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Analysis of the Impact of Changes in Construction Technology on the Assumed Time and Cost Variable of a Construction Project

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Abstract: The intensively developing construction industry makes it necessary for investors to make choices related to the proper selection of materials that meet criteria and parameters imposed on them in terms of acoustic, insulation, fireproofing or durability, while at the same time meeting visual expectations and new trends in construction in the 21st century. The elements that make up a building, when combined, must form a durable, load-bearing and usable compartments in accordance with innovative standards. The market analysis for the construction sector in Poland and Europe described in the article shows that manufacturers currently offer a variety of typical and innovative building materials. In addition, the construction industry is going through construction projects that meet new trends, which require new technological solutions for the realization of the detailed design, which generates new attributes of buildings and structures.

The article discusses new solutions and standards in terms of the assumed investment budget and the adopted time frame for the execution of the assumed construction tasks. This article shows in a more detailed way the various stages of the construction of a volume building in which execution technology of the foundations, walls and ceilings have been modified. The initial design technology assumed reinforced concrete footings, masonry walls made from aerated concrete blocks and a monolithically poured ferroconcrete ceiling The task specified the optimization of time and cost variables for a better standard in the form of discussing the design of a replacement technology with foundations in the form of a reinforced slab, precast walls made of expanded clay concrete and Filigran floors. In addition to the analysis of each technology and the assumed materials, the article summarizes graphically the timeframes needed to carry out the various stages of the replacement design and a typical baseline design. In summary, the costs of realisation of the actual stages of work, taking into account market prices in Poland, where the prices of of construction materials and expert labour are changing rapidly due to the timing of the pandemic Covid19 and the war between Russia and Ukraine, which is Poland's neighbour.

Keywords: Design of Buildings, Models and Methods of Construction Project, Building Materials, Project Management.

Introduction

After examining the current knowledge on the subject on typical and innovative construction technologies, two different construction methods have been analysed, which offer a different way of looking at the creation of the various stages of the work, which will result in building compartments or foundations with satisfactory parameters in accordance with the guidelines contained in Eurocode 2 or Eurocode 6. In Poland the majority of construction facilities constitutes constructions based on traditional construction methods. Analysing the foreign market, where more and more residential buildings are being constructed from modules or prefabricated elements, thus following the trend of quick and economical use of passive building materials, Poland is now beginning to join its foreign neighbours. Increases in the maintenance prices of residential buildings, mainly in terms of gas, fuel, and energy prices resulted in a tendency to erect buildings with new economic conditions i.e. for buildings with a residential function with a floor area of up to 100 m2 as well as the choice of technology and new types of building materials that are easy to work with or prefabricated which makes them easy to assemble on-site, resulting in faster construction time.

Materials, Methods and Norm Rules

Based on the initial typical technical and architectural/building design, detailed cost estimates were made taking into account the availability and quality of the materials used. Using the technology of the originally envisaged project as well as the replacement project based on the impositions according to 'Sekocenbud' for the second quarter of 2023, two separate cost estimates were created showing the amounts for the individual stages of the work required for the technologies analysed. In each cost estimate prepared and analysed, positions were calculated assuming for calculations the rate of PLN 22.00 net, indirect costs were assumed at the level of 65.00 %, while profit was assumed at the level of 10.00 %.

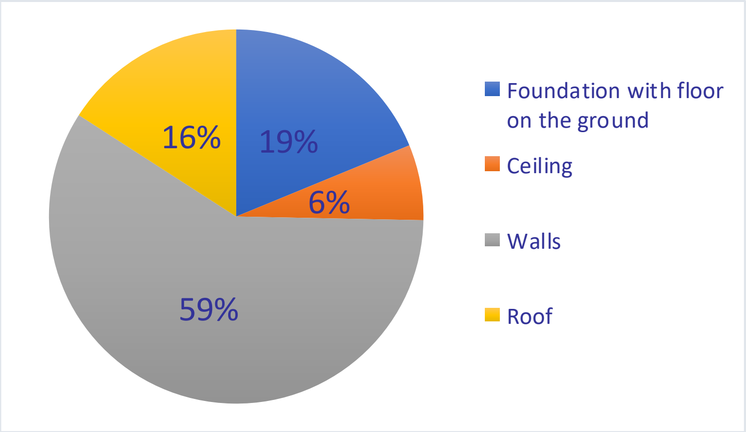

Figure 1 Amounts presented as percentages of the project with original assumptions [own elaboration]

