sciendo

CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594

CEER 2022; 32 (4): 0323-0344
DOI: 10.2478/ceer-2022-0061
*Original Research Article*

# CHALLENGES IN THE DESIGN OF PREFABRICATED SINGLE-FAMILY BUILDINGS WITH EXPANDED CLAY TECHNOLOGY - SELECTED ARCHITECTURAL AND ENVIRONMENTAL ASPECTS

Tomasz BRADECKI[1], Anna TOFILUK[2] , Barbara UHEREK-BRADECKA[3]
[1]Silesian University of Technology, Faculty of Architecture
[2]Warsaw University of Technology, Faculty of Architecture
[3]University of Technology Katowice, Faculty of Architecture

## Abstract

The architectural form of buildings is determined by many factors, one of the most important is construction technology. It remains in a close and inseparable relationship with architectural design. Contemporary technologies in construction are constantly subject to improvements, streamlining, changes aimed at increasing all kinds of efficiency (cost, thermal efficiency, labor input, etc.). One of today's widely discussed determinants of changes in the way buildings are designed and constructed is environmental issue. An awareness of environmental degradation and climate change and their consequences prompts the search for increasingly sustainable solutions. This paper summarizes the research on prefabricated solutions and their implementation, especially in single-family residential architecture. This article presents pre-design, design, and post-design experiences related to planning and realization of single-family houses with prefabricated wall technology made of light expanded clay concrete. The authors implemented comparative qualitative and quantitative research through case studies, the method also uses experiences from their own research by design practice. The advantages and disadvantages of prefabrication in the selected technology are presented. The authors attempt to answer the question of whether the individual architectural design approach is

---

[2] Corresponding author Warsaw University of Technology, Faculty of Architecture, anna.tofiluk@pw.edu.pl, +48603794245

reflected in the relevant environmental considerations, including, first, those related to the mitigation of climate change and adaptation to its consequences, and to what extent the discussed technology fits into the assumptions of climate and environmentally responsible design.

Keywords: climate change mitigation and adaptation, building energy efficiency, single family houses, prefabrication, prefab architecture, offsite architecture, expanded clay, lightweight expanded clay concrete, sustainability by prefabrication

## 1. INRODUCTION

According to the current definition of prefabricated architecture in the literature [28,29,30,37,38], buildings constructed with this technology are structures whose erection is primarily associated with the production of substantial building components under controlled factory conditions, and later with a relatively brief time of their assembly on the construction site. The advantages of prefabricated buildings include a faster construction process on the building site, which is independent of weather conditions since most of the work takes place at the factory. In addition, prefabrication "promises" (although this is often difficult to verify) lower production costs for components and the entire building, which should be a consequence of the mass production of components. Nowadays, better technical quality of erected buildings and their components produced by prefabrication technology is also emphasized. Factory conditions make it possible to control the production process of components much more precisely than it can be done on the construction site. Although prefabrication as a method of constructing buildings has been seriously discussed in the architectural and construction community for one hundred years, and its first "traces" can be found even as far back as the 16th century [19,26,29,30], it is only today that it seems to have a chance to fulfill the hopes placed in it. The contemporary way of designing with digital tools ensures precision and easy "transfer" of the virtually formed model of a building element to the production line. The precision of design and fabrication under controlled conditions of an industrial plant ensures the matching of elements on the construction site difficult (if not impossible) to achieve not long ago [3,9,35].

Prefabricated architecture in Europe, including Poland, has been a technology considered and used primarily in the context of multifamily housing since the first half of the 20th century [5,6,18,32]. Architects and decision-makers alike have placed, and continue to place, hope in it for the rapid construction of affordable and decent housing. It is rare to discuss prefabricated solutions in the context of single-family housing, although such house construction also has a long tradition in the world. There are also Polish solutions that are part of this trend and can be an important contribution to the discussion of prefabricated single-family housing in Poland.

According to data from Poland's Central Statistical Office, half of the Polish population lives in single-family buildings, and there is no indication that this situation will change any time soon. We are erecting as many apartments in single-family buildings as in multi-family buildings. Between 2017 and 2021, 49.9% of completed housing units were in single-family buildings, and 50.1% were in multifamily buildings [41]. At the same time, most of the single-family buildings being erected are built based on typical designs, also known as a catalog or ready-made designs ("Typical designs are created for an unidentified, anonymous client. (...) Such a project is created quickly, as it does not have to meet the individualized needs of the client and is most often intended for 'multiple uses', i.e., the construction of an unspecified number of buildings on its basis." [23]). It is estimated that only about 35% of single-family buildings were designed on an individual order, and 65% in buildings erected according to a catalog design [12,15]. Thus, about 1/3 of all residential units are in typical, repetitive single-family buildings.

