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PROBLEMS OF EARLY LARGE PANEL STRUCTURES IN POLAND

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ABSTRACT

The first buildings composed of prefabricated elements appeared in Poland in the 1960s and large housing estates were constructed in this technology already in the 1970s. Rising housing demands had impact on the rapid development of factory-produced structures and the creation of a series of technologies, such as W_k-70, Wrocław Large Panel (WWP) or the Szczecin system (Sz-s). Over the years, several defects of this technology have surfaced on different levels of building erection or exploitation. Part of these flaws was related with the aesthetics of the structures, without influence in their construction, whereas others required fast actions for maintenance of safety to the residents. The paper presents an overview of the most important Polish systems of large panel structures, as well as the sources of defects and flaws that may appear in buildings constructed in this technology.

Key words: large panel technology, multifamily residential building, defects

INTRODUCTION

Following the military operations, migrations and resettlements caused by the Second World War, Poland lost a large number of its residential buildings. During the first years after the war, the basic housing requirements were appeased by refurbishment of old and building new constructions from salvage material derived from the demolition of even entire buildings. Often, the number of marriages several times exceeded the number of newly constructed flats. For example, in 1950–1955 about 400,000 flats were built, whereas the number of marriages contracted during this period was four times larger (Polak, 2002). In the 1970s and 1980s, an exceptional number of flats was erected, with the highest number, 283,600, in 1978 (Fig. 1). There was a strong need to fulfil such high demand by various types of housing programmes and a search for a technology allowing for a fast construction of a large number of buildings. An ideal solution, although not devoid of flaws, was the large panel technology. In 1950–2000, a total of 7.8 million flats with a total area of 489.36 km^2 was built in Poland.

Buildings made of prefabricated elements, known as large panel structures, can be found in almost every Polish city. The have become permanent architectural elements within old historical developments or comprise new housing estates. Prefabricates are elements produced beyond the construction site and then delivered and assembled on-site. One of the assets of such technology is significant reduction in construction time.

Over the years, the contribution of the construction technologies has changed. The large block technology (using up to 2.4 m wide elements) applied in the 1970s became less popular in favour of the large panel technology (Fig. 2).

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With regard to the types of large panel constructions, a number of systems have been developed in Poland. The most important ones include:
– groups of central open systems,
– groups of central closed systems,
– groups of closed regional (local) systems.

The groups of central open systems were based on unified catalogues containing large scale elements assembled in prefabricate series with a module multiple of 60 cm (Cholewicki & Gałkowski, 1979). This allowed for shaping various plans for flats, segments and buildings. This group includes systems W-70 and W_k-70.

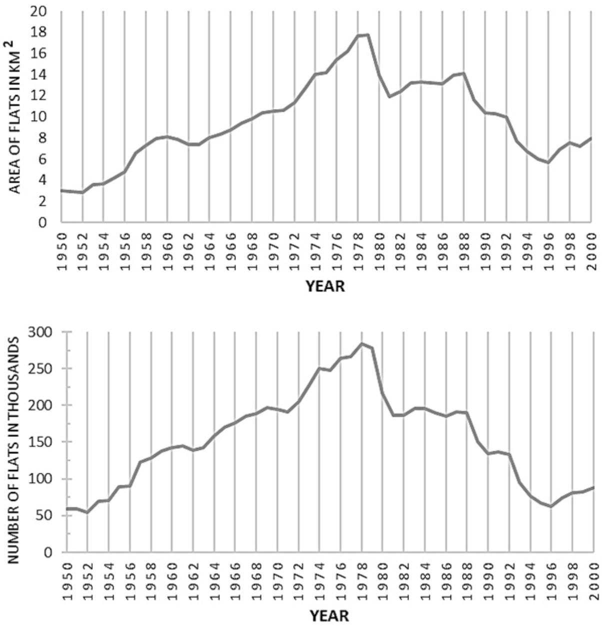

Fig. 1. Number and area of flats built in 1950–2000 (Statistical Yearbooks of the Republic of Poland, 1970–2000)