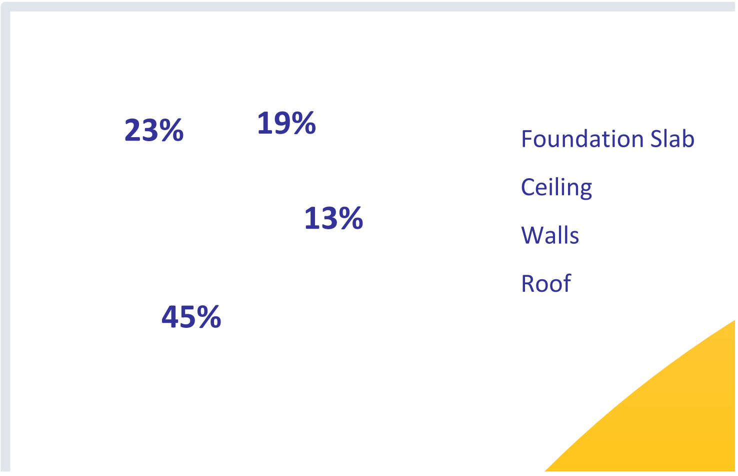

Figure 2 Amounts presented as percentages of the project with replacement assumptions. [own elaboration]

A cost estimate for a single-family building, taking into account initial assumptions, was calculated based on the use of material data included in the construction project. The calculation of the price values takes into account all excavation work to be carried out, including removal of the excavated material and its subsequent disposal. The strip foundation was made of C16/20 concrete, reinforced with ribbed steel fi 12, class B500SP, the floor on the ground will be made of a sand and gravel ballast on which 10 cm of concrete of the B500SP variety will be poured, and then, after laying two layers of PE foil, EPS 100 polystyrene with a thickness of 15 cm will be laid. The final stage is the pouring of a 7 cm thick cement screed, which should be reinforced with fi 3 steel mesh. The walls were assumed to be made of brick from cellular concrete blocks - 24 cm thick of the 500 variety, to be laid with a thin joint. In addition, the cost estimate includes the cost of plastering and smoothing in order to show the unavoidable costs associated with levelling the walls. The ring beam and floor were calculated as a monolithic reinforced concrete structure, consisting of concrete class C16/20, reinforced with fi 12 bars of class B500SP. The calculations also take into account the formwork to be used during construction, as well as the installation of the formwork and its removal. The roof stage was calculated on the basis of the design, assuming a rafter and rafter-timber construction made of spruce wood class C 24, on which a vapour-barrier foil will be nailed later. The roof stage was calculated on the basis of the design, assuming a rafter and collar beam structure made of spruce timber of class C 24, onto which a vapour-permeable membrane is planned to be nailed, counter-battens and further battens, on which the ceramic roof tiles will be laid and gutters will be installed.

The cost estimate for the replacement technology includes a 20 cm thick foundation slab of C20/25 waterproof concrete, reinforced with fi 8 bars of AIIIN class steel. The walls were calculated on the basis of quotations from the subcontractor company, which is planned to be the general contractor for the investment. The prefabricated elements made of expanded clay concrete require slight smoothing with gypsum plaster, which has also been taken into account in the calculation.

The costs assumed in the valuation take into account the creation of the workshop drawings for the prefabricated walls, based on the original design, prefabrication, transport to the construction site and subsequent installation of the walls. The Filigree, which is the replacement floor in the described design, was calculated based on a subcontractors' quotation, and the total price includes the replacement design, prefabrication, transport and erection on site and the construction of the concrete topping layer. The roof structure is const. for the variants studied, but the amount of execution of this phase of work due to the higher number of labourers. The charts below show the percentages of the amounts for each of the work phases analysed.

Design data

The schedule created and analysed constitutes an action plan, which was presented in diagrams. Its purpose is to facilitate the organisation of the construction and the individual construction activities at each stage of the project. For the purposes of the investment in question, schedules were created based on the following system single-shift, 8-hour schedules with free Saturdays and Sundays, except for the necessary concrete conservation work. The schedule of the original project assumes the work of 4 workers, where the schedule with the alternate technology due to the large-scale elements assumes the work of 6 workers. Figure 3 provides a summary of the time required to complete the same tasks but with different technologies.

