PAWEŁ MIKA*, PROFESSOR TOLKYNBAYEV TEMIRKHAN**, ZHAKSYLYKOVA LEILA***

Classification of Precast Concrete Façade Elements Used in Contemporary Residential Buildings

Abstract
In recent years, a slow change towards prefabrication has been observed in the construction sector. An increasing amount of construction work is done off site. The benefits of such arrangements are noted, as it results in the construction of better-quality buildings and can lead to lowering a project's overall carbon footprint. These changes concern every stage of construction and nearly every material solution, including external walls made from concrete panels. The objective of this study was to develop and present a classification of concrete prefabricated elements in terms of their structural properties and to determine which of these elements are most often used in the design of housing. The study found that structural sandwich elements and cladding panels were among the most popular technologies.

Keywords: prefabricated concrete façade elements, housing, contemporary architecture, load-bearing walls, self-supporting walls, non-load-bearing walls, exoskeletons

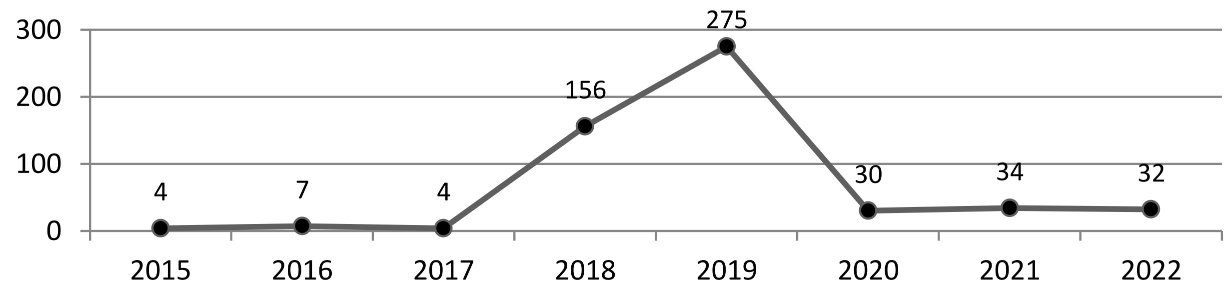
1. Introduction

The immense urban layouts built during the period of socialism have shaped the negative stance of users, developers and architects towards prefabrication-based technologies for many years (Abdrassilova, Danibekova 2021). However, it should be noted that this does not apply to Poland alone and does not stem from the nature of the technology itself, but from the numerous faults of the prefabs used, poor quality workmanship, errors in assembly and improper maintenance (Dębowski 2007; Osmonova 2016).
However, small-sized prefabricated structural elements, such as masonry units, beams and lintels, or larger elements such as hollow-core pre-stressed slabs, remained in use. This is because they were created at specialist plants, under optimal conditions, where a manufacturer can ensure constant quality control, which is typically significantly better than on a construction site.
Since the 1930s, enhanced traditional construction technology, in which the main load-bearing elements are walls made of brick or CMUs whose dimensions enable them to be manually built in, has predominated in Poland in housing construction. It has been used consistently in over 95% of housing projects (GUS 2022).
However, the construction market is changing. It is reacting to the economic, social and political situation in the region. It tries to follow emergent needs and evolves. This is why it is surprising that the technology that used to predominate housing construction in almost all of Central Europe in the 1970s and 80s is making a very slow return to Poland.