In this context, the low degree of prefabricated technology used in the construction of single-family homes in Poland is puzzling. Although there are no precise estimates relating to single-family construction, the CSO's data for 2020 states that "Residential construction was dominated by traditional improved erection technology, which was used in the construction of 98.5% of new residential buildings put into use." [41] Traditional improved technology is "a method of residential building erection in which the load-bearing structure is walls made of bricks, blocks or hollow blocks of a weight and size that allows them to be built by hand." [27]

Since we design and construct buildings with typical floor plans conceived as repetitive and reusable, prefabrication seems a natural complement to such an approach. A customer buying a repetitive design can at the same time buy a ready-made technology that will reduce construction time to a minimum, as well as the cost of erecting the building while allowing to skip the whole complicated process of selecting contractors and suppliers. These types of buildings are called "kit-homes" [1,10,26] in the English-language literature, and are sets of factory-made parts of various sizes and materials, allowing to erect (assemble) on-site a complete, typical, ready-to-occupy building. The history of this type of building begins in the 17th century with the British colonization of today's India, Africa, Australia, New Zealand, and the United States. Fear of unfamiliar local materials and lack of access to technological facilities in the new lands resulted in the production of building components in the homeland and their transportation to the colonies [29].

The idea of prefabricating single-family building structures has been explored in theory and practice by some of the greatest creators in the history of architecture. Classic examples include: Le Corbusier's theoretical Dom-Ino project (from 1914), the Dymaxion House planned for mass production designed by Richard Buckminster Fuller (1920), the concept of the Baukasten in Grossen system by Walter Gropius and Adolf Meyer (1923), Ernst May's Praunheim estate buildings in Frankfurt (1926-1930), Walter Gropius' prototype house No. 17 at the Werkbund exhibition in Stuttgart (1927), Robert Krafft and Walter Gropius' Copper Houses (Kupferhäuser) (1930-34). More contemporary examples include Warsaw's so-called Finnish houses (1945, Fig.1), prototype houses built during the years of the Case Study House program in the USA (1945-1966) by, among others, the Eames couple, Eero Saarinen, Richard Neutra, the Oriental Masonic Gardens estate designed by Paul Rudolf (1970) in New Heaven, row houses erected using large-panel technology in the Prototypy estate in Warsaw (1960s, Fig.1), the Cellophane House designed by the KieranTimberlake studio and temporarily erected in New York (2008) for the exhibition Home Delivery: Fabricating the Modern Dwelling (at MoMA), the Oxley Woods estate of Rogers Stirk Harbour and Partners office in Milton Keynes (2007), part of the buildings of the Port Loop estate of Shedkm architects in Birmingham (2020). [1,10,14,19,22,23,26,26,29,31,34,35,36].

Fig. 1. Warsaw prefabricated Finnish houses (1945) and row houses in the Prototypy estate (1960s, today additionally insulated), authors' own photographs

Today, prefabricated technology suppliers are convinced that not only repetitive buildings can be erected using prefabricated technology. Digital tools present both in the design phase and the process of highly automated production allow prefabrication of components of custom-designed buildings. The culmination of such an approach at today's stage of prefabrication development is the 3D printing of building components and even entire houses [3,9,35].

The nature of manufacturing large building components in an industrial plant requires detailed planning of the supply chain and the entire production process which promotes accurate estimation of needs and thus contributes to saving energy, and materials and minimizing waste. Off-site production of significant building components and rapid on-site assembly with the right approach also promote planning of the disassembly process following the idea of "design for disassembly" (low-energy disassembly and reuse of components) and the assumptions of circular economy [8,25]. Although comprehensive and objectified studies comparing the carbon footprint of prefabricated and conventional buildings are difficult to conduct today and rare, there is reason to believe that prefabricated technologies can significantly contribute to reducing both embedded and operational carbon footprints. "A study comparing prefabricated and conventionally erected buildings (concrete elements poured in situ) showed an advantage for the former in terms of the carbon footprint generated (the example comes from China; Mao et al. 2013). The results showed that the carbon footprint of the prefabricated building was about 9% lower. This result was due to less material used, less transportation required, and lower energy consumption of construction equipment." [40].

Contemporary literature defines and categorizes prefabricated buildings by dividing them into 4 groups [26,29,30,31,33,36]:

- repetitive buildings assembled from many elements usually of relatively small size (the mentioned "kit-homes"),
- buildings made of panels,
- objects constructed from significantly sized three-dimensional (volumetric) structures, one element can even be an entire housing unit (e.g., container buildings)
- hybrid solutions combining the above types and other types of prefabricated buildings.