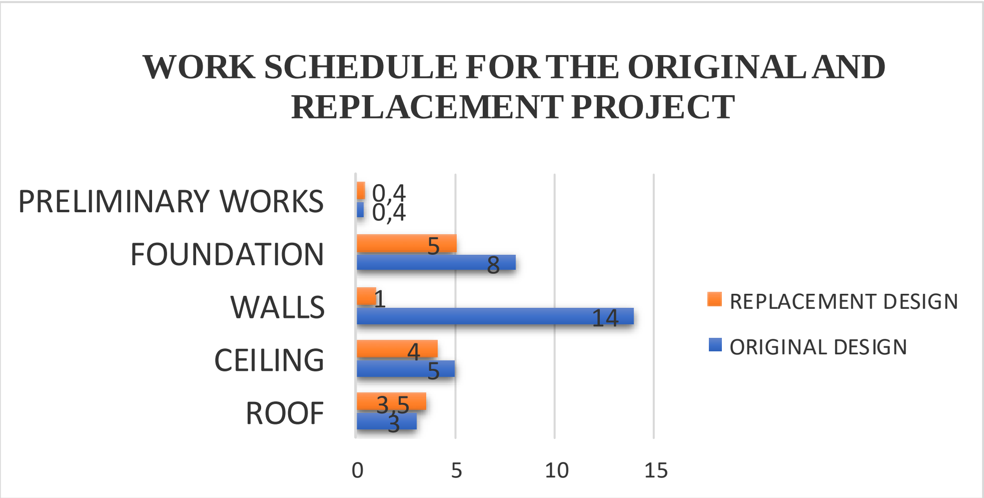

Figure 3 Work schedule expressed in weeks. [own elaboration]

The figure is expressed in weeks and takes into account the necessary technological breaks as well as the time needed to purchase and deliver the materials, finished elements as well as assemble and disassemble the necessary formwork and boarding.

The graph in Figure 3 clearly shows the difference due to the different technologies. The different time is also influenced by the different number of employees, the increased number of technological interruptions of the original design assumptions in relation to the replacement assumptions. The ratio of technological breaks to the real work carried out on the construction site is presented in Figure 4 and Figure 5, where the following percentages are shown.

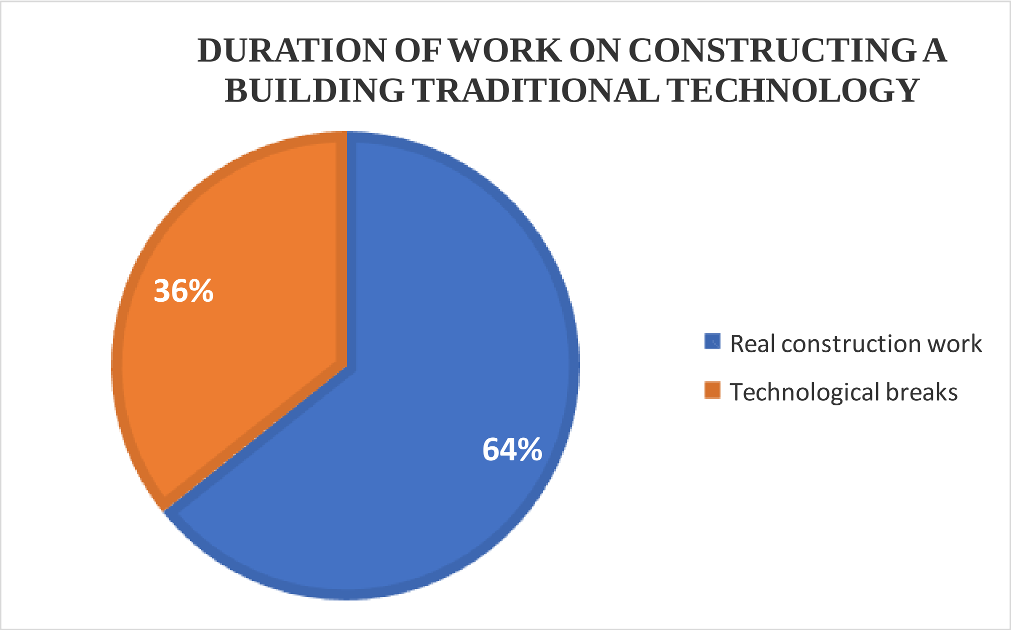

Figure 4 Technological works and breaks for traditional technology based on the construction works schedule. [own elaboration]

