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## **PREFABRICATION OF BUILDING SERVICES**

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### **Abstract**

It is anticipated that prefabrication in construction industry will grow in popularity on a global scale in the near future. Analyzing specificity of the Polish market it can be predicted that the growth will be the most noticeable in residential and commercial buildings segments. Several studies have documented numerous benefits of prefabrication compared to traditional building methods. These include significant cost and time savings, enhanced productivity, increased quality of products and works, finally better environmental performance and reduced waste. The technology is gaining popularity not only in architecture and construction sectors, but as well in closely related fields, in particular building services. The paper presents proven applications of prefabrication in building services: prefabrication of repeatable building elements (horizontal pipes/ducts distribution, prefabricated wall modules and other), prefabrication of risers and shafts, prefabrication of technical rooms, modular bathrooms and toilets, finally preassembled or modular buildings including installed services. The shift from traditional construction methods to prefabrication requires significant changes in the construction process: design specific to off-site manufacturing, including BIM utilization, dedicated procurement and tendering strategy, well managed construction logistics, trainings of the staff to ensure proper education level. It is needed as well to overcome negative attitude towards prefabrication among the construction process participants, which may be quite often encountered according to the literature. This requires increasing the awareness of the prefabrication benefits and teaching all parties involved that prefabrication methodology is consistent with lean production principles – it efficiently reduces all types of waste, especially related to time, cost and material.

## 1. Introduction

Prefabrication is a construction technology, in which building elements are manufactured in a factory and afterwards are transported in whole or in parts into construction site, where they are connected. Above meaning can be found in the very word prefabrication, "pre" means the initial or earlier occurrence of something, whereas "fabrication" means production. Prefabrication is therefore a process of earlier production of elements that, after assembly, give a ready product, in this case a building structure<sup>1</sup>.

According to Technavio report prefabrication is one of the most widely used modern methods of construction on the globe. Specialist estimate, that worldwide prefabricated construction market will increase at a compound annual growth rate of around 6,6% between 2016 and 2020<sup>2</sup>. What is more, off-site manufacturing is in the centre of modern methods of construction (MMC) idea, which considers improvements in the construction technology aimed at reducing time, cost and waste of the process. APAC region is dominating prefabrication market globally due to dynamically urbanized economies like China, India or Indonesia and Europe is considered as the second market worldwide. Two European regions shall be mentioned here for their impact in the off-site technology growth, namely Great Britain and Scandinavia. Great Britain was developing prefabrication strategy already in XVII century, when building its colonial power and since then played invaluable role in the technical development of the method. Scandinavia, on the other hand, should be distinguished for the use of prefabrication of wooden elements. In Poland prefabrication used to be commonly associated with the so-called "large slab", a technology used widely in housing construction up to the '90s of the last century. In social consciousness appeared kind of stigmatization of the method - it became a synonymous of extensive blocks areas, monotonous architecture and relatively low quality of workmanship. Poland was not isolated in these views - Australian publication<sup>3</sup> lists negative perception of prefabricated housing and

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<sup>1</sup> Adamczewski, G. and Nicał, A., 2012. *Wielkowieściowe prefabrykowane elementy z betonu*. Inżynier budownictwa, 3, pp.46-53.

<sup>2</sup> Smith, R.E., 2009, May. History of prefabrication: A cultural survey. In *Third International Congress on Construction History*.

<sup>3</sup> Steinhardt, D.A., Manley, K. and Miller, W., 2013. Reshaping housing: the role of prefabricated systems.

associations with provisional, temporary structures as one of the main factors ceasing the technology development. In recent years, however, can be noticed increasing interest in prefabricated technologies and at the same time a change in the way of perceiving prefabrication technology. In Poland, prefabrication is already commonly used in public, infrastructure and industrial construction<sup>4</sup>.

A spectacular example of public investments was number of stadiums built for the football championships in 2012. Prefabricates are broadly utilised in the construction of multi-storey car parking, in factory and warehouse halls construction, and for infrastructural use in the construction of bridges, footbridges or underground passages. While in mentioned sectors has been noticed increased usage of prefabrication in recent years, in housing segment the trend is opposite, which can be described as a specific feature of the Polish market<sup>5</sup>. On the contrary, in Scandinavia, prefabrication is used mainly in multi-family and office housing and is utilised in round 80% of all facilities in this sector<sup>6</sup>. Analysing the trends in prefabrication usage in Europe and taking into account the forecasted global incensement in technology implementation, it can be expected that in upcoming years in Poland will be noticed not only increased share of prefabrication in the construction segment in general, but that the tendency to use prefabricated elements will be especially noticeable in the residential and office sectors. The housing market will be most likely driven also by the government program, “Mieszkanie Plus”, which is based on cheap construction using prefabricated solutions.

## 2. Prefabrication and sanitary installations

Sanitary installations in buildings historically have origin in equipping particular buildings with imprecisely defined structure and form with the necessary installation elements. Such systems were created at the construction site and the implementation of prefabrication in case of

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<sup>4</sup> Szmigiera, E.D. and Woyciechowski, P.P., 2004. Niekonwencjonalne rozwiązania w prefabrykacji elementów z betonu. In *Konferencja Dni Betonu. Tradycja i nowoczesność*. Polski Cement.

<sup>5</sup> Adamczewski, G. and Nicał, A., op. cit.

