete elements takes 70 days,

Table 3. Environmental parameters of single-family house no. 1 in three different technologies

Element	Environmental parameters								
	Type of construction technology								
	Traditional brick			Reinforced concrete prefabrication			Timber frame		
	EE [MJ]	GWP [$kgCO_{2eq}$]	AP [$kgSO_{2eq}$]	EE [MJ]	GWP [$kgCO_{2eq}$]	AP [$kgSO_{2eq}$]	EE [MJ]	GWP [$kgCO_{2eq}$]	AP [$kgSO_{2eq}$]
Foundation slab	37840	5675	32	37840	5675	32	37840	5675	32
Walls	127005	14176	64	92435	11543	62	57152	–16342	59
Ceilng	34876	10460	26	25859	8369	23	13953	–3261	15
Roof	16175	–4026	21	16175	–4026	21	16175	–4026	21
Total	**215896**	**26285**	**143**	**172309**	**21561**	**138**	**125120**	**–17954**	**127**

Table 4. Environmental parameters of single-family house no. 2 in three different technologies

Element	Environmental parameters								
	Type of construction technology								
	Traditional brick			Reinforced concrete prefabrication			Timber frame		
	EE [MJ]	GWP [$kgCO_{2eq}$]	AP [$kgSO_{2eq}$]	EE [MJ]	GWP [$kgCO_{2eq}$]	AP [$kgSO_{2eq}$]	EE [MJ]	GWP [$kgCO_{2eq}$]	AP [$kgSO_{2eq}$]
Foundation slab	24310	3826	24	24310	3826	24	24310	3826	24
Walls	114803	12903	58	84078	10489	56	44706	–13508	54
Ceilng	22397	7017	21	17384	6021	18	12674	–2196	14
Roof	11755	–2985	20	11755	-2985	20	11755	–2985	20
total	**173265**	**20761**	**123**	**137527**	**17351**	**118**	**93445**	**–14863**	**112**

while in the timber frame technology it takes 80 days. In the case of a single-family house no. 2, construction in traditional brick technology takes 158 days, using prefabricated reinforced concrete elements takes 63 days, while in timber frame technology it takes 69 days. A summary of the construction times of the analysed houses are presented in Tables 5 and 6.

Table 5. Construction time of single-family house no. 1 in three different technologies

Construction stage	Construction time		
	Type of construction technology		
	Traditional brick	Reinforced concrete prefabrication	Timber frame
Earthworks	1 day	1 day	1 day
Foundation slab	34 days	34 days	34 days
Rough stage	86 days	15 days	10 days
Fit-off stage	11 days	11 days	16 days
Enclosed stage	47 days	9 days	21 days
Total	**173 days**	**70 days**	**80 days**

Table 6. Construction time of single-family house no. 2 in three different technologies

Construction stage	Construction time		
	Type of construction technology		
	Traditional brick	Reinforced concrete prefabrication	Timber frame
Earthworks	1 day	1 day	1 day
Foundation slab	30 days	30 days	30 days
Rough stage	77 days	14 days	9 days
Fit-off stage	9 days	9 days	13 days
Enclosed stage	41 days	9 days	16 days
Total	**158 days**	**63 days**	**69 days**

The cost estimates for the analysed variants of construction of a single-family house made in three different construction technologies: traditional brick, reinforced concrete prefabrication, timber frame were made in the Norma Pro program by Athenasoft. Data and calculations made in bill of quantities for individual house construction technologies were used to prepare the cost estimates. The material bases for the preparation of cost estimates were labour standards taken from the Polish Contractors Estimator and own calculations, while the financial bases were market prices as of December 2021, compiled based on KRESBUD company data and Sekocenbud 4.2021 data [20].