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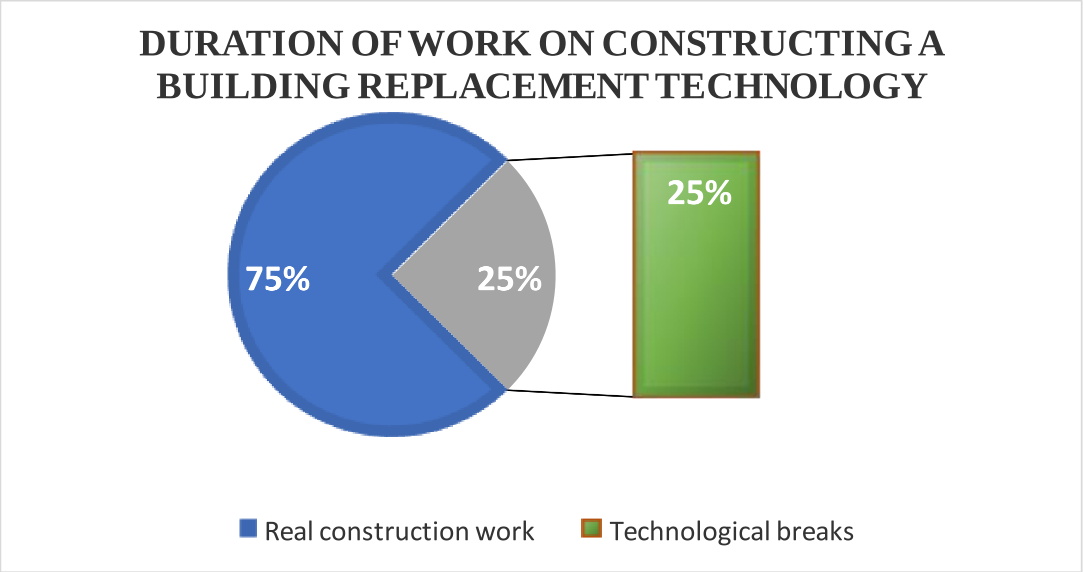

Figure 5 Technological works and breaks for replacement technology based on the construction works schedule.

Investment description

The planned construction project involves the introduction of a single-family development on plot of land with registration number 2560/50 in Kozy municipality, at Margaretki street. The subject of the investment is a single-family, detached building, with a width of 10.50m wide and 8.50m long, with a total built-up area of 90.00 m^2. The original design of the investment envisaged the foundation of the building on a reinforced concrete footing, which is the most commonly used type of foundation, which is characterised by simplicity of execution. This makes it possible to create lower heights than foundations made of brick. The advantage of the strip footing is that work can be carried out below the groundwater level. The footing which has been designed for the investment project in question is to be cast in C16/20 concrete reinforced with B500SP steel about dimensions of 60.00 x 40.00 cm, and two footings of the same material as the footing measuring 140.00 x 40.00 cm. The walls in the original design were to be 24 cm thick cellular concrete blocks, which are extremely lightweight and have very good sound and heat insulation properties. Cellular concrete is a mixture of water, sand, building lime and various types of binders, as well as an admixture of aluminium, which is necessary in order to create the desired pores. Thanks to its mineral origin, cellular concrete is non-flammable and also guarantees the highest degree of fire resistance.