<sup>6</sup> Adamczewski, G. and Woyciechowski, P.P., 2014. *Wielkowymiarowe elementy prefabrykowane stosowane w budownictwie infrastrukturalnym*. Inżynier Budownictwa: miesięcznik Polskiej Izby Inżynierów Budownictwa., (4).

many unknowns in the building structure, would be impractical and basically impossible to carry through<sup>7</sup>. However, along with the technical development and improvement of the design process, already since World War II, several times appeared attempts to implement prefabricated sanitary installations in construction<sup>8</sup>. According to the British publication, the peak of prefabrication popularity took place in the 1960s, when the construction industry focused on industrial construction. Most of the contractors at that time had specialized teams that assembled system's parts on the construction site before the final installation in the building structure. The fact of prior connection of selected elements before entering the building can be considered as the beginning of prefabrication in its present meaning. Next period of interest in prefabrication can be dated to the '90s, when many buildings with repeatable technologies, such as supermarkets, appeared on the market. Investors were trying to find a way to optimize the construction process, and in parallel were established number of subcontractor companies offering prefabrication services. Repeatability of installation systems is often mentioned in the literature as one of the main factors driving the prefabrication technology, but it should be emphasized that without the development of design techniques, especially without defining the building's architecture and construction structure at a relatively early stage of investment, introduction of prefabrication in building services would be impractical and inefficient<sup>9</sup>.

### 2.1 Benefits of implementing prefabrication in building services

Global interest in prefabrication, also in the building services sector, which can be observed in recent years is connected with numerous benefits to all participants of the investment process. The main benefits of precast technology are listed below:

- price - one of the most fundamental advantages is the financial economy of the technology. Financial savings are usually at least in 10% range compared to traditional technology, although in the literature can be

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<sup>7</sup> Dwyer, T., 2016. *Module 102: Offsite manufacture for building services*. CIBSE Journal. [online] Available at <https://www.cibsejournal.com/cpd/modules/2016-11-mod/> [Accessed 29.12.2017]

<sup>8</sup> Marsh, C., 2003. *Building services procurement*. Routledge. p.82-84.

<sup>9</sup> Dwyer, Y., op. cit.

found estimates of cost reduction even up to 50%<sup>101112</sup>. Financial savings are basically a result of all advantages of the method mentioned next. Especially worth mentioning is the labor cost, which, depending on the market's origin, ranges from 30% up to 50-60% of the total installation costs<sup>1314</sup>, thus significant acceleration of the installation process leads directly to measurable cost reductions. What is more, part of the labor moves from the construction site to the factories and working in stable factory conditions is considered to be not only more efficient, but also cheaper. In addition a British report<sup>15</sup> can be quoted, showing that up to 40% of working hours on a construction site is wasted,

- execution time - prefabrication technology significantly limits the installation's execution time. Estimates in the literature states that the installation time is limited by up to 30% -75% compared to traditional technology<sup>161718</sup>. Shortening time of completion to a large extent is a result of transferring of a large part of the works to the factory, which can be carried out simultaneously with the construction site works. Important is also reduction of errors at the execution stage, elimination of failures and re-works, which is the effect of a carefully planned design and production process in the factory. A spectacular example of the dynamics of prefabricated building construction is the construction of a hotel in

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<sup>10</sup> Fraser N., Race G.L., Kelly R., Winstanley A., Hancock P., 2015. *An Offsite Guide for the Building and Engineering Services Sector*, The Building and Services Association.

<sup>11</sup> Jacobson M., Stannus W., Stavroulakis N., 2014. *Fabricating the future*, Ecolibrium, p.32-42.

<sup>12</sup> Wilson, D.G., 1998. *Prefabrication and preassembly: Applying the techniques to building engineering services*. BSRIA.

<sup>13</sup> Hui, S.C. and Or, G.K., 2005, July. Study of prefabricated building services components for residential buildings in Hong Kong. In *Hubei-Hong Kong Joint Symp.*

<sup>14</sup> Pasquire, C., Gibb, A. and Bower, D., 2005. 'Lean' as an Antidote to Labour Cost Escalation on Complex Mechanical and Electrical Projects. In *13th International Group for Lean Construction Conference: Proceedings* (p. 3). International Group on Lean Construction.

<sup>15</sup> Egan, J., 1998. *Rethinking construction: report of the construction task force on the scope for improving the quality and efficiency of UK construction*. Department of the Environment, Transport and the Regions, London.

<sup>16</sup> Fraser N., Race G.L., Kelly R., Winstanley A., Hancock P., op. cit.

<sup>17</sup> Jacobson M., Stannus W., Stavroulakis N., op. cit.

<sup>18</sup> Wilson, D.G., op. cit.

China - a building with 30 floors (16.700m<sup>2</sup>) was built out of prefabricated elements in 360 hours (15 days)<sup>19</sup>,

- product quality - the effect of transferring a large part of works to the factory is as well the assurance of a sufficiently high quality of the product by working in a controlled and basically unchanged internal environment. What is more, it is possible to properly check and the quality of the products before the elements are being transported to the construction site,

- improvement of construction management - optimization of the construction process is related to a lower number of workers at the construction site, reduction of stored materials and precise delivery schedules of ready-made elements from the factory. Because of frequent deliveries of large-size elements, it is needed to strictly keep to construction schedules and activities plans, including the use of cranes and specialist equipment. Specific construction logistics is one of the main challenges in the prefabrication implementation, but at the same time creates a very effective rigor of the process. This may be confirmed by a the report<sup>20</sup> according to which only 34% of construction projects carried out in a traditional way are handed over according to the schedule, and 61% according to the assumed budget. In contrast, one of the main general contractors on the market claims that 97% of its construction sites using prefabrication fulfill the time and financial frames.