The prepared cost estimates of construction works show that the cost of building a single-family house no. 1 in traditional brick technology is €76,256.92, with the use of prefabricated reinforced concrete elements € 63,110.79, while in timber frame technology € 72,602.72 (excluding VAT). The cost of 1 m^2 for the analysed construction technologies is 801.86 €/m^2 (3,688.08 PLN/m^2), 663.63 €/m^2, 763.44 €/m^2, respectively. On the other hand, in the case of a single-family house no. 2, the cost of construction in traditional brick technology is € 51,064.06, with the use of prefabricated reinforced concrete elements € 44,898,70, while in the timber frame technology € 49,730.68. The cost of 1 m^2 for the analysed construction technologies is 872.89 € /m^2, 767.50 € /m^2, 850.10 € /m^2, respectively. The presented amounts are of net value. The cost of construction of the analysed houses is presented in Tables 7 and 8.

Table 7. Construction cost (excluding VAT) of a single-family house no. 1 in three different technologies

Construction cost	Construction time		
	Type of construction technology		
	Traditional brick	Reinforced concrete prefabrication	Timber frame
Earthworks	€ 583.38	€ 583.38	€ 583.38
Foundation slab	€ 6,798.31	€ 6,798.31	€ 6,798.31
Rough stage	€ 32,020.38	€ 27,784.48	€ 20,370.84
Fit-off stage	€ 14,500.66	€ 14,500.66	€ 20,976.61
Enclosed stage	€ 22,354.19	€ 13,443.96	€ 23,873.58
Total cost	**€ 76,256.92**	**€ 63,110.79**	**€ 72,602.72**
Cost of 1 m^{2}of usable area	**801.86 € /m^2**	**663.63 € /m^2**	**763.44 € /m^2**

Table 8. Construction cost (excluding VAT) of a single-family house no. 2 in three different technologies

Construction cost	Construction time		
	Type of construction technology		
	Traditional brick	Reinforced concrete prefabrication	Timber frame
Earthworks	€ 351.10	€ 351.10	€ 351.10
Foundation slab	€ 4,715.33	€ 4,715.33	€ 4,715.33
Rough stage	€ 21,441.80	€ 19,690.84	€ 12,710.23
Fit-off stage	€ 9,064.09	€ 9,057.56	€ 13,729.76
Enclosed stage	€ 15,491.52	€ 11,083.86	€ 18,224.27
Total cost	**€ 51,063.84**	**€ 44,898.70**	**€ 49,730.68**
Cost of 1 m^{2}of usable area	**872.89 €/m^2**	**767.50 €/m^2**	**850.10 €/m^2**

5. Results analysis

The analysis of the prepared schedules of construction works and cost estimates shows that it takes longest time to build a house in traditional brick technology which is also the most expensive one. High construction costs in this technology result, among others, from the time needed to complete the building. The construction of a single-family house with the use of prefabricated reinforced concrete elements takes the shortest time, and at the same time it is the cheapest technology among the analysed ones. It is about 17% cheaper than the traditional brick technology and about 13% cheaper than the timber frame technology in case of house no. 1, while it is about 12% cheaper than the traditional brick technology and about 10% cheaper than the timber frame technology in case of house no. 2. The shortest time to build a house in the prefabricated reinforced concrete technology is due to the assembly of ready-made elements brought to the construction site and practically no external and internal finishing works. Construction in timber frame technology is cheaper by approximately 5% (house no. 1) and approximately 3% (house no. 2) than construction in traditional brick technology, but it is much faster. Construction of a house in the prefabricated reinforced concrete and timber frame technology is much shorter than the traditional brick technology mainly at the stage of construction at a rough stage. The implementation of the rough stage in the analysed houses in the reinforced concrete prefabrication technology is shorter by 71 days, and in the timber frame technology by 76 days compared to the traditional brick technology. The building area of the building does not significantly affect the time of building a house in all the analysed construction technologies. The conducted calculations showed that in the case of a house with a smaller usable area, the differences in construction costs are smaller with the use of the analysed construction technologies.