This classification needs to be supplemented by the construction materials used, which are shown in Table 1. It highlights the technology of lightweight expanded clay concrete and its place in the classification.

Table 1. Prefabricated architecture - solution classification

| **Type of prefabricated technology** | **Kit-homes** | **Panels** | **Volumetric structures (3d)** | **Other types** |
|---|---|---|---|---|
| Structural materials | different types of materials | timber frame panels and CLT panels | timber frame 3d structures and structures made of CLT panels | different types of materials |
| | | metal frame panels | structures made of metal (frame) | |
| | | reinforced concrete panels including lightweight expanded clay concrete panels | reinforced concrete 3d structures | |

Expanded clay concrete is a type of concrete in which the main aggregate is expanded clay, often also called LECA, which is an acronym for lightweight expanded clay aggregate. Expanded clay aggregate „*is produced from special plastic clay with no or little content of lime. The clay is dried, heated and burned in rotary kilns at 1100–1300 °C. LECA is porous ceramic product with a uniform pore structure with potato shape or round shape due to the kiln circular movement.* [24]"

As research [24] shows, expanded clay is a porous building material that is lightweight, non-combustible, resistant to moisture and chemical agents, and with particularly good thermal insulation properties. Expanded clay concrete is a material with a lower density than ordinary concrete and is lighter. It is characterized by high fire resistance, low absorption, high compressive strength, frost resistance, good sound absorption, ability to accumulate heat, not much heat transfer coefficient (especially compared to traditional concrete).

Expanded clay and expanded clay concrete are used extensively in the construction sector. The main lines of application include insulating floors/slabs, making drains, gardening, and reinforced expanded clay concrete walls.

Fig. 2. Expanded clay concrete panels, authors' own photographs

One of the most spectacular uses of expanded clay concrete in architecture is the canopy at the Portuguese pavilion erected for the 1998 Expo in Lisbon, designed by Álvaro Siza. This iconic building still surprises today with its concrete cable-hung canopy with a span of more than sixty meters and a thickness of only 20 centimeters. To reduce the dead weight of the structure, a special concrete was developed using expanded clay as aggregate.

Considering Polish single-family housing construction, the listed advantages of prefabricated technologies, experience both domestic and foreign with prefabricated single-family houses, and especially the potential of this technology related to climate and environmentally responsible design, the low participation of such solutions in Polish single-family house designs puzzles and calls for discussion. This article aims to analyze the opportunities offered by prefabrication of single-family houses in Polish design and construction practice, which is still rarely present. The point of reference for consideration and analysis are buildings erected in recent years using prefabricated technology with walls made of lightweight expanded clay concrete. An attempt is made to discuss the potential of this technology. The authors describe the objects in a multifaceted context with particular attention to the environmental issues that are so important today.

## 2. METHOD

Most of today's prefabrication implementations and research are aimed at multifamily construction. In Poland, there are at least a few dozen companies implementing construction of single-family houses from prefabricated elements. The scale of their activities has a small market share. Karolina Matysiak [16] rightly states that among the latest Polish single-family realizations, houses made with wooden technology are particularly popular. Meanwhile, Katarzyna Chęcińska [4] refers to experience in prefabricated concrete and states that “*The biggest advantage of this type of technology is the reduction of the time of construction from several months to just a few weeks - taking into account all the stages of construction and for the "assembling" of the structure itself - this time can be even a week (...) Precast concrete products are durable, show a long life, have good thermal and acoustic insulation, fire resistance, have no harmful effect on the environment.”*

Previous research related to prefabricated single-family houses in concrete panel technology on Polish soil has been very fragmentary and has touched on somewhat different issues than those analyzed by the authors. Nevertheless, they encourage the further pursuit of the topic of both the realization of such buildings and research on them [4,16,20,42].

The cited studies show that precast concrete elements are a good component for the construction of single-family houses and that it is possible to disassemble and reassemble them in the construction of other buildings. Above that, they are a tool for creating aesthetically pleasing architecture, which also has some potential for future transformation (modernization, renovation).

Research on single-family buildings made of expanded clay concrete panels has not been conducted in Poland in the context of architectural and sustainable development.

This paper describes the research by design experience in realization of single-family houses using prefabricated reinforced panels made of expanded clay concrete. The introductory part of the article presents the theory and contemporary state of knowledge and research devoted to prefabrication and innovative technologies in architecture and construction. Special attention was paid to the environmental aspect. Reference was made to Polish and foreign literature on the subject. The research problem presented by the authors concerns the issue of using prefabrication in the design process of single-family buildings and determining the limitations of architectural constraints, along with other related considerations.