Related aspect is the increase of works safety - transfer of a significant part of works to stable environment of factories significantly improves accident statistics of the whole process,

- compactness of prefabricated solutions - extremely efficient use of available space in buildings is associated with the implementation of multi-branch cooperation at an early investment stage, careful planning of details and the use of advanced BIM or at least 3D tools. Prefabrication is often used when dealing with complicated parts of the installations, for example machine rooms, for their equipment and the distribution of pipes or ducts. Precise planning of all elements at the production stage in the factory allows, according to some manufacturers, to save as much as 40%

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<sup>19</sup> Myers, D., 2016. *Construction economics: A new approach*. Taylor & Francis.

<sup>20</sup> Fraser N., Race G.L., Kelly R., Winstanley A., Hancock P., op. cit.

-60% of the space for technical rooms<sup>21</sup>. Savings are also associated with a lower usage of materials,

- environmental impact - prefabrication is considered to be cleaner technology compared to traditional building methods. To a large extent it is a consequence of construction waste reduction by the precise design of particular elements and the transfer of a significant part of production to a controlled factory environment. The activity of equipment on the construction site is also significantly reduced, what is more it is possible to limit by as much as 60%<sup>22</sup> the movement of trucks transporting components to the construction site - one truck with ready prefabricated elements can be equivalent to 38 trucks delivering components in traditional technology. As a result, impact of construction on the environment, noise emission and pollution production is significantly limited.

## 2.2 BIM

Properly prepared project documentation is one of the key elements enabling the proper implementation of prefabricated technology. Projects must be legible, transparent and provide an appropriate level of detail allowing production of elements in factory conditions. Virtual model of physical building components which is possible to obtain in BIM technology fits perfectly into the above requirements<sup>23</sup>. Some authors explicitly claim that in order to introduce prefabrication into the investment process, two basic elements must be provided: the use of BIM technology to create project documentation and the necessary optimization of the production process and product orders<sup>24</sup>. In the construction process using prefabrication, the emphasis on high-quality design is much greater than in the case of traditional technology. There is no room for lack of precision, uncoordinated elements and potential

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<sup>21</sup> Moduls, 2017. *Prefabricated Machine Room, Efficiency to real estate construction by enhancing machine room building*. [online] Available at [http://www.moduls.fi/365\\_upload/content\\_images/files/Moduls%20presentation%20EN-G-HR.pdf](http://www.moduls.fi/365_upload/content_images/files/Moduls%20presentation%20EN-G-HR.pdf) [Accessed 30.12.2017]

<sup>22</sup> Fraser N., Race G.L., Kelly R., Winstanley A., Hancock P., op. cit.

<sup>23</sup> Samarasinghe, T., Mendis, P., Ngo, T. and Fernando, W.J.B.S., 2015. BIM Software Framework for Prefabricated Construction: Case Study Demonstrating BIM Implementation on a Modular House. In *6th International Conference On Structural Engineering And Construction Management* (pp. 154-162).

<sup>24</sup> Dwyer, T., op. cit.

collisions - it would be too time-consuming and expensive to rebuild products in the factory.

BIM technology is used for prefabrication in the following aspects:

- building a 3D model that visualizes all the elements of the installation,
- ensuring that the model elements are of necessary accuracy and all needed information about them are stored in - impossible to obtain in 2D / CAD technology,
- multi-branch coordination – within one model it is possible to coordinate architecture, construction and building services branches. Collaboration and introduction of multi-branch designers at the early stage of the project is recommended for both investments in the traditional way and using prefabrication. In this case, however, multidisciplinary working is crucial and basically enforced by the necessity to produce elements for particular branches in advance of the construction process itself,
- generating material specifications,
- input for the production of prefabricated elements in the factory - before the start of a factory production it is needed to prepare accurate enough model of elements being the subject of production. Most often BIM models from the designers need to be remodeled according to factory specifics, but still create a solid base for future work,
- streamlining the logistics of the construction site – BIM can lead the project plan and create visualizations of elements deliveries and installation, including crane operations and tracing the modules routes through the facility to their final destination.

It should be also mentioned that BIM standards for precast technology are being dynamically developed. The standards for BIM models used in the prefabrication field shall determine necessary information to be included in the model and ways of communication between participants of the investment process in order to efficiently exchange data on the model<sup>25</sup>.

### 2.3 Lean construction

The concept of lean management, sometimes called "slim management" in Poland, was developed in the 90s of the last century based on the

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<sup>25</sup> Nawari, N.O., 2012. BIM standard in off-site construction. *Journal of Architectural Engineering*, 18(2), pp.107-113.



production management system of the Toyota concern. The approach is a set of practices, tools and organizational solutions which primary task is to reduce production costs by eliminating activities not adding any value to the entire process, referred to in Japanese as "muda", or waste<sup>26</sup>. Numerous lean concept principles can be found in the construction industry and the idea of prefabrication:

- searching for a way to maximize production efficiency, which can be considered as the basic commonality of both ideas,
- reduction of waste from the production process - minimization of post-production waste is one of the basic aims of lean management and also one of the main advantages of prefabrication technology,
- the assembly process of prefabricated units is largely predictable and requires less man-hours of work. Also increasing the amount of predictable activities throughout the production process is consistent with the assumptions of lean management,
- production of elements in the factory in advance to the construction drives better pre-planning process, more accurate design and "freezing" the design changes after starting production at the factory. This eliminates many issues traditionally encountered on the construction site caused by late changes in the project, often necessary to implement already on the site. Early optimization of the project and reduction of design changes throughout the process are consistent with the idea of lean management,
- multidisciplinary coordination at an early design stage improves communication and information flow - lean management states that effective communication of all parties involved is necessary for the proper course of the entire process.

### **3. Typology of prefabricated sanitary installations**

There is wide range of possible applications of prefabrication in building services. Most typical usage examples are described below, categorized on the basis of the publication<sup>27</sup>.