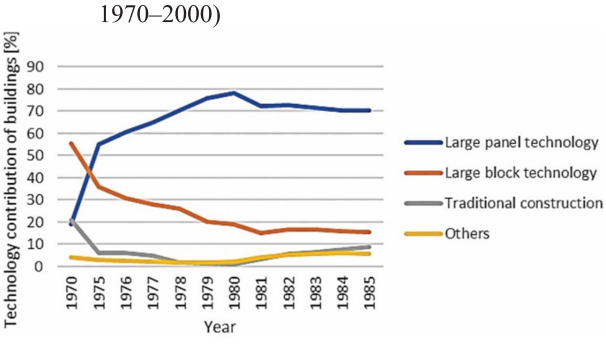

Fig. 2. Technology contribution of buildings erected in 1970–1985 (Statistical Yearbooks of the Republic of Poland, 1971–1986)

The group of closed central systems was characterised by a strictly determined location of the large panel elements. Its application resulted in a building, segment or flat with a repeatable restricted plan. Examples of this group are the OWT-67, OWT-67/N, OWT-75, WUF-T, WUF-T75 and Szczecin S-Sz systems.

Similarly, as in the group of closed central systems, the group of closed regional systems was restricted to a repeatable solution, with an additional restriction of using a given solution in a particular region. This group includes: the Wrocław Large Panel (WWP), RBM-75, Dąbrowe ŁSM (Łódź), Częstochowa Large Panel (CzWP) and Rzeszów Large Panel (RzWP).

RESIDENTIAL PREFABRICATION IN 1970–1985

In 1970–1985, a total of 1,471,800 buildings with a total usable area of 77,200 m^2 and cubic capacity of 351,700 was erected. 80% of the residential buildings were constructed in central systems, whereas the remaining 20% were erected in regional systems. The contribution in the number of erected buildings in particular systems during this interval is presented in Figure 3.

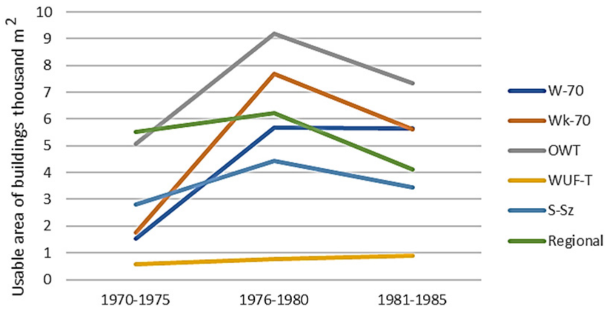

Fig. 3. Usable area of buildings erected in 1970–1985 in different systems (Dzierżewicz & Starosolski, 2010)

Beside specific features of each system, the designers had to take into account the restrictions resulting from the provisions determining the room and flat area, i.e. the design technical standards (Polish acronym NTP, which stands for *normatyw technicznego projektowania*). Comparative lists of standard areas are presented in Tables 1 and 2 (Korzeniewski, 2011).

Table 1. Minimal requirements for particular rooms in multifamily buildings according to examples of design technical standards (Korzeniewski, 2011)

The name of the space or functional object	NTP-1959	NTP-1974
Living room	16 m^2	18 m^2
Two-person room	9 m^2	11 m^2
Single room	6 m^2	8 m^2
Kitchen	4.5 m^2	6 m^2
Bathroom	3.2 m^2	3.2 m^2
Toilet	0.8 × 1.1 m	0.9 × 1.1 m
Built-in wardrobes	0.54 m^2 per person	0.7 m^2 per person
Hall	as a result within the area of the flat	as a result within the area of the flat

Table 2. List of changes of flat area in multifamily buildings for non-farming residents in Poland determined by design technical standards (Korzeniewski, 2011)