2. Objective of the study

In the construction of buildings typically referred to as 'panel-block', curtain walls and load-bearing wall assemblies predominated. The objective of thus study was to classify the types of currently used prefabricated concrete façade elements and to determine which of these were typically used by architects in housing projects. This analysis is justified as the progressing automation of manufacturing has led to new possibilities in decorative concrete element production. In addition, changes that take place in design (BIM software) and construction processes have contributed to a significant development of precast concrete façade elements (PCFEs) used in contemporary architecture. Optimisation that reduces material consumption, heavy equipment use and labour, which also cuts down on energy consumption, also allows prefabrication to be aligned with sustainable development (Mika 2017; Radziszewska-Zielina, Gleń 2014; Jiao, Li 2018; Derkowski 2021).
When we analyse recent years from the standpoint of Polish housing construction, we can observe increased interest in precast systems among real estate developers. At present, it is too early to speak of a re-emergence. The Sprzeczna 4 project in Warsaw, designed by BBGK Architekci, has played a significant role in popularising PCFEs. This multi-family residential building was built entirely out of prefabricated elements and its façades were made from decorative concrete that had been dyed red. Numerous publications on the project in trade journals and online in 2016–2018 could affect decisions made by architects and developers in their technology choices for planned projects. In 2018 and 2019, there was an observable increase in the number of buildings where panel and block systems were used (ill. 1). However, a decline soon followed, although the interest dropped to a level above the one recorded in 2017.
The percentage of housing buildings erected using large prefabs during the peak period (2019) was a mere 0.32%. Translated to the number of dwellings, it was 5.3%. In comparison, this level for dwellings in

* Paweł Mika, PhD. arch., Faculty of Architecture, Cracow University of Technology, https://orcid.org/0000-0001-6132-7662, email: pawel.mika@pk.edu.pl
** Tolkynbayev Temirkhan, PhD. Professor, Faculty of Architecture and Civil Engineering/L.N. Gumilyov Eurasian National University, Astana, The Republic of Kazakhstan, https://orcid.org/0000-0002-8549-3064, email: temtol1961@mail.ru
*** Zhaksylykova Leila, PhD. arch., Department of Architecture and Urban Studies, Politecnico di Milano, Italy, https://orcid.org/0000-0002-1869-9150, email: sara.zhaksylykova@mail.ru



Ill. 1. Number of single- and multi-family residential buildings built in panel and block technologies and handed over in the years 2015–2022 (based on data by Statistics Poland) (author: Mika P.)

Germany was reported to have been around 10% for many years (Kirschke, Sietko, 2021). Developing Asian countries such as Kazakhstan and India (Sherfudeen, Kumar, Raghavan et al. 2016) also opt for concrete prefabs. The sudden increase in demand for housing requires the use of a technology that can save time, energy and resources.

It should also be noted that not all buildings created using panel and block technologies have façades finished with decorative concrete. On the other hand, there are buildings erected using enhanced traditional technology whose façade cladding consists of decorative concrete panels.

3. Methodology and scope of the study

This paper presents the results of a study intended to formulate a classification of PCFEs that define the final character of architecture. The elements were analysed in terms of architecture and structural properties. The classification was based on collected materials on 70 single- and multi-family residential buildings from a variety of climate zones. All of the buildings were constructed after 1990. The following methods were used in the study:

- Multiple-case study – the sample of buildings was rated against a set of criteria such as façade cladding material, prefab structure and role of prefabs in the structural system;
- Quantitative and statistical research – based on the building cases investigated and statistical data obtained from Statistics Poland;
- Logical argumentation (based on analysis and synthesis).

4. Classification of prefabricated concrete façade elements

4.1. Non-load-bearing prefabs are elements that do not carry any loads nor transmit any forces directly to a building's foundations. Their self-weight and wind-generated forces are transferred to the main structural system of a building via adhesive joints, anchors or a frame. Among these, the following are distinguished:

4.1.1. Façade cladding prefabs – the main task of this type of façade cladding, apart from an aesthetic function, is to protect thermal insulation and damp proofing from changing atmospheric conditions and mechanical damage. They are to aid in the maintenance of high parameters by layers that affect a building's comfort of use. There are two methods of mounting cladding currently in use – adhesion and anchoring. For adhesion, epoxy or polyester resin-based glues are typically used (Lorenc, Mazurek 2007). The second method, despite being more costly and time-consuming, has gained greater popularity as it allows a ventilation gap to be formed, thus allowing for the passage of air that dries thermal insulation. Anchor-based mounting, especially via a frame, allows for much greater freedom in building massing design. The cladding layer does not need to follow the geometry of the load-bearing walls in such cases.