#### **3.1 Prefabrication of repeatable parts of the installation**

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<sup>26</sup> Fuller, R.B., 1999. *Your private sky: R. Buckminster Fuller: the art of design science*. Springer Science & Business Media.

<sup>27</sup> Wilson, D.G., op. cit.

Prefabrication method is especially recommended for systems consisting of repeating units, elements and when multiple copies of the basic configuration of elements are being used.

### 3.1.1 Repetitive horizontal distributions

In the case of buildings with repetitive floors, especially office buildings, prefabrication is used in the installation of regularly repeated, basically identical services on particular floors. The fragments of the installations prepared off-site are usually distributions in the communication parts of buildings. In some cases it is possible to prepare in the factory the entire installation, for example for a heating and cooling system based on four-pipes fan coils, complicated due to large amount of components. In addition to office buildings, prefabricated solutions are used in public buildings or hospitals - an example shown in Fig. 1.



**Fig. 1. Prefabricated horizontal distributions of sanitary installations for a hospital facility in Australia**

*Source: Fredon Air, 2017. Horizontal services module assembly for Blacktown hospital. [online] Available at <https://www.youtube.com/watch?v=kq6QH14srMw> [Accessed 31.12.2017]*

### 3.1.2 Prefabricated wall modules

Prefabricated wall modules is a solution dedicated especially for sanitary rooms in any type of buildings. The method is based on construction of complete sanitary walls including construction parts and sanitary assembly elements (most frequently toilet bowls, washbasins, urinals,

bidets and other sanitary utensils) - examples are shown in Fig. 2. System walls afterwards are attached to the building walls and connected with footrests and cables. Walls are easy to assemble, flexible, tested in terms of fire protection and sound insulation - due to the significant reduction in construction time, the solution is especially useful when sanitary rooms in a building are frequently repeated. Wall modules are offered by the majority of leading producers of sanitary equipment. Although the method is most often applied for bathroom, toilet and toilet rooms, it can be successfully used for installation of heating, ventilation, air conditioning and other sanitary systems.

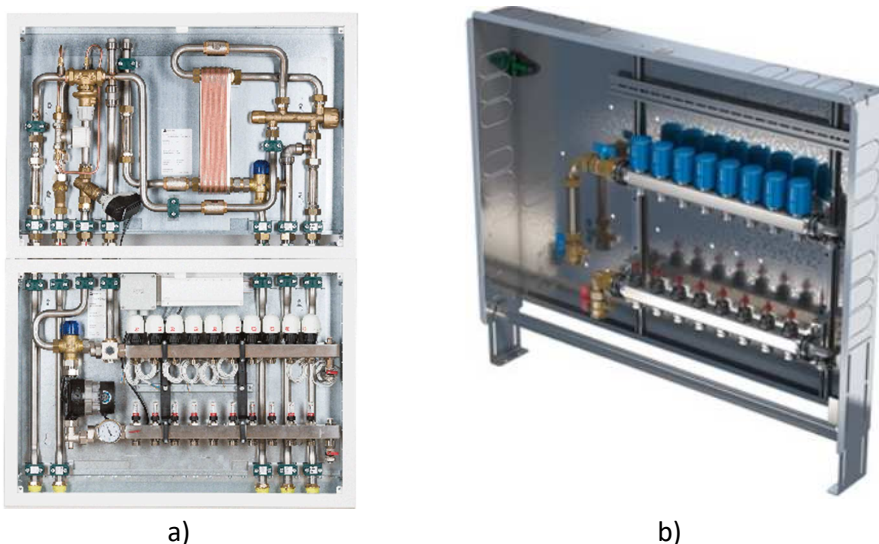


**Fig. 2. Prefabricated TECE wall modules a) extended system of wall modules, b) transport to the construction site**

*Source: TECE, 2017. Prefabricated wall modules.[online] Available at <https://www.tece.com/en/prefabricated-wall-modules> [Accessed 14.08.2017]*

### 3.1.3 Other repetitive sanitary elements in buildings

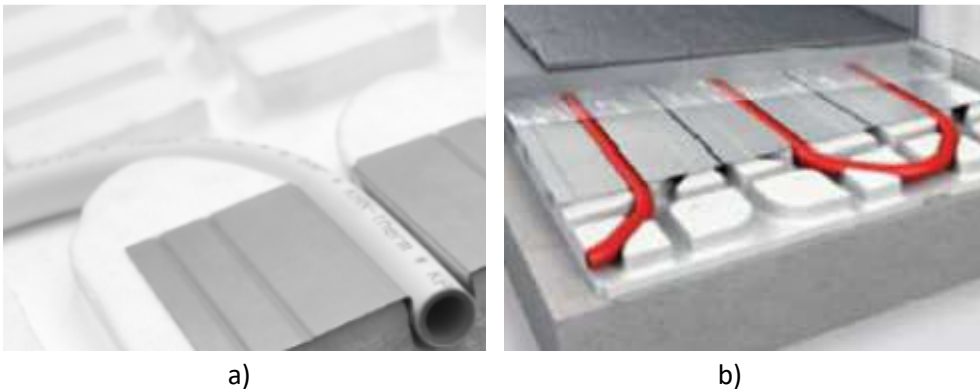
In addition to the above-mentioned examples, repetitive solutions of smaller scale are also found in buildings. Mentioned here should be prefabricated heating manifolds, which are assembled in accordance with the investor's requirements in the factory and delivered to the site ready to be connected or prefabricated compact heat interface units for use in apartments. Residential heat interface units contain complete equipment for the distribution of heat and domestic hot water within the apartment. These solutions allow to save time during installation and configuration and to avoid many executive errors, for example related to the wiring of actuators. Examples of solutions are shown in Fig. 3.