At the outset, the authors briefly discussed the various prefabrication technologies that can be used in single-family housing. The main part of the text presents the authors' own experience based on research by design approach.

Authors are practicing architects and came across the prefabrication technology in practice since 2005 and used the design and construction experience of dozens of single-family houses. From among the many completed projects, several were selected that varied in size and complexity (number of floors, type of roof, functional layout). All projects were consulted and developed with an experienced manufacturer-builder of prefabricated buildings made of expanded clay concrete panels. A comparative and descriptive method was used for selected features of the buildings. Photo documentation was presented to illustrate the problems. The discussion presents the problems of design and implementation. Summary of selected indicators such as no of storeys, built up area, approximate number of transport trailers, Ep value, Time of construction specific to the case studies have been examined. Comparison of selected realization possibilities for structural elements of single-family buildings realized in traditional technology and prefabricated walls made of expanded clay concrete has been presented. The data has been collected in tables. Comparison allows for discussion on which design aspects have impact on sustainability of the implementation process.

The summary and conclusions are presented in the last part of the paper. The authors attempt to answer the question of whether the individual architectural design approach is reflected in the face of important environmental considerations, including, first, those related to the mitigation of climate change and adaptation to its consequences, and to what extent the discussed technology fits into the assumptions of climate and environmentally responsible design.

## 3. RESEARCH BY DESIGN, CASE STUDIES OF PREFABRICATED EXPANDED CLAY CONCRETE SINGLE-FAMILY HOUSES

This section presents the author's projects implemented in the Silesian province in 2016-2022, presents their parameters, and describes their realizations. These are single-family buildings constructed with the technology of prefabricated expanded clay concrete walls. The analysis of the existing state of research on single-family prefabricated architecture and the accompanying self-designed buildings and empirical studies, conducted during supervision at construction sites, allow us to formulate conclusions and recommendations. They will set a direction of change for design work in the future.

### 3.1. One-story house in Rachowice

The design of the house in Rachowice (Pilchowice municipality) is a proposal for a contemporary single-storey detached house with a garage. The main design idea exposes the living area, which is designed as a raised, prominent block with extensive glazing opening the view to the terrace. The garage part is protruding from the rest of the building. Since the entire functional program of the building is located on one floor, the built-up area is large (225m²), and the body is fragmented. Other parameters of the building and the following buildings are included in Table 2. The walls of the building were constructed of expanded clay concrete, the whole was covered with flat roof, the structure of which is filigree type plates. Fig. 3 shows the stage of construction after the completion of the floor casting, the formwork for the concrete slab is visible.

Fig. 3. Single-storey house, Rachowice - photo during wall installation, authors' own photographs

### 3.2. Two-storey house in Pilchowice

The house in Pilchowice is a two-story building, composition of solids with a flat roof. Part of the house is a two-car garage. The first floor provides an open space including a kitchen, dining, and living room and one additional room. On the upper floor bedrooms, dressing room, gym and one extra room are located. The built-up area is 156m² with a usable area of 208.6m². The form of the building can be considered partially compact. The ground floor garage is protruding. The outline of the 2nd floor is enlarged in relation to the shape of the first floor (Fig.4a, 4b). Fig.4 shows the foundation slab and the crane and trailers with prefabricated walls. During installation, maneuvering space and an access road are needed to allow for large-scale transportation. In this case a concrete pergola has been designed and realized on site (Fig.4b).

Fig. 4. Two-storey house in Pilchowice, concrete foundation slab and installation of prefabricated walls is started, authors' own photographs

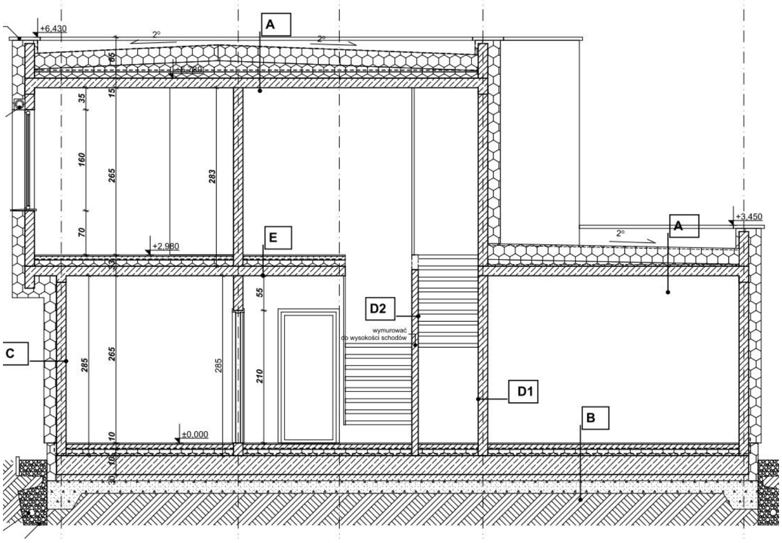

Fig. 4a. Two-storey house in Pilchowice, cross section; authors' own illustrations