In the schedule of building a house in brick technology, traditionally critical activities include excavation and construction of the foundation slab. During the rough stage, activities such as bricklaying the walls of the building, reinforcement of the rim on the walls with the installation of anchors, building the ceiling, installation of insulation and foundation, construction of the roof structure. All activities related to the implementation of the fit-off stage, i.e. the installation of the roof membrane with lathing, the roof covering with a coated sheet with finishing, installation of window and door openings, while at the enclosed stage insulation of the building walls with mineral wool panels, insulation of the foundation slab, plastering internal walls, priming of internal walls, construction of electrical installations. In the schedule of building a house in the reinforced concrete prefabrication technology, the critical activities are the excavation and construction of the foundation slab. At the rough stage it is production, transport and installation of prefabricated walls, production, transport and installation of a prefabricated ceiling system, installation of insulation and foundation, construction of the roof structure. These are also all activities related to the implementation of the fit-off stage, while at the enclosed stage, the critical activities are: plastering the chimneys along with painting the facade, insulating the foundation slab, priming internal walls and building electrical installations. In the schedule of building a house in the timber frame technology, critical activities, as in previous construction technologies, are the excavation and activities related to the construction of the foundation slab, all activities related to the implementation of the rough stage and fit-off stage. At the enclosed stage the critical steps are plastering the chimneys with painting the facade, insulating the foundation slab, filling with mineral wool, covering with plasterboard, filling and priming walls and ceilings, building electrical installations, and building underfloor heating. The remaining works have reserves of time and the increase in the execution time of any of them does not determine the postponement of the investment deadline. In the construction schedule in reinforced concrete prefabrication technology, the critical path runs through the work on the production of elements. Therefore, it is important to properly prepare the production and transport schedule for the construction of these elements because the course of the entire investment depends on it.

Regardless of the technology used to build a single-family house, the feature that determines obtaining the maximum use of the time allocated for construction is the correct planning of the delivery time of the material necessary to build the house at every stage of construction, the employment of qualified employees who will manage the entire construction process and the mutual coordination of individual works [21–23]. Correct planning of works, especially in the case of building a house with the use of prefabricated reinforced concrete elements and in timber frame structure, allows for the construction of a building in a relatively short time with performance parameters that do not differ from the traditional brick technology. Sudden unplanned events that were not included in the cost estimate or schedule are also important. In recent years, they have been the coronavirus pandemic or the war in Ukraine. Such events most often result in a sudden increase in the prices of building materials and delays in construction works.

To consider aspects of construction in relation to the surrounding environment LCA analysis were performed. Based on estimated parameters embodied energy *EE*, global warming potential *GWP* and acidification potential *AP,* it was found that building a house using a traditional brick method has the lowest environmental benefits.

The performed analysis of the construction variants in terms of embodied energy *EE* shows significant differences in favour of the prefabricated and timber frame construction technology compared to the traditional brick technology. In case of house no. 1 reductions in *EE* were about 20% and 42% respectively, while in house no. 2 reductions were about 21% and 46%.

Significant differences between the compared variants of construction of single-family houses were obtained in the case of global warming potential *GWP*. The construction of a single-family house with the use of timber frame method allow to reduce in *GWP* about 120% compared to prefabricated method and 146% compared to traditional brick one in case of house no. 1, while 117% and 140% respectively in house no. 2. The difference is mainly due to the fact that wood shows good values of *GWP* parameter compared to other considered materials. Wood absorbs significant amounts of CO_2 during its growth and values for this parameter are negative.

In case of the acidification potential *AP*, a 4% (prefabricated method) and 11% (timber frame method) reduction in this parameter were observed in house no. 1 compared to the traditional brick method. In house no. 2 the reduction were 4% and 9% respectively. The difference in this parameter was not as significant as in the case of the previous assessed ones. This is probably due to the fact that the wood does not show such significant values of the parameter *AP*, as it ceases to absorb harmful emissions after extraction.

An analysis of the environmental impacts of the use of traditional building materials on building construction compared to more environmentally beneficial materials was dealt with, among others, by Švajlenka and Kozlovská [16], Morel et al. [24], Pajchrowski et al. [25]. These authors, like us, conclude that the use of alternative materials to build a house has many benefits, both in terms of its environmental impact and the speeding up and efficiency of the construction process.