**Fig. 3. a) prefabricated residential heat interface unit, b) prefabricated distributor heating manifold**

*Source: a) Taconova, 2017. TacoTherm Dual Piko.[online] Available at <http://www.taconova.com/pl/produkty/pv/technika-systemowa/5/tacotherm-dual-piko/401/> [Accessed 05.11.2017], b) UPONOR, 2017. Prefabrykowane szafki rozdzielaczy. [online] Available at <https://www.uponor.pl/pl-pl/instalacje/produkty/rozwi%C4%85zania-prefabrykowane> [Accessed 06.01.2018]*

Worth mentioning are also modern solutions in the area of underfloor heating in buildings – studies are carried out on numerous improvements aimed at faster and easier installation of underfloor heating. On the market are available for some time dry floor heating systems based on prefabricated system boards made of foamed polystyrene or chipboard on which heating pipes are laid. These boards have prefabricated cuts making the board appropriately contoured for more simple assembly. The entire system is very compact and usually consists of four elements: the system board, radiating plate, heating tube and PE foil, an example shown in Fig. 4.

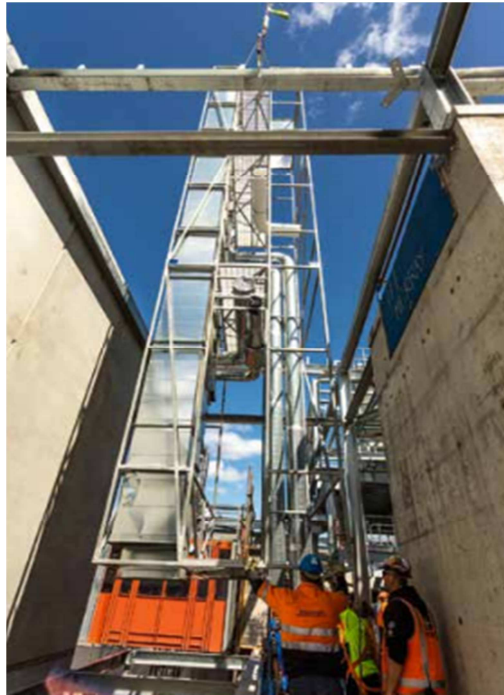


**Fig. 4. Floor heating using dry method a) detail, b) a cross-section through the floor**

*Source: Roth, 2017. Metoda sucha TBS ogrzewania podłogowego. [online] Available at <http://www.roth-polska.com/pl/Metoda-sucha-150.htm> [Accessed 06.01.2018]*

### 3.2 Prefabricated risers and shafts

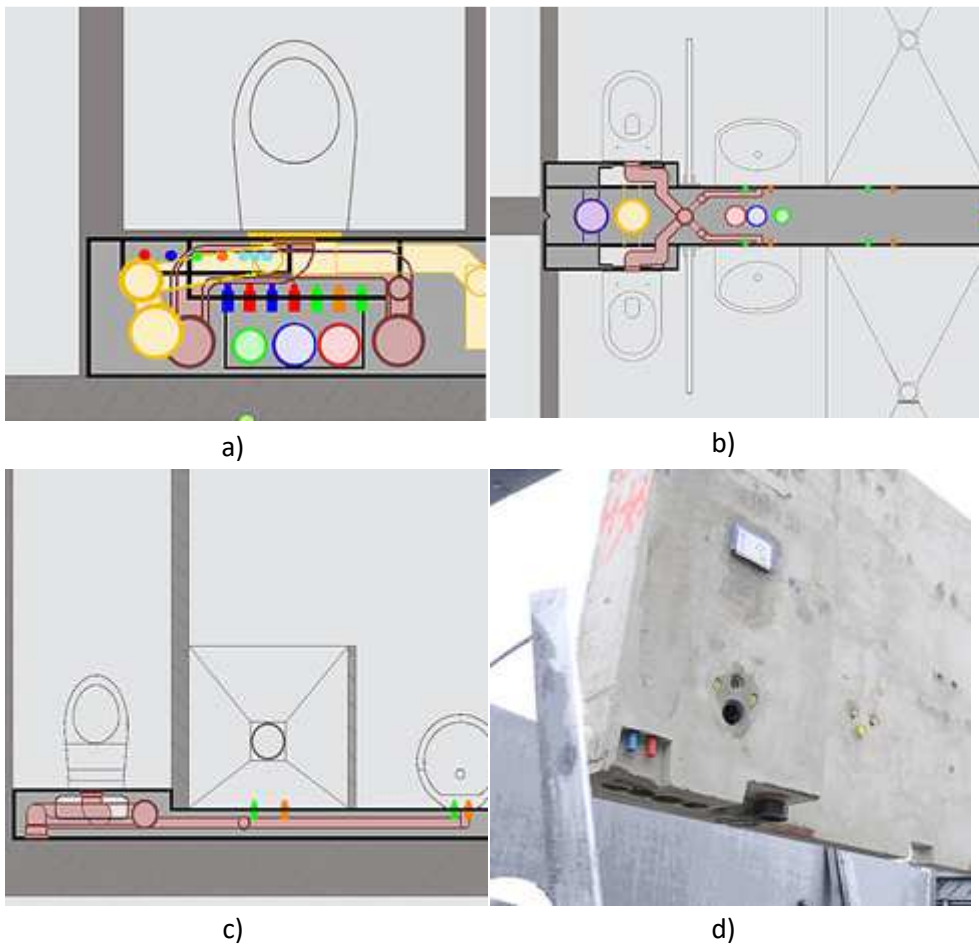
One of the most popular solutions using prefabricated technology is prefabrication of building services risers and shafts. In the literature can be found a number of examples of prefabrication of risers in high and high-rise buildings, for example the assembly of one of the largest blocks of multi-branch risers in Australia with a height of 10 floors, Fig. 5. Apart from a substantial acceleration in assembly time, one of the major advantages of the method is a significant increase of work safety level, by moving a greater part of the work at heights to the factories. The solution is applicable not only to high-rise buildings and it is often used in multi-story residential buildings, hotels or dormitories.