Fig. 4b. Two-storey house in Pilchowice, concrete pergola; authors' own photographs

### 3.3. Two-storey house in Gliwice

The house in Gliwice on Czekanowskiego Street is a two-story building with a two-car garage located on a narrow plot. The living zone on the first floor is extended by a winter garden and a patio entirely covered by the terrace of the first floor. This gives the possibility to use the patio-garden zone all year round without getting wet. The usable area is 292 m$^2$ (the first floor, the second floor, non-utility attic). The building is covered with a hipped roof (wooden structure) with a slope of 30 degrees.

Thanks to the ground-floor garage and terrace, the house can be considered a fragmented structure. In addition, extensive glazing is proposed on the first floor, so that the body of the house cannot be considered fully compact and energy efficient. Fig.5 shows the shell during the implementation of the roof, pictured from the terrace and conservatory.

Fig.5. Two-storey house in Gliwice – installation of the roof; authors' own photographs

### 3.4. Two-storey house in Wyry

A single-family house of the area of 251 m² has been designed in 2016 in the town of Wyry. A typical functional layout with a living zone on the first floor and a night zone on the second floor has been proposed. The project is distinguished by a living room open on two floors. The body of the building can be considered compact, except for two corner recesses (entrance and covered terrace). Fig.6 shows part of the house from the living room side. The visible large window opening (two stories high) was formed by two prefabricated elements. The lack of a ceiling in this part of the building represented a complication at the stage of technical design and implementation.

Fig. 6. Two-storey house in Wyry – installation of the roof; authors' own photographs

### 3.5. Two-storey house in Łany Wielkie

A single-family house of the area of 132 m² has been completed in 2019 in the town of Łany Wielkie. The design was prepared for a longitudinal plot of the dimensions of 18x71 m, with entry from the south. Two-sided hood-free roof with the angle of inclination of 30º. The two-story living space, of the height of 6.7 m at the top, with a mezzanine, results from the concept of open space (Bradecki Uherek-Bradecka 2019). The compact body of the building has been preserved, the only element sticking out of the outline like the projecting roof, which protects the terrace and glazing from excessive overheating (Fig.7). The roof structure supported by steel posts was made using elements of expanded concrete beams. The geometry and complexity of this part of the building were a difficulty at the stage of technical design and implementation.

Fig. 7. Two storey house in Wyry – construction site; authors' own photographs

## 4. DISCUSSION

The realizations presented above allow the following conclusions. Effective design of prefabricated buildings requires knowledge and experience of the possibilities of combining walls, their transportation, assembly, as well as possible subsequent use. The technology of prefabricating walls from expanded clay concrete has limitations in joining and making corner elements, including overhanging elements, or supported by columns. Most of the cases shown have walls with a height of 285cm. This is considered a typical height, as it allows for 265cm clear height after finishing, and transporting walls of higher dimensions makes the cost significantly more expensive. Most single-family buildings in this technology are designed based on walls of similar height for economic reasons.

Interior design in prefabricated buildings can be considered somewhat limited due to limits on ceiling spans and the size of window openings. For projects with large glazing open to 2 floors (Fig.6, Fig. 7), it was necessary to divide prefabricated elements. In buildings made of expanded clay concrete in single-family houses, external walls and selected internal walls with a thickness of 15cm are used, the rest of the internal walls 10cm, all of which perform structural functions. Overhanging elements in the body of the buildings seem to be problematic, due to the structural limitations of the ceilings. These are most often designed as thin slabs reinforced on site and poured over concrete. They are often too thin to carry the weight of prefabricated walls installed before concreting, and it is not possible to design overhanging slabs, which are used in traditional technology. Solutions for ceilings that are in part soffits are also problematic. The case of the house in Gliwice was special because the ceiling also served the function of roofing, and the irregular functional layout made it necessary to realize the floor slabs and the terrace roofing on one level.

During the use of the buildings, residents mentioned small hairline cracks on the plaster, which are not a structural defect, and naturally show how the building works. Cracks can also appear in buildings constructed with traditional technology if the building walls are not properly dried (preferably left for the winter).

Based on the analysis of selected cases for expanded clay technology, environmental aspects at the stage of production, transportation and use should be distinguished. Emissions of pollutants that arise during the production of walls are comparable to those realized at the construction site, except for the reduction of wet processes.