Housing category corresponding to the number of inhabitants	NTP--1959	NTP--1974	PR-5 (1978)	NTP-1974 (change from 1982)
M-1	17–20	25–28	not established	to 30
M-2	24–30	30–36	to 42	to 44
M-3	33–38	44–52	to 62	to 56
M-4	42–48	56–63	to 72	to 65
M-5	51–57	65–73	to 82	to 75
M-6	59–65	75–85	to 92	to 85

RESIDENTIAL PREFABRICATION IN 1970–1985

The building structure is the system of the construction walls of floors and foundations, whose task is to transform load and counteract against external forces according with the intended use of the building. The construction walls transform the dead load, and the horizontal and vertical loads from other elements of the building. They include: load-bearing walls (transformation of vertical load from floors and walls of the upper storeys), self-supporting walls (transformation of load from walls of the upper storeys) and rigidifying walls (playing a rigidifying role).

One of the main subdivisions of prefabricated buildings is based on the type of construction that transforms loads from floors and walls. They include buildings:

- with load-bearing walls,
- with a framework,
- composed of multispace prefabricates.

The largest group comprises buildings with a construction composed of load-bearing walls. Depending on their location with regard to the horizontal axis of the building, they include the:

- longitudinal pattern (Fig. 4a),
- crossing pattern (Fig. 4b),
- transverse pattern (Fig. 4c).

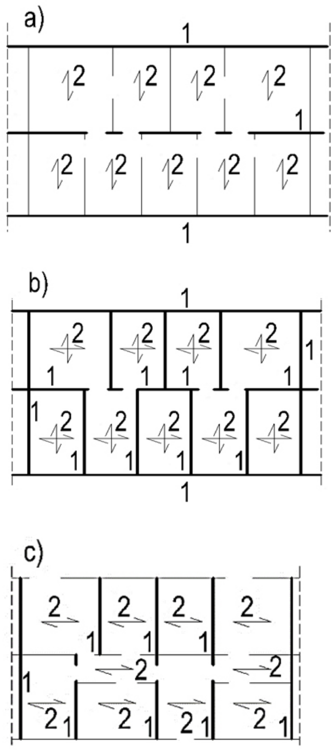

Fig. 4. Construction patterns of buildings with load-bearing walls: a – longitudinal; b – crossing; c – transverse (1 – load-bearing walls, 2 – direction of floor span)

In the longitudinal pattern the load-bearing walls are located parallel to the building axis. In the transverse pattern, they are located perpendicular to the building axis, whereas in the crossing pattern, the load-bearing walls are located in both directions.

The OWT-67 system was elaborated in 1967, and based on systems OW-700 and OW-1700K. It was characterised by enhanced functionality and increased industrialisation of the construction process. In subsequent years, various modifications were introduced in order to customise the system to design technical standards and adapt it for agriculture (RBM-75). OWT-67 belongs to closed central systems. It was based on repeatable elements with a determined number of prefabricate size groups. The gross storey height was 270 cm, and the spacing of transverse construction walls was 270 and 540 cm. The underground part was made as a monolith; buildings with up to 5 storeys had a precast floor, whereas medium high buildings – a monolithic floor. Floor slabs were full, made of reinforced concrete with a crossing reinforcement, assembled on three ledges with the fourth one prepared for the monolithic joints. In 1975 a solution marked as OWT-75 was prepared. It had a series of modifications, such as increased thickness of the load-bearing walls from 14 to 15 cm, increased floor thickness from 15 to 16 cm, increased thickness of the thermal isolation layer and elevation fabric layer to 6 cm, a new method of interconnecting the prefabricated elements, as well as new elements such as sanitary blocks and interwindow pillars. An important change was introduction of compulsory mounting on rectifying screws (Fig. 5).