This advantage was used in the design of the Bryant Residential Tower (New York, US, 2017, designed by David Chipperfield Architects, ill. 2). Three-dimensional cladding prefabs form horizontal and vertical façade visions that imitate columns and beams. The actual structure is hidden inside a building. This measure allows the formation of façades with richer tectonics and deeper, more pronounced light-and-shadow effects (Wilson 2001).

4.1.2. Curtain façade prefabs – walls made out of such elements can take on the form of uniform (solid or openwork) or wall assemblies. Similarly as in the case of cladding, they can be either hung from or affixed to a building's load-bearing elements. Curtain walls made from concrete prefabs, contrary to cladding, are a fully-fledged partition. They are used in every climate zone. They gained the most popularity in places were weather conditions make construction work difficult. Combined with prefabricated frame structural systems, they allow for the rapid construction of buildings regardless of weather. They are typically used to build hospitals, hotels, multi-level car parks or office buildings – projects based on a specific, repetitive structural module, yet sometimes architects also use them in housing design.

4.1.2.1. Uniform curtain prefabs take on the form of decorative concrete panels. They can be used in housing buildings in climate zones where there is no need for thermal insulation, namely an additional layer, or in buildings that do not require heating, such as the logistics centre in Lyon designed by Jocelyne Duvert of Tectonique architects, 2000 (Detail 2001). Openwork prefabs are a variation of this technology, and are primarily used in subtropical, tropical or equatorial climates. Their main function is to cover or shade interiors, protecting them from overheating while also providing necessary light and ventilation.

This solution was used in a building at 56 Rafael Finat Street in Madrid (Spain, 2003, designed by Matos&Castillo, ill. 3).

The building's galleries were covered with a concrete grate from floor to ceiling (MatosCastillo URL).

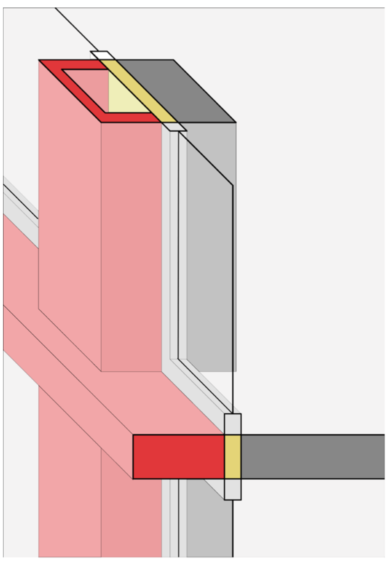
4.1.2.2. Curtain prefab assemblies consist of at least two layers. Depending on need, apart from a finish layer in the form of a decorative concrete panel, they can be integrated with thermal insulation, vapour barriers, and internal finishes. This technology was used in ETS University Residences (Montreal, Canada, 2013, designed by Régis Côté and Associates, ill. 4). The panels consist of a concrete façade layer that is 5 cm thick, mounted to a light steel frame, whose space is filled with polyethylene foam that forms a seamless insulation layer (Slenderwall URL).

4.2. Self-supporting façade prefabs are bound to the structural system of the entire building so as not to transfer their load to it. Free movement joints allow for the independent operation of the façade and load-bearing structure. They are supported by a foundation and transfer forces into the soil through it. Self-supporting façade prefabs come in uniform/single-layer and assembly variety. They are often purely decorative. They define the architectural expression of a building.

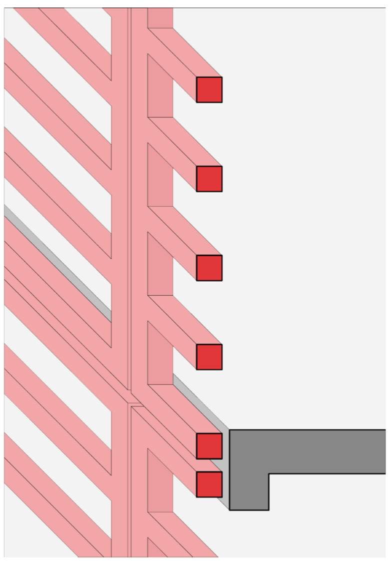
One of the disadvantages of this technology is the probability of cracks forming on walls, both inside and outside the building. They can be caused by thermal stress, present mostly in uniform or assembly-type prefabs with an internal load-bearing fault (Krause 1974). This problem does not concern assemblies with an internal structural layer hidden behind a thermal control layer. The main advantages of this technology include the possibility of replacing the entire façade without interfering with the structural system of the building when its aesthetic or technical standard becomes insufficient. An almost complete independence from the structural system provides immense potential for designing the from of the elements themselves and the building's massing.