It is necessary to mention the heat transfer coefficient Uc [W/m$^2$·K], which according to Polish regulation for external walls in 2018 was 0.23, and in 2022 is 0.2. Expanded clay walls are characterized by a lower U than masonry, which, including the insulation layer, is 0.18. All the cases discussed were insulated with 20cm thick polystyrene foam, which is commonly implemented nowadays. This means that thanks to the use of expanded clay, the exterior walls have a better coefficient of penetration, and therefore the construction houses in this technology are more energy efficient. At the same time, exterior walls are 15cm thick, while masonry walls are 20cm, and most often 25cm. Thanks to this, it can be concluded that houses implemented in the technology of expanded clay concrete have slightly larger areas, if they were to be compared with their counterparts of identical construction area implemented in traditional technology. The data is collected in Table 2. In months, the estimated completion time of the open shell of the buildings (calculated after the completion of the foundation) is presented. On the basis of design experience and comparative analysis from supervisions of realization in traditional technology, it can be concluded that due to prefabrication the realization time is much shorter. Table 2 gives the estimated minimum completion time of the shell for both variants of the implementation technology. Table 3 shows a comparison of the realization possibilities of the most important structural elements realized with traditional and expanded concrete technology.

Table 2. Summary of selected indicators specific to the case studies; authors' compilation

| | No of storeys | Built up area/ usable area | Approximate number of transport trailers | EP value (annual demand for renewable energy per surface unit kWh/ ($m^2$·year) | Time of construction, walls, and roof, expanded clay/ traditional[month] |
|---|---|---|---|---|---|
| Rachowice | 1 | 225 | 2 | 75,6 | 1,5/4 |
| Pilchowice | 2 | 208 | 5 | 81,4 | 5/7 |
| Gliwice | 2+p | 196,8/<br>292,80 | 6 | 76,1 | 4/8 |
| Wyry | 2 | 223,26/<br>251,56 | 5 | 52,25 | 2/5 |
| Łany Wielkie | 2 | 106,87/<br>132,19 | 4 | 88,4 | 3/6 |

Table 3. Comparison of selected realization possibilities for structural elements of single-family buildings realized in traditional technology and prefabricated walls made of expanded clay concrete, study by the authors

| | Traditional technology | Prefabricated technology |
|---|---|---|
| foundation | Footings or foundation slab | Foundation slab |
| walls | No limit | Limits because of transportation trial capacity and walls height |
| ceiling/ flat roof | Structural limitations specific to monolithic structures | Structural limitation of spans (including due to transportation), overhanging elements |
| pitched roof | Wooden pillars, joined to the walls | Wooden pillars, leaning on the walls |

## 5. CONCLUSIONS

The discussion conducted allows the following conclusions. Prefabrication of expanded clay concrete walls limits slightly the individual architectural approach, but has significant environmental advantages:

- limits the execution time and allows to reduce the number of wet processes (bricklaying, concreting, plastering) and reduce the amount of energy consumed on the construction site;

- allows the erection of buildings whose partitions (walls) are characterized by very good thermal insulation, and thus correspondingly low annual energy consumption;
- experience of the implementation of the discussed buildings shows that at the stage of erecting prefabricated walls of expanded clay concrete, the construction process does not generate waste, finished walls are brought to the construction site and assembled with little additional input;
- although the potential for demolition and reuse of expanded clay concrete walls has not yet been investigated, by analogy with other research results [11,20], it is hoped that the potential of expanded clay concrete panels in this regard is significant;
- it is impossible to determine conclusively whether the technology presented is environmentally sound, due to the fact that apart from prefabrication of walls and facilitation of plastering and installation, most of the other construction processes remain identical or analogous to traditional ones; but it is to be expected that other solutions such as prefabrication of sandwich walls that require only dry assembly on site are more environmentally sound. Nevertheless, the authors believe that prefabrication of expanded concrete elements is rational and necessary. The cases studies presented confirm that a customized approach to architectural design using prefabricated elements can have positive environmental effects. Optimization of selected spatial solutions can have a partial impact on reducing the effects of climate change. This is evidenced primarily by reduced lead times and a reduction in wet processes that contribute to gas emissions.

The authors point to the need for further and more detailed studies of the qualities and possibilities of designing and constructing buildings using prefabricated technologies. This is particularly justified in the era of the need to reduce emissions both at the stage of design and construction, as well as the use of buildings.

## ADDITIONAL INFORMATION

The article presents projects conducted within the framework of the author's architectural practice (Studio BB architects, Tomasz Bradecki, Barbara Uherek-Bradecka), as well as realizations of buildings carried out by Solida and Krosbud.