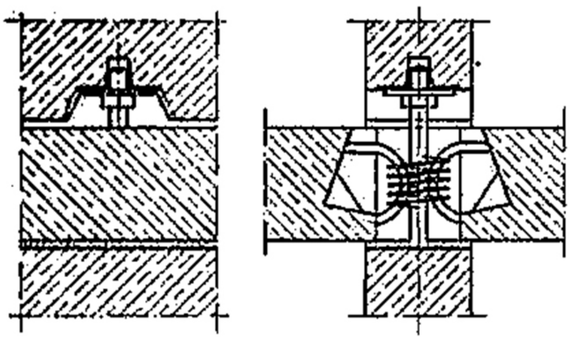

Fig. 5. Connection of the OWT-75 system with a rectification screw (Thierry & Zaleski, 1982)

The system known as the Warsaw Universal Form (WUF-T) was created in 1967. The first buildings in this technology were erected in 1968–1970 in Warsaw. In subsequent years, modifications of this system were introduced: WUF-T/75 (version adjusted to the standard from 1975) and WUF-T/K (Cracow version introducing construction modifications). The entire group of WUF systems represents a closed central group, therefore they were used in the entire country. The floor slabs were mounted on two, three or all ledges (Thierry & Zaleski, 1982). Construction stability during the assembly of connections between the prefabricated elements was maintained by welding.

In 1968 a national competition was opened for working out a construction-assembly system, which would become the leading one for the contemporary building industry. The open W-70 system, worked out by Maria and Kazimierz Piechotka, was selected. Due to the clever assumptions and a modular 60 × 60 cm grid, it became one of the most popular systems of large panel construction in Poland. The system included a catalogue of prefabricated elements, construction joints and knots, and examples of their application. System W-70 was characterised by four spans, from 2.4 to 6.0 m, with a 1.2 m spacing. Reinforced concrete load-bearing walls were constructed as elements with a thickness of 15 cm and duct floor slabs had a thickness of 22 cm.

A particular variety of system W-70 is the W_k-70 system elaborated in 1972–1973. It maintains all basic assumptions, with differences in solutions and dimensions of particular elements and edge finish. The duct floor slabs were replaced by full floor slabs with a thickness of 16 cm. The assembly of the floor slabs on the transverse walls and the mounting of exterior and interior walls are modified in this system.

The Szczecin system (S-Sz) was worked out as a closed central system in 1968–1969. It was based on two main spans of 2.4 and 4.8 m. Corridor buildings had an additional span of 1.55 m. The bay depth was 4.8 m and 5.4 m, and the gross storey height was 2.8 m. Similarly, as in the case of the systems discussed above, over the years the solutions accepted for S-Sz were adjusted to operating norms and standards. The constructed flats (from M1 to M6) were based on a grid of 240 × 480 cm and 480 × 480 cm. The basic construction system was transverse, in some cases with a longitudinal system. The catalogue of

49 basic segments and sections allowed to adapt the buildings to requirements in different parts of the country. Reinforced concrete load-bearing interior walls had a thickness of 15 cm and full floor slabs had a thickness of 14 cm.

An example of a closed regional system is the Wrocław Large Panel (WLP) elaborated in 1966–1968. In 1975 it became adapted to the requirements of DTS-74, and in 1983–1985 the exterior walls were modified (Dzierżewicz & Starosolski, 2010) to conform with Polish standard PN-B-02020 (Polski Komitet Normalizacyjny [PKN], 1982). The basis of this system are repeatable segments allowing to raise five and eleven storey buildings on modular grids at 120 × 540 cm, 270 × 540 cm or 270 × 540 cm in size. The bay depth was 5.4 m and the gross storey height was 2.7 m. The thickness of exterior walls with isolation depended on their location in the building and reached 16, 17–19, 21, 22 or 28 cm (Dzierżewicz & Starosolski, 2010). The load-bearing walls, interior walls and reinforced concrete floor slabs were planned at a thickness of 14 cm. High precision of the construction was achieved by application of rectifying screws during the mounting.