Ill. 2-7. Façade structure diagrams for different PFCE technologies (author: Mika P.)

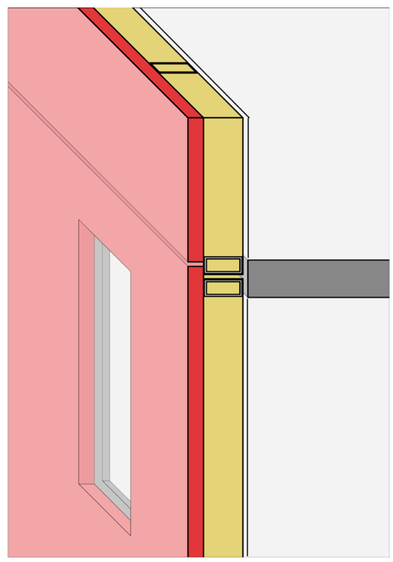
Ill. 2. The Bryant Residential Tower, New York, US, 2017, designed by David Chipperfield Architects
Ill. 3. 56 Rafael Finat Street, Madrid, Spain 2003, designed by Matos&Castillo
Ill. 4. ETS University Residences, Montreal, Canada, 2013, designed by Régis Côté and Associates
Ill. 5. Apartment building in Basel, Switzerland, designed by Miller&Maranta
Ill. 6. Sprzeczna 4 apartment building, Warsaw, Poland, 2017, designed by BBGK Architekci
Ill. 7. Housing Complex with Offices, Paris, France, 2019, designed by Brenac & Gonzalez & Associés, moa architecture



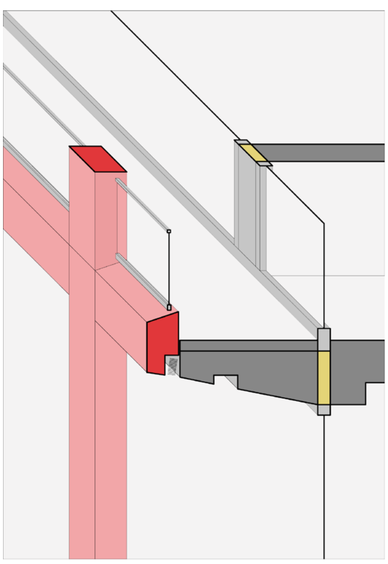
il. 2



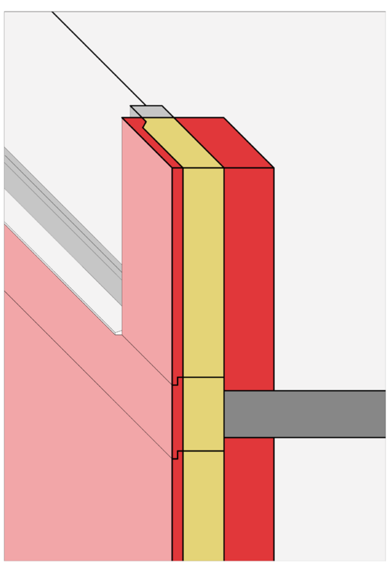
il. 3



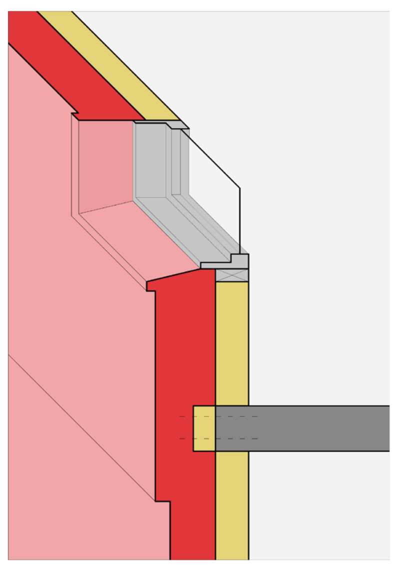
il. 4



il. 5



il. 6



il. 7

Self-supporting PCFEs were used in the construction of an apartment building in Basel (Switzerland, designed by Miller&Maranta, ill. 5). The building's self-supporting façade is a combination of prefabricated elements and concrete cast on site. It was combined with load-bearing decks only from the side of the slabs (Detail 2006).