## REFERENCES

1. Bergdoll, B, Christensen, P [ed.] 2008. Home Delivery: Fabricating the Modern Dwelling. The Museum of Modern Art, New York.

2. Bradecki, T, Uherek-Bradecka, B 2019. Open Living Concept in Barn-House Architecture: Single Family House Case Studies, *2019 IOP Conf. Ser.: Mater. Sci. Eng. 471 082055*.
3. Caneparo, L 2014. Digital fabrication in architecture, engineering and construction. Springer Science and Business Media.
4. Chęcińska, K 2008. Domy jednorodzinne Z prefabrykatów betonowych, Budownictwo, technologie, architektura 4(44)/2008, s. 66-69
5. Chomątowska, B 2018. Betonia. Dom dla każdego [Concrete. A home for everyone], Wydawnictwo Czarne, Wołowiec.
6. Cymer, A 2018. Architektura w Polsce 1945-1989 [Architecture in Poland 1945-1989], Centrum Architektury Narodowy Instytut Architektury i Urbanistyki, Warszawa.
7. Dong, L, Wang, Y, Li, HX, Jiang, B and Al-Hussein, M 2018. Carbon Reduction Measures-Based LCA of Prefabricated Temporary Housing with Renewable Energy Systems. *Sustainability*, 10, 718. https://doi.org/10.3390/su10030718
8. European Commission, Directorate General for Regional Policy 2011. Cities of Tomorrow. Challenges, Visions, Ways Forward. Available online: https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/citiesoftomorrow/citiesoftomorrow_final.pdf (accessed on 5 September 2022).
9. Graser, K, Kahlert, A and Hall, DM 2021. Dfab House: implications of a building-scale demonstrator for adoption of digital fabrication in AEC, *Construction Management and Economics*, 39:10, 853-873. https://doi.org/10.1080/01446193.2021.1988667
10. Herbert, G 1984. Dream of the Factory-made House: Walter Gropius and Konrad Wachsmann. MIT Press, Cambridge.
11. Huuhka, S, Kaasalainen, T, Hakanen, JH and Lahdensivu, J 2015. Reusing concrete panels from buildings for building: Potential in Finnish 1970s mass housing. *Resources Conservation and Recycling*. https://doi.org/10.1016/j.resconrec.2015.05.017
12. Jak budują Polacy? Wyniki badania SILKA YTONG: polskie budowanie [How do Poles build? SILKA YTONG survey results: Polish constructing]. Available online: https://inzynierbudownictwa.pl/jak-buduja-polacy-wyniki-badania-silka-ytong-polskie-budowanie/
13. Jimenez-Moreno, P 2021. Mass Customisation for Zero-Energy Housing. *Sustainability*, 13, 5616. https://doi.org/10.3390/su13105616
14. Koźluk, M, Śmiechowski, D and Potempski, M 2019. Przewodnik Architektoniczny Osiedla Jazdów [Architectural Guide to the Jazdów Estate]. SAWAPW, Warszawa.

15. Majka, M 2016, Polak buduje dom tradycyjnie – raport o budowie domów w 2015 roku [Pole builds house traditionally - report on house construction in 2015], [in:] Dom dla rodziny [Home for the family]. Małopolska Okręgowa Izba Architektów RP, Kraków.
16. Matysiak K, Prefabrykacja w budownictwie jednorodzinnym, Zawód architekt 87/2022, s.16-26
17. Mao C. et al. 2013. Comparative study of greenhouse gas emissions between off-site prefabrication and conventional construction methods: two case studies of residential projects. *Energy and Buildings* 66:165-176.
18. Mika, G 2017. Od wielkich idei do wielkiej płyty. Burzliwe dzieje warszawskiej architektury [From great ideas to great plates. The turbulent history of Warsaw architecture]. Skarpa Warszawska, Warszawa.
19. Moradibistouni, M, Isaacs, N, Vale, B 2018. Learning from the past to build tomorrow: an overview of previous prefabrication schemes. Available online: https://www.researchgate.net/profile/Milad-Moradibistouni/publication/330970744_Learning_from_the_past_to_build_tomorrow_an_overview_of_previous_prefabrication_schemes/links/5c5de622a6fdccb608b2773f/Learning-from-the-past-to-build-tomorrow-an-overview-of-previous-prefabrication-schemes.pdf (accessed on 5 September 2022)
20. Orchowska, A 2016. Architektoniczne rozwiązania z zastosowaniem re-użycia płyt prefabrykowanych, *Czasopismo Inżynierii Lądowej, Środowiska i Architektury*, JCEEA, 2016, 63 (4/16), 365-374.
21. Pan, W, Iturralde, K, Bock, T, Martinez, RG, Juez, OM and Finocchiaro, PA 2020. Conceptual Design of an Integrated Façade System to Reduce Embodied Energy in Residential Buildings. *Sustainability* 12, 5730. https://doi.org/10.3390/su12145730
22. Piątek, G 2021. Najlepsze miasto świata. Warszawa w odbudowie 1944–1949 [The best city in the world. Warsaw in rebuilding 1944-1949] W.A.B., Warszawa.
23. Projekty indywidualne vs. Projekty typowe, [eng. Individual projects vs. standard projects] https://www.prawo.egospodarka.pl/100194,Projekty-indywidualne-vs-Projekty-typowe,1,92,1.html (accessed on 5 September 2022)
24. Rashad, AM 2018. Lightweight expanded clay aggregate as a building material – An overview. *Construction and Building Materials* Volume 170, 757-775. https://doi.org/10.1016/j.conbuildmat.2018.03.009
25. Ryńska, E 2021. Developing and Designing Circular Cities: Emerging Research and Opportunities. IGI Global. https://doi.org/10.4018/978-1-7998-1886-1