DEFECTS, FLAWS, DETERIORATION

Over time, the building loses its primary usable value, whose diminishing may be analysed with regard to technical and moral (functional) issues. The insufficient dimensions of flats or rooms, their functional pattern, dimensions of window openings, corridor width, and technical solutions become unsatisfying with time to fulfil the permanently rising expectations of the residents.

Moral deterioration of a building cannot be stopped or reversed by refurbishment or components exchange; the only solution is to upgrade the object. It should be remembered, however, that objects erected with application of industrial methods are poorly susceptible to upgrade due to their specific construction. This is a general feature of all systems, regardless the time of their development (Ligęza, 2015a, 2015b).

All buildings are subject to gradual and natural degradation, and the particular elements undergo deterioration. The degree of usable value loss depends on the degree of technical deterioration and negligence during design, construction or at current maintenance. Technical deterioration may be decreased by repair or exchange of the destroyed elements. It should be analysed as a function of deterioration of the construction and finish elements, building equipment and installations (Wierzbicki & Sieczkowski, 2013).

The applied materials, production method, types of interconnections, geometry and dimensions of the elements cause that buildings in the large plate technology have several features distinguishing them from traditionally erected buildings. Beside typical problems that may arise during construction and exploitation, buildings made of prefabricated elements have flaws and damages resulting from the specific characteristics of such buildings (Fig. 6).

Flaws created during the design stage were mainly related to the poor knowledge of guidelines governing the design of buildings in such technology. Erection of buildings in traditional technologies allows to lose

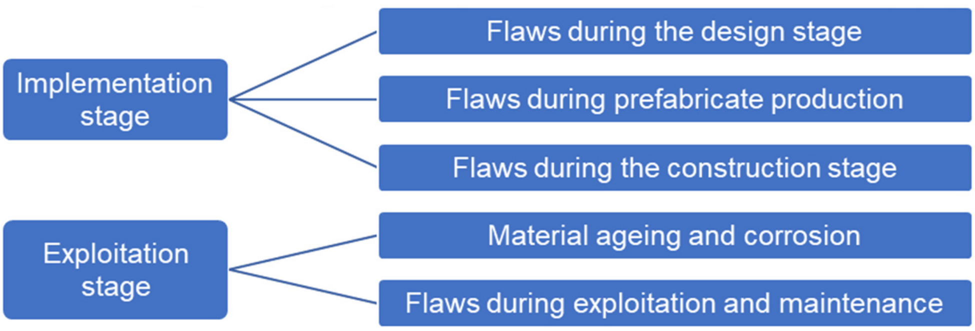

Fig. 6. Causes and types of damage in buildings erected by industrial methods (Thierry & Zaleski, 1982)

dimension deficiencies during bricklaying and mortar levelling of subsequent layers. In the large plate technology, however, it became indispensable to set the admissible tolerance of prefabricate dimensions and tolerance of their erection. This influences for example backlash in nodes and welds, depth of floor slab support, correct assembly of prefabricated elements and in consequence quality of the resulting interconnections. The backlash value depended on the type of connection adopted by the designer, material parameters of the elements and conditions indispensable for making the connection. Large plate technology allows for fast erection of buildings, but requires observing regulations enforced in the design by all participants of the erection process. Errors may be caused at various stages of the construction, which may be difficult or even impossible to eliminate during further actions. Therefore, determining the admissible tolerances at particular stages is very important. These tolerances refer to: establishing the measurement base, determining the axes of the construction elements, transfer of measurement points between the elements, levelling and plumbing of the assembled elements. There was almost no construction experience in the beginning of existence of the large plate technology. Thus, designers adopted weld dimensions based on theoretical assumptions, whereas the contractors were not always possible to make them according to the assumed method. Larger material deterioration and improper assembly cased the development of a series of flaws with impact on the technical and usable value of the erected buildings. A large problem is the selection of inappropriate materials. Lack of knowledge on the material parameters and difficulties in their accessibility coupled with incorrect design solutions caused water penetration, freezing of the diaphragms, corrosion and in consequence damage of the building elements.