**Fig. 5. Installation of one of the largest prefabricated, multi-branch risers units in Australia**

*Source: Jacobson M., Stannus W., Stavroulakis N., 2014. Fabricating the future, Ecolibrium, p.32-42*

In German-speaking countries common solution is to utilize prefabricated installation shafts designed as partition walls. Such a walls occur in many variants, the most popular are: walls replacing typical installation shafts and combining the function of shaft and a covering (Fig. 6a), walls to which installation accessories can be connected on both sides (Fig. 6b), walls installed in front of reinforced concrete structures (Fig. 6c).



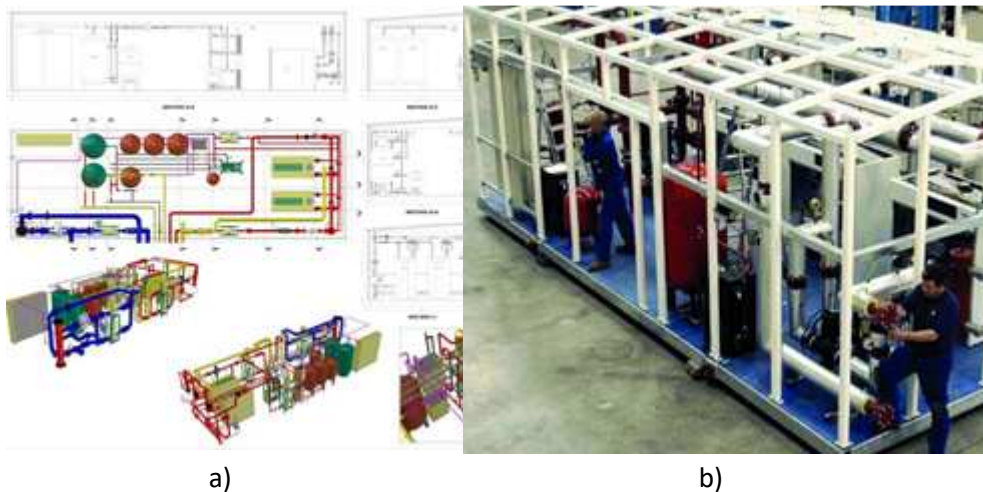
**Fig. 6. Instabloc installation walls replacing typical shafts a) "SWS" type, b) "SWT" type, c) SWV type, d) wall transported to the construction site**

Source: Instabloc, 2017. Sanitary walls. [online] Available at <http://www.instabloc.at/en/products/sanitary-walls.html> [Accessed 20.08.2017]

### 3.3 Prefabrication of plant rooms and other technical rooms

Prefabrication is a proven solution for complex installations, which execution on the construction site is labor-intensive, time consuming and what is more involves work on a small area, where precision is extremely important. An example of applications are all types of plant rooms, heat centers, boiler rooms, pumping stations and other sanitary technical rooms. Inherent in the off-site production process BIM technology or at least preparation of 3D models, is greatly functional for this type complex

installation, which have to be designed in a very compact manner, but at the same time providing functionality, provision of service spaces, access to actuators, etc. Off-site production brings as well significant time reduction of the installation process. Examples of documentation in 2D and 3D for the off-site production of plant rooms as well as assembly of the installation are shown in Fig. 7.



**Fig. 7. Prefabrication usage for plant room installation a) technical documentation of a plant room, b) assembly example in off-site environment**

Source: a) Constantair, 2017. *Prefabricated Packaged Plantrooms*. [online] Available at <http://www.constantair.co.uk/prefabricated-packaged-plantrooms/> [Accessed 06.01.2018], b) Edquarter, 2018. *Turning up the heat*. [online] Available at <http://edquarter.com/Article/turning-up-the-heat> [Accessed 06.01.2018]

### 3.4 Prefabrication of repeatable modules - sanitary facilities

One of the more well-known examples of prefabrication usage in modern construction are prefabricated sanitary facilities, most often bathroom pods. In Japan, 80% of newly designed buildings are equipped with prefabricated bathrooms<sup>28</sup>, but the solution is gaining popularity all around the world, in Fig. 8a is presented factory in Poland specialized in

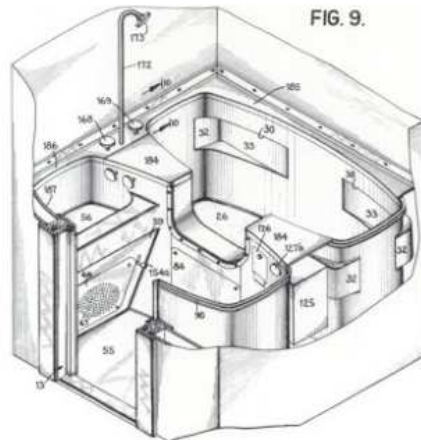
<sup>28</sup> Modular Building Institute, 2018. *Saving Time with Modular Bathroom Pods*. [online] Available at <http://www.modular.org/images/Bathroom%20Pods%20Whitepaper%20Dec16.pdf> [Accessed 07.01.2018]



production of prefabricated bathroom pods. Sanitary pods are made entirely in factories and arrive to the construction site fully equipped with sanitary facilities. The story of a prefabricated bathroom is related to the person of Buckminster Fuller, an American visionary of architecture who created a concept called "Dymaxion". The name of the concept has origin in combining the words dynamics, maximum and tension. From the 1930s, by "Dymaxion" Fuller was referring to a series of his innovative projects on the subject of future homes, one of them being a prefabricated house and a prototype of a self-sufficient unit not producing waste. But a Fuller's project, which was close to starting a mass production, was a prefabricated bathroom, designed inside "Dymaxion" house and also for individual installations in traditional construction. The project was even patented in 1938<sup>29</sup>, Fig. 8b. Mass production finally was not started due to the resistance of sanitary installation engineers who blocked the production process, fearing for their own work<sup>30</sup>.