Due to its porous form, itis not recommended for walls in wet environments, due to its high capillary rising. In order to obtain the best thermal parameters, the blocks should be brickwork with a thin joint. The next technological stage is the execution of the ceiling, which was designed as a monolithic reinforced concrete ceiling in the initial design, where the span of such floors in the case of unidirectionally reinforced slabs usually does not exceed 3.0 to 3.5m, while cross-reinforced slabs, i.e. bi-directionally reinforced slabs, due to their greater stiffness, they can reach up to 5.0m. The main benefit of reinforced concrete floors is easy access to materials and the elimination of the need for heavy installation equipment. The monolithic slabs are also characterised by their low thickness, which means there is no buckling or sagging of the load bearing elements under the slab. This phenomenon is undesirable as it leads to cracks in the underside of the ceiling. The main disadvantage of reinforced concrete floors is their complicated installation process and long process intervals. Once the reinforced concrete floor is in place, it is possible to masonry work can be resumed after the reinforced concrete floor has been completed. The roof of the project in question was designed as a collar beam roof, and this is also the same for the replacement project. A collar beam is used when there is a span between the external walls with a span of more than 7.0 m. This structure consists of rafters connected to each other by a maypole, a beam that is used to brace two rafters together. The main function of the rafter batten, apart from bracing, is to transfer horizontal forces from one rafter to the other, so that the rafter located on the opposite side to the wind direction cooperates in the transfer of wind pressure loads. The roof truss designed for this project, after the necessary calculations have been made, is to be made of 8 x 18 cm rafters and 8 x 20 cm collar beams and the entire structure is to be made of spruce or pine timber of C24 class. The design of the replacement technology assumes the construction of the foundation in the form of a foundation slab with a thickness of 20 cm. The main advantage of the ground slab is to ensure the rigidity of the facility, as the ground slab, thanks to its large even surface, it is resistant to changes that occur in the soil structure. Another advantage is insulation, which is why the slab is ideally suited to wetland areas. The process of laying the foundation is relatively short due to the simple construction and lack of need for vertical insulation. The disadvantage of the slab is undoubtedly the need to plan all the connections before making the construction of the foundation. The walls in the technology described have been replaced from masonry to prefabricated ones made of expanded concrete. This material is highly resistant to extremely high temperatures and to absorb water. Lime-cement walls themselves consist of approximately 75% expanded clay, 15% water and cement, which makes up approximately 10 % of the total mixture and acts mainly as a binder. During production, the walls are made of expanded clay of different strengths and densities, and after transport to the construction site, they are connected to each other with metal pins, which are then casted in concrete. The main disadvantage of erecting walls using this technology is the limited production capacity due to transport and dimensions. The floor was changed from reinforced concrete monolithic to Filigran, consisting of a reinforced concrete slab that is prefabricated and has a thickness ranging from 4.5 to 7 cm. This slab contains the bottom reinforcement and is completed on site with a layer of concrete of a thickness depending on the floor load and span. The two floor layers are connected to each other by means of the rough upper surface of the precast and the spatial girders. The Filigran floor has many advantages, the main one is that the overall construction time is considerably reduced. Because they are already arriving at the construction site ready-made reinforced slabs that act as lost formwork eliminate the need of making formwork.

Another advantage is the freedom of shape and ease of installation, where it is not necessary to make any separating ribs or other complicated truss formwork.

Summary

When analysing the various options for the realisation of a building project, it is necessary to create different building models for different: execution technologies, new or innovative building materials, building investment execution experts, in order to examine the main investment variables, i.e. time and cost and design innovation in line with trends. Analysing the materials presented in this article, there are no ideal solutions that do not have flaws. Each building material and technology used in a project with initial or replacement assumptions has a number of advantages, which create optimum models for the assumptions made. The analysed costs to be spent on the construction of both the initial design and the replacement design are comparable. In the replacement design the costs of the walls are generated by their prefabrication and the costly material of expanded clay, while in the traditional masonry technology, the subsequent finishing of the walls, namely plastering and smoothing, is expensive. In terms of the time required for construction, the prefabricated system is unbeatable. The total time needed to complete a prefabricated building is around 4 months from the start of preparatory work on site. Constructing a building using the traditional method is considerably longer, but the choice of subcontractors to carry out the stages is considerably greater than for the prefabricated building option. The construction industry is one of the most rapidly developing sectors in Poland and worldwide, striving to ensure that buildings are constructed quickly and ergonomically, and that the resulting buildings are zero-emission buildings. Increasingly frequent choice, when constructing volume buildings, is to opt for prefabricated materials that require little on-site processing, as prefabricated elements which are also more precisely manufactured, which is something the investors pay a lot of attention to these days.

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