4.3. Load-bearing façade prefabs (structural) are intended to transfer not only the load of their self-weight but also wind forces and the weight of other building elements that they support (e.g., from decks, roofs). The joints are made so as to incorporate the elements into the structural system of the building. Due to the type of partition we can obtain with them, we can distinguish:

4.3.1. Wall elements – which can be used to construct a fully-fledged external partition that meets all functions – support, control and aesthetics. The prefabs that belong to this category are highly diverse, both in terms of dimensions, geometry and structure. Due to the roles they can play, they are also cost-effective, which translates into their popularity, especially in countries where atmospheric conditions require casting or plasterwork to be limited.

Frank Lloyd Wright was a pioneer of this technology. Already in the 1920s, he developed the Textile Block System (Pfeiffer 2010). He used in it in the John Storer House, the Samuel Freeman House, and the Alice Miliard House. Despite the system's ingeniousness and exceptional aesthetic effects, it proved uneconomic and difficult to implement (Bigaj 2012). We can find projects that clearly reference Wright's works in contemporary architecture, both technologically and aesthetically (e.g., the Pentimento House, Tumbaco, Equador, 2006, designed by Jose María Sáez and David Barragán) (Gillin 2013).

4.3.2. Walls – these prefabs take on the form of full-storey walls. Panel and block technologies widely used in Poland in the second half of the twentieth century belonged to this type. At present, structural assemblies are popular primarily in Northern Europe. They typically consist of a support, control and finish layer (e.g., Hedorf's Residence Hall, Denmark 2009, designed by KHR Architekter Frederiksberg, Sprzeczna 4 apartment building, Warsaw, Poland, 2017, designed by BBGK Architekci, ill. 6).

4.3.3. Exoskeletons – have the form of an openwork, reinforced-concrete load-bearing structure behind which there is a partition that meets all project-specific requirements in terms of protection against external factors. These are not typical façade solutions. Architects design them specifically for a given project (Mika 2018). The exposed structural system becomes the façade's or even the entire building's dominant element. In this case, the form is determined by both aesthetic and static considerations. The possibility of hiding a building's true nature, as in the case of cladding or curtain walls, is limited to a minimum.

However, this solution comes with a range of benefits. Placing the structural system on the outside frees up the interior from any intermediate supports. It allows for full-storey glazing and prevents interior overheating – the structure acts as an envelope against solar rays. The places where uninsulated structural elements connect with decks remain problematic, as heat bridges form there.

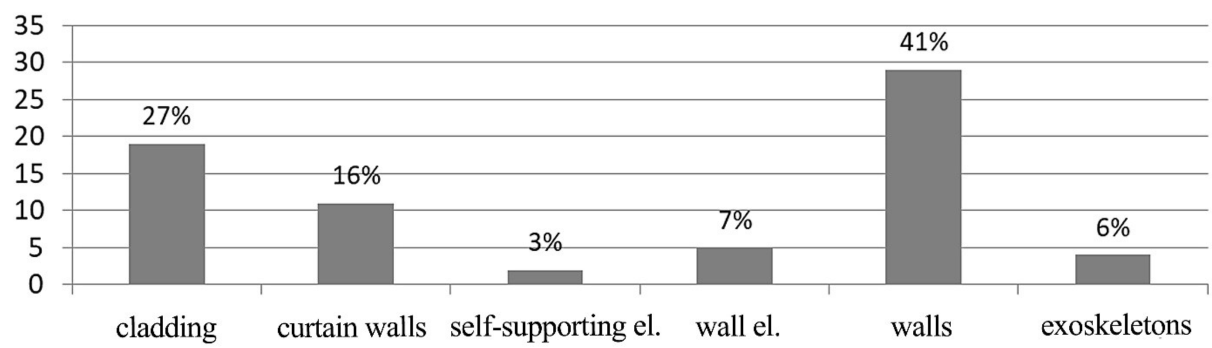
A sample project in which this technology was used is the Housing Complex with Offices (Paris, France, 2019, designed by Brenac & Gonzalez & Associés, moa architecture, ill. 7). In this case, the building's façades were finished with cladding prefabs from grey concrete, while in the upper section they took on the form of an external load-bearing structure made from white elements. The use of the technology was motivated by creating an interior without supports, which would be easily adaptable and offer a view of Paris's skyline (Pintos 2019).