It should be noted that due to the small dimensions of the analyzed buildings and simple structures, it was decided to use a foundation slab with the same dimensions for each of the analyzed variants. This allowed for a precise comparison of the influence of other building elements on the estimated parameters.

Nowadays, more environmentally friendly solutions in construction houses are increasingly being launched. This work is also proof that the realization of prefabricated and timber frame buildings makes it possible to achieve more sustainable and efficient construction. Of course, the complete resignation of investors from building a house using the traditional brick method seems unrealistic in the near future. However, alternative methods of building houses will gain a greater share in the implementation of new investments.

6. Conclusions

The paper presents a comparison of construction technology, time and costs as well as environmental parameters of construction of two selected single-family houses made in three different construction technologies: traditional brick, reinforced concrete prefabrication and timber frame.

The conducted analyses have shown that the time of realization of a single-family house in reinforced concrete prefabrication technology is the shortest and requires the involvement of the smallest financial resources of all three analysed construction technologies. The construction of a house in timber frame technology significantly reduces the construction time compared to the traditional brick technology. Construction of the house using reinforced concrete prefabricated and timber frame technologies also has the environmental benefits in terms of the energy, global warming potential and acidification potential.

It can be predicted that the construction of single-family houses with the use of prefabricated reinforced concrete elements and in a timber frame structure will develop in Poland and other Central and Easter Europe countries in the coming years and will be widely used. This will be due to lower costs, shorter construction time and environmental benefits. It is only necessary to convince future investors that buildings made in technologies other than those traditionally made of brick have similar functional parameters, and when properly erected, they show similar durability.

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Analiza technologii, czasu i kosztów budowy domu jednorodzinnego trzema metodami: murowaną tradycyjnie, prefabrykacji żelbetowej, szkieletową drewnianą

Słowa kluczowe: dom jednorodzinny, dom murowany, dom prefabrykowany żelbetowy, dom szkieletowy, czas budowy, koszt budowy

Streszczenie:

W artykule przedstawiono kompleksową analizę technologii, czasu i kosztów budowy domu jednorodzinnego trzema metodami: murowaną tradycyjnie, prefabrykacji żelbetowej, szkieletową drewnianą. Celem analiz było określenie, czy prefabrykowane i szkieletowe budownictwo ma potencjał do zastąpienia tradycyjnych metod budowy w kontekście kosztów i czasu budowy. W tym celu dokonano analizy jakościowej obejmującej wykaz korzyści każdej z analizowanych technologii budowy oraz analizy ilościowej, w której porównano koszt gotowych domów na m^2. Analizy przeprowadzano dla dwóch domów jednorodzinnych o podobnych cechach z wykorzystaniem oprogramowania do harmonogramowania i kosztorysowania. Przeprowadzone analizy wykazały, że najkrótsze terminy wykonania budynku są w przypadku budowy budynku w technologii prefabrykowanej żelbetowej. Stosowana technologia budowy z gotowych elementów prefabrykowanych przekłada się na czas budowy domu, a tym samym na mniejsze koszty jego budowy. Czas realizacji domu w przypadku konstrukcji szkieletowej drewnianej oraz z prefabrykatów żelbetowych jest podobny, jednak koszt konstrukcji szkieletowej jest znacznie większy. Najdłużej trwa budowa domu w technologii murowanej tradycyjnie oraz wymaga zaangażowania największych środków finansowych ze wszystkich trzech analizowanych technologii budowy. Pomimo tego technologia murowana tradycyjnie jest najczęściej stosowana w budownictwie w Polsce oraz innych krajach Europy Środkowo-Wschodniej.

Wynika to głównie z powszechnego przekonania inwestorów o trwałości budynku wykonanego w tej technologii oraz z przyzwyczajeń inwestorów wynikających z długoletniej tradycji budowy. Jednakże analizy prowadzone na świecie pokazują, że zmiana w technologii budowy jest krokiem w rozwiązywaniu problemów związanych z niską jakością oraz zmniejszeniem kosztów i czasu budowy, przy jednoczesnym zwiększeniu produktywności i zrównoważonym rozwoju sektora budowlanego.

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