A series of negligence at various levels took place during production and transportation of the prefabricated elements: material flaws, poor quality of the produced elements, damage during storage and transportation. The reasons of decreased concrete quality include low quality of the applied aggregate, application of various aggregate fractions and humidity, application of incorrect recipes and addition of water for better workability.

A correct vibration stage allows to remove air and gases formed during the reaction of the components and correct coverage of the reinforcement by the concrete mixture. An adequate production regime was often not complied with during the process. The stage of concrete concentration was imprecise or completely omitted.

Part of the used forms was supple which caused deformation of the prefabricates, thus disqualifying their further usage. Problems that appeared during element formation include: poor quality of forms and their locks, insufficient stiffness and high degree of deterioration of the metal elements. Overlap of several of these factors caused the occurrence of high dimension deviations and shape errors. An attempt of assembling such elements caused numerous problems to the contractors and resulted in the generation of further discrepancies in the relation to the initial design (Thierry & Zaleski, 1982).

Lack of material caused that on-site pickup of transports was restricted only to checking the exact number of the supplied elements without control of their quality.

Large panel technology induced the need of gaining new knowledge among the persons linked with construction business. The existing method of production, mounting and control was completely different from that required by the new technology. Due to lack of experience, numerous flaws took place in the beginning, with their frequency rising proportionally to the number of contractors with low qualifications. There was a lack of contractors that could verify correct interconnections in the nodes, quality of weld infilling or assembly precision. Although the design projects assumed an axial assembly of the prefabricated elements, quite frequently they were mounted in accordance with the margins. In a complete building the displacements from the correct position were up to 10 cm vertically, up to 20 cm horizontally, up to 6 cm inclined from the vertical within a single storey, and up to 7.5 cm displacement of load-bearing walls between the storeys (Thierry & Zaleski, 1982). Such flaws led to further problems related with incorrect geometry of the welds and incorrect node shaping, which contributed to construction safety decrease.

A common problem was the imprecise execution of flashing. Water penetrated into different parts of the construction causing corrosion and decreasing the isolation properties of the exterior diaphragms.

Fast development of housing imposed the need to work out new material solutions. Because some of them have not been precisely tested yet at that time, flaws caused by improper selection appeared over the years. Irrelevant solutions include application of an excessively thin layer of foam glass and sealing of welds with tarred rope (Thierry & Zaleski, 1982).

Worth mentioning is also the correct exploitation and maintenance of the building. Small defects that are not removed on time may cause the development of larger damage. Neglecting increasing problems with ventilation may cause the appearance of mildew and fungus.

Beside the causes mentioned above, worth mentioning are sources of defects that may appear in all types of building constructions:
- aggressive impact of the external environment,
- impact of natural disasters,
- occurrence of construction disasters,
- humidity and water impact on the construction,
- shocks and vibrations,
- soil and foundation subsidence,
- influence of temperature and material shrinkage.

PROBLEMS OF LARGE PANEL CONSTRUCTIONS AFTER LONG-TERM EXPLOITATION

The large contribution of large panel constructions in the housing resources of Poland, their variable technical condition, changing norms and regulations, as well as growing concern in the safety of such buildings have caused rapid increase of publications focused on these issues (Sobczak-Piąstka & Podhorecki, 2015).

All buildings are subject to technical deterioration during their exploitation. For a correct assessment of such deterioration, it important to use methods giving unambiguous results. Dębowski (2007) presented several methods of determining deterioration, including assessment of buildings erected from prefabricated elements. The report contains an analysis based on the assessment of defects in 223 buildings. It has been shown that most of the applied methods are used to assess traditional constructions and because of their specific properties cannot be used in the case of buildings made from prefabricated elements.