5. Results

Among all of the investigated housing buildings, the most – 41% – had façades made from decorative concrete in the form of prefabricated load-bearing walls. In 27% of cases, the façades were finished with concrete cladding, 16% had curtain walls featuring concrete prefabs. In 7% of the cases, the external walls were made from wall elements, while the façades of 6% consisted of exoskeletons. Self-supporting walls were present in only 3% of the cases (ill. 8).

The highest number of buildings with prefabricated load-bearing walls was probably the result of this technology allowing for so-called full prefabrication – apart from the load-bearing layer, the wall element can have a thermal control layer, a concrete finish layer, and also come premade with windows, sills, internal plasterwork and utility ducts. This lowers the amount of on-site work and shortens project completion time.

Ill. 8. Percentage share of PFCEs used in contemporary housing construction (author: Mika P.)



According to Statistics Poland, in the case of panel technology (namely curtain or load-bearing walls), the average building construction time was around 22 months, while enhanced traditional technology offered a completion time that was almost twice as long.
The second-most often used PFCE technology were prefabricated cladding elements. They can be used with practically every structural material. They are perfectly suited for creating ventilated façades and their aesthetic design potential (shape, surface type, tectonics, colour, admixtures) are constantly expanded. The third-most popular technology were curtain walls, which also allow for full prefabrication, yet require a specifically designed load-bearing structure to carry the load of the façade due to their weight. Wall elements came fourth, yet all of the buildings that featured them were single-family houses. Their prefabricated façades had either the form of single-layer walls or wall assemblies with the thermal control layer located inside (so that the concrete could be exposed externally). These solutions are not used often, and when they are, the situations are quite specific, for instance in buildings located in warm climate zones. The greatest advantage of exoskeletons is its potential in terms of interior arrangement and the large spaces that do not have supports that can be created, which is not a priority in single- and multi-family housing. Such solutions are much more beneficial for office buildings, whose tenants often rearrange interior spaces. This is why projects with this structural system are rare. Self-supporting walls were found to be the least popular technology.

6. Conclusions

This study demonstrated that PFCEs have a wide range of applications in housing construction. Despite not being used often in Poland, there is potential for growth, especially in comparison to highly developed countries with similar climate conditions. Using PFCEs, we can build both non-load-bearing and load-bearing walls, which cover all of the currently available structural system types. Despite their overall significance in construction being on the rise, as proven by numerous buildings erected in recent years, their overall share in our country is still marginal.
Interest in PFCEs stems from both high energy savings, growing potential for creating complex structures and the quality of elements that play a key role in aesthetic façade design.
The analysis of project cases that featured concrete façade solutions, as presented in this study, demonstrated that these technologies can meet all requirements set before modern façades. This is both due to the material itself and the nearly complete freedom in the components' form and aesthetic design.
The prefabrication palette on offer, in terms of statics, structure and size, allows informed designers to move freely between desired aesthetic features while having the option of meeting other requirements set before external partitions.
Façade element prefabrication in architecture is justified if the choice to implement it is the consequence of a designer's aesthetic and compositional decisions. The form should not be the result of the application of technology.