a)



b)

**Fig. 8. Prefabricated bathroom modules a) prefabricated bathroom factory in Bolesławiec, b) Fuller's prefabricated bathroom from 1938**

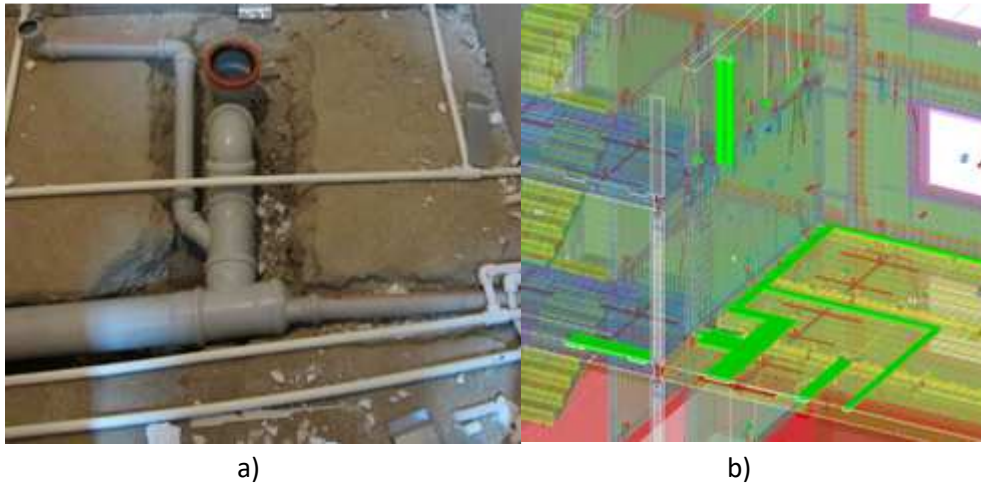
Source: a) Ready Bathroom, 2017. Galeria łazienek prefabrykowanych. [online] Available at <http://readybathroom.eu/gallery.php> [Accessed 15.08.2017], b) Fuller, R.B., 1999. *Your private sky: R. Buckminster Fuller: the art of design science*. Springer Science & Business Media.

<sup>29</sup> Davies, C., 2005. *The prefabricated home*. Reaktion books.

<sup>30</sup> Fuller, R.B., op. cit.

### 3.5 Integrated installations in prefabricated or modular buildings

All the above-mentioned examples of the use of prefabricated installations can be successfully used in any type of construction, including the traditional one. However, when talking about a building constructed itself in a prefabricated technology, it should be considered what is the most optimal solution for the building services installation. A common situation is when the structure of a building is made of prefabricated building elements, that building services are installed already after finishing the construction stage, which involves the necessity of forging floors, walls, holes, etc., an example shown in Fig. 9a. Optimal solution is therefore off-site preparation of the distribution of sanitary and electric building services. Preparation of BIM models including architecture, structure and installation grids in the early stage of the process allows for proper multidisciplinary coordination, collision-free installation and precise determination of drilling. An example of the BIM model prepared for the prefabricated residential complex of Tollare Torg in Sweden is shown in Fig.9b. Ready construction elements with integrated installations or specially prepared for their distribution allow quick assembling on the construction site and significantly eliminate execution errors. Worth mentioning is also modular construction concept, which can be described as the development of the idea of prefabricated bathrooms and which involves the assembly of buildings made of ready modules entirely prepared at the factory, equipped with all branch installations, partition walls, finished bathrooms, toilets and kitchens.



**Fig. 9. Sanitary installations in prefabricated buildings a) assembly of sanitary installations after completion of construction works b) BIM model of prefabricated structure with installation grid**

Source: a) Ecotech, 2017. *Prefabricated house, from order to moving in*. [online] Available at <http://www.ecotech-bg.com/index.php/en/component/k2/item/55-prefabricated-house-from-order-to-moving-in> [Accessed 14.08.2017], b) Tollare Torg, 2017. [online] Available at <https://www.tekla.com/bim-awards/tollare-torg#> [Accessed 14.08.2017]

#### 4. Barriers in prefabrication implementation

Prefabrication in spite of all the above mentioned advantages is related with the necessity of changes in the investment process, with distinct approach to the purchasing and production mechanisms, and finally with a shift in the way of thinking about the construction process by all the parties involved. The most common barriers and difficulties in implementing prefabrication, which can be applied both for prefabrication as such and for off-site manufactured building services, are listed below:

- *Critical thinking about prefabrication*, which should be treated as a more cultural or social than technical issue<sup>31</sup>. The issue is stronger in particular societies, for example in Poland and other post-communist countries due to associations with poor quality of construction dated to second half of the 20th century, and less significant in Scandinavian countries, where societies are more into pragmatic approach to

<sup>31</sup> Steinhardt, D.A., Manley, K. and Miller, W., op. cit.

technology. Negative associations with prefabrication appearing in societies can be regarded as a barrier especially for the development of prefabricated housing - if real estate developers will have problems with selling apartments produced in prefabrication technology, traditional method of construction will be the preferred one,