Following the long-term experience of the Building Research Institute (Instytut Techniki Budowlanej) in the diagnosis of large panel buildings, Szulc (2017) presented the results of studies on the interconnections in such constructions. The possibility of using modern scanning techniques to assess the correct implementation of such elements was also discussed.

Defects of various types of fastening elements are a major problem. Due to material deficiencies resulting in the application of joints made of improper kinds of steel in large panel constructions from the 1960s−1980s, a problem appeared with the durability of curtain walls (Wójtowicz, 2016).

Changing norms, standards and expectations of the residents have caused that large panel buildings no longer meet these demands. Therefore, studies are conducted (Szulc, 2018) to determine the technical possibilities of upgrading large panel buildings.

Development of computer modelling and numerical optimization allows for their application also in construction. Thanks to these methods it is possible to model the construction interconnections and analyse their behaviour in different strain conditions (Górski & Szulc, 2019).

New construction technologies allow to improve the safety and with time even prevent construction failures. Measurements of deviation, vibrations, shifting and loading of the construction made with application of remote sensors allow to react in cases when the boundary conditions are exceeded. Sivasuriyan et al. (2021) discussed the possibilities of monitoring the state of the building construction using static, dynamic and finite elements methods in order to detect and predict construction damage. Various types of sensors are used to monitor the construction state: fibre optic, piezoelectric, temperature sensors and accelerometers. This allows to monitor various types of buildings, including multi-storey, commercial and monumental constructions.

Guo et al. (2019) analysed the operation of a construction interconnection between prefabricated elements used in low-rise buildings. The presented results were obtained from experiments and numerical analyses. Based on them, a numerical calculation model for a three-storey construction, tested with regard to earthquake resistance, was prepared.

Resistance analysis of prefabricated elements was also presented by Chu, Xiong, Liu and Sun (2021). Five types of reinforcing walls were tested: one wall pre-casted on-site, one wall without vertical interconnections, and three walls with vertical connections. Based on the results obtained from experiments and numerical calculations, the optimal solutions for seismic areas were indicated. According to the results, the numerical model may be a good tool for simulating the proposed system of reinforcing walls.

RECAPITULATION

The paper presents an overview and characteristics of Polish residential housing erected in the large panel technology in 1970–1985. Large housing demands in Poland were catalysers of the development of industrial housing. A series of systems were established, of which part after modifications are used till present.

Defects appearing at different stages of the investment process and during the building exploitation may significantly influence residential comfort. Some of them may be very simply eliminated whereas others require extensive upgrade.

Several studies and analyses conducted recently with regard to the quality and safety of large panel constructions unequivocally indicate that a large part of the existing buildings are in a condition allowing for their long-term exploitation.

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PROBLEMY WCZESNEGO BUDOWNICTWA WIELKOPŁYTOWEGO W POLSCE

STRESZCZENIE

Pierwsze budynki z elementów prefabrykowanych powstały w Polsce w latach 60. XX wieku a już w latach 70. budowano w tej technologii całe osiedla. Duże zapotrzebowanie na mieszkania przyczyniło się do gwałtownego rozwoju budownictwa uprzemysłowionego i powstania wielu systemów, takich jak: Wk-70, wrocławska wielka płyta (WWP) czy tzw. szczeciński (Sz-s). Systemy wielkopłytowe stanowią duży udział w polskim budownictwie mieszkaniowym. Na przestrzeni lat ujawniały się wady mające źródło na różnych etapach realizacji i użytkowania budynku. Część z nich dotyczyła wrażeń estetycznych bez wpływu na konstrukcję budynku, a inne wymagały podjęcia radykalnych działań w celu zapewnienia bezpieczeństwa użytkownikom. W artykule przedstawiono przegląd najważniejszych polskich systemów budownictwa wielkopłytowego oraz źródła wad i usterek mogących pojawiać się w budynkach wznoszonych w tej technologii.

Słowa kluczowe: wielka płyta, budynek mieszkalny wielorodzinny, wady