BIBLIOGRAFIA / REFERENCES

[1] Abdrassilova G., Danibekova E., 2021. The transformation of modern architecture in Kazakhstan: from soviet "internationalism" to a post-soviet understanding of the regional identity. *Spatium*, no 46, 73-80.
[2] 2006. Apartment block in Basel. *Detail,* no 1-2.
[3] Bigaj P., 2012. Prefabricated technologies of Frank Lloyd Wright's concrete residences - textile block system. *Technical Transactions,* R. 109, Z. 29, 7-A, 3-23.
[4] Derkowski W., 2021. Precast concrete – a sustainable solution for construction sector. *Materiały Budowlane*, no 11, 9-11.
[5] Dębowski J., 2008. Determination issue of the technical usage degree in prefabricated concrete slabs. *Technical Transactions,* R. 104, Z. 9, 4-A, 27-34.
[6] Expressive and dynamic residence hall. *World Architecture News*, 27/10/2009, https://www.worldarchitecturenews.com/article/1503840/expressive-dynamic-residence-hall, (accessed: 16.01.23).
[7] Gillin J., 2013. Quito Parts. *Dwell* 12/01/2013, 99.
[8] Jiao L., Li X.D., 2018. Application of prefabricated concrete in residential buildings and its safety management. *Archives of Civil Engineering,* Vol. 64, no 2, 21-35.
[9] Kirschke P, Sietko D., 2021. The Function and Potential of Innovative Reinforced Concrete Prefabrication Technologies in Achieving Residential Construction Goals in Germany and Poland. *Buildings*, no 11.
[10] Krause C., 1974. *Prefabricated exterior walls*. Arkady, Warszawa.
[11] Logistikzentrum in Lyon. 2001, *Detail,* no 1.
[12] Lorenc M., Mazurek S., 2007. *To use a stone*, Studio JASA, Wrocław.
[13] Matos Castillo, https://www.matoscastillo.com/index.php?/proyectos/68-viviendas-en-rafael-finat/, (accessed: 09.11.22),
[14] Mika P., 2017. Concrete prefabricated elements in a sustainable residential, multi-family housing. *SGEM International Multidisciplinary Scientific GeoConference,* no17, 811-818.
[15] Mika P., 2018. *Exoskeleton – construction that defines the aesthetics of architecture,* in: *Technologie budowlane: konstrukcje i materiały.* red. W. Celadyn, S. Kuc, Wydawnictwo Politechniki Krakowskiej, Kraków, 61-75.
[16] Osmonova K., 2016. *Experiencing Liminality.Urban Identification, Renting, and Achieving Success among the Newcomers in Astana*, Kazakhstan, dissertation.
[17] Pintos P., *Two Towers at La Chapelle International / Brenac & Gonzalez & Associés + moa architecture*. https://www.archdaily.com/945002/two-towers-at-la-chapelle-international-brenac-and-gonzalez-and-associes-plus-moa-architecture, (accessed: 15.01.23).
[18] Pfeiffer B.B., 2010. *Frank Lloyd Wright 1917-1942. The Complete Works*, Taschen, Köln.
[19] Radziszewska-Zielina E., Gleń M., 2014. Studies of the Prefabricated Housing Construction Market in Poland. *Selected Scientific Papers: SSP: journal of civil engineering*, Vol. 9, No. 2, 25-26.
[20] Sherfudeen A., Kumar N., Raghavan N., Pillai R., Kalidindi S., 2016. Promoting precast concrete for affordable housing – An overview on promotional policies worldwide and challenges and possibilities in India. *The Indian Concrete Journal*, 05, 13-24.
[21] Slenderwall, https://slenderwall.com/news/press-releases/273-2013-design-award-pci-best-multi-family-housing-ets-student-housing-phase-iv-in-montreal-quebec, (accessed: 09.11.22).
[22] Statistics Poland, https://stat.gov.pl/ (accessed: 10.02.23)
[23] Wilson R., 2021. Building study: Bryant Hotel, New York, by David Chipperfield Architects. *Architects' Journal* 28. 04. 2021, https://www.architectsjournal.co.uk/buildings/building-study-bryant-hotel-new-york-by-david-chipperfield-architects, (accessed: 07.01.23).