26. Seelow, AM 2018. The Construction Kit and the Assembly Line—Walter Gropius' Concepts for Rationalizing Architecture. *Arts* 7, 95. https://doi.org/10.3390/arts7040095
27. Słownik pojęć stosowanych w statystyce publicznej [Glossary of terms used in public statistics]. Available online: https://stat.gov.pl/metainformacje/slownik-pojec/pojecia-stosowane-w-statystyce-publicznej/917,pojecie.html (accessed on 5 September 2022).
28. Smith, EAT 2019. Case Study Houses. The Complete CSH Program 1945-1966. Taschen, Köln.
29. Smith, RE 2010. Prefab Architecture: A Guide to Modular Design and Construction. John Wiley & Sons, Inc., Hoboken, New Jersey.
30. Smith, RE, Quale, JD, [ed.] 2017. Offsite Architecture: Constructing the Future. Routladge, New York.
31. Staib, G, Dörrhöfer, A and Rosenthal, M 2013. Components and Systems: Modular Construction - Design, Structure, New Technologies. Birkhäuser, München.
32. Szafrańska, E 2013. Large Housing Estates in Post-Socialist Poland as a Housing Policy Challenge. *European Spatial Research and Policy*, 20(1), 119–129. https://doi.org/10.2478/esrp-2013-0006
33. The National Audit Office 2015, Using modern methods of construction to built homes more quickly and efficiently. Available online: https://webarchive.nationalarchives.gov.uk/ukgwa/20170207052351/https://www.nao.org.uk/wp-content/uploads/2005/11/mmc.pdf (accessed on 5 September 2022)
34. Timberlake, J and Kieran, S 2011. Cellophane House. KieranTimberlake, Philadelphia.
35. Timberlake, J and Kieran, S 2004. Refabricating Architecture. McGraw-Hill, new York.
36. Tofiluk, A 2019. Prefabricated Architecture, Past and Future: from Past Industrialized Residential Buildings to Contemporary Requirements. [in.] Defining the archtectural space- tradition and modernity in architecture, vol. 6, OW Atut, Wrocław.
37. Tofiluk, A 2020. Prefabrykowana architektura mieszkaniowa a zmiany klimatyczne [Prefabricated housing architecture and climate change]. *Builder* 272, 3, 51–55.
38. Tofiluk, AM 2021. Walter Gropius i prefabrykacja – w poszukiwaniu dostępnej architektury mieszkaniowej [Walter Gropius and prefabrication - looking for affordable housing architecture]. *Kwartalnik Architektury i Urbanistyki* 3, 4–15.

39. Tofiluk, AM and Płoszaj-Mazurek, M 2022. Technologia prefabrykacji a forma architektoniczna [Prefabrication technology vs. architectural form]. *Builder* 7, 50–56.
40. Tofiluk, AM and Płoszaj-Mazurek, M 2022. Architektura i prefabrykacja w kontekście projektowania zrównoważonego [Architecture and prefabrication in the context of sustainable design]. *Builder* 4, 56–62.
41. Urząd Statystyczny w Lublinie [Statistical Office in Lublin], Budownictwo w 2021 roku [Construction in 2021].
42. Woźniczka, M 2021. Eksperymentalny dom prefabrykowany w systemie OWT w Krakowie – Kurdwanowie. Studium przypadku. *Builder* 288, 7, 96-99. DOI: 10.5604/01.3001.0014.9363

*Editor received the manuscript: 22.09.2022*