- *education and appropriate competences* – prefabrication is associated with significant changes in the design, procurement and construction processes and therefore many participants involved, who are often accustomed to traditional roles, sharing responsibilities and methods, may show conservative attitude and oppose to potential changes<sup>32</sup>. Thus proper education of engineers and technicians is crucial, aiming to increase the openness to changes in the construction process, but also to provide the participants with the appropriate competences necessary to properly perform new tasks,

- *designing methods* - production of prefabricated elements requires the use of at least three-dimensional models, and preference is given to models containing information about the building and its components (BIM). Although implementation of such a design methodology brings definite benefits to the entire process, it is often regarded as an implementation barrier due to expensive software licenses, lack of properly qualified staff and simply because many engineers are used to work in 2D. It is often a case, that the decision to involve prefabrication in the project is made too late in the process when the design is already very advanced. Changing the design outlines at such a stage practically results in redrawing the technical documentation cause unnecessary prolongation of the whole design process<sup>33</sup>. Therefore, it is crucial to implement prefabrication as early as possible in the design process,

- *influence of the investment process* - in the classic investment process approach based on general contracting - design-tender-general contracting, selection of a general contractor is based on complete design documentation. In such process investor is forced to make decisions on design solutions at a very early stage, so after choosing a particular general contractor, design optimizations usually take place, and often

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<sup>32</sup> Lovell, H. and Smith, S.J., 2010. Agencement in housing markets: The case of the UK construction industry. *Geoforum*, 41(3), pp.457-468

<sup>33</sup> Schoenborn, J., 2012. *A case study approach to identifying the constraints and barriers to design innovation for modular construction* (Doctoral dissertation, Virginia Tech).

even entire building services systems needs to be redesigned. In the prefabrication industry commonly discussed are advantages of a different way of leading the investment process, which is design-build approach based on ordering both design and construction works from one specialized company. The method involves greater integration of the design and execution process, and closer collaboration of the entire team, including multi-branch engineers. Close cooperation of designers and engineers responsible for execution phase, ensure that solutions developed are usually optimal both in terms of design and execution aspects, and what is more costly and time-consuming late design optimizations and redesign work is eliminated,

- *production process and it's preparation* - organization of a production process in the case of precast technology is significantly different from traditional approach. It requires in advance availability of executive documentation of elements, preparation of material orders and creating an appropriate production schedule, taking into account assembly dates and production capacity of factories regarding both direct production activities and temporary storage needs<sup>34</sup>. What is more, attention needs to be given to transport and assembly works, transport of prefabricated elements from the factory to the construction site and the speed of assembly work on the construction site, much faster compared to traditional construction, all of listed features might be a difficulty for the parties involved.

## 5. Conclusions

The article presented the outline of the prefabrication idea, discussed the advantages of its implementation in the sanitary field, presented the common areas of prefabrication utilization regarding building services, and finally listed the main barriers to technology implementation. Global market research indicates that the trend of increasing the prefabrication share in the construction market in the coming years will be continued. Due to the specific features of the Polish construction market, mainly excessively low participation of prefabrication in housing sector, and at the same time unmet housing needs of Poles, dynamic changes in technology of execution can be predicted, especially in the residential field. An important stimulus is also

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<sup>34</sup> Adamczewski, G. and Woyciechowski, P.P., 2014. *Prefabrykacja – jakość, trwałość, różnorodność*. Zeszyt 1. Warszawa: Stowarzyszenie Producentów Betonów.

the government program “Mieszkanie Plus”. In 2016, in the resolution regarding implementation of "National Housing Program", the government recognized an increase in the number of apartments as one of the basic objectives - by 2030, the number of apartments per one thousand inhabitants is to reach the European Union average, which means an increase from 363 to 435 flats per 1,000 people. One of methods used to achieve the intended goal is to use prefabricated solutions, as cheaper and faster to implement compared to traditional technology.

Technological changes of prefabrication does not only concern architecture and construction fields, but also building services disciplines, including sanitary installations. Prefabricated and modular construction of buildings requires application of appropriate technological solutions in the field of sanitary installations, as the construction process is in a coherent whole and it is not possible to develop only selected parts. Potential lies also in prefabrication of building services installed in traditionally constructed buildings, mainly in off-site production of complicated or repetitive parts of the installation, like plant rooms and other technical rooms. Above mentioned usage of prefabrication takes place mainly in office buildings, public utilities, hotels, hospitals, industrial facilities. Described trends are reflected in latest conferences regarding the future of sanitary installations in buildings, emphasizing that one of the most important directions of sanitary sector’s development is prefabricated technology and integration with modular buildings. What might be interesting, in the American report<sup>35</sup>, in the list of most commonly used building elements made in prefabrication technology, the MEP systems (mechanical, electrical and pipe systems) are listed in second place, right after external walls elements.

Without a doubt one of the most important factors stimulating the development of prefabrication technology is the financial aspect. Therefore, there is a need for reliable research comparing the costs of traditional and prefabricated construction. Although all off the sources confirm the reduction of costs due to prefabrication, currently available the estimates often show quite divergent results. There is also a lack of data on total cost reduction in the life cycle of the building, and not only during the execution phase. What is more, many researches on prefabrication concern the technological and material aspects of

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<sup>35</sup> Construction, M.H., 2011. Prefabrication and modularization: increasing productivity in the construction industry. *Smart Market Report*.

prefabrication, while much less attention is given to research on investor, intermediate participants of the process and final users preferences. In this context, research results<sup>36</sup> conducted among architects, engineers and contractors may be quite surprising. Participants of the construction process familiar with the prefabrication technique asked about projects in which it the technology was finally abandoned for the main reasons listed: lack of available design documentation taking into account prefabrication and investors' reluctance to the method. Among the participants of the construction process not using prefabrication at all and explaining reasons for this fell arguments as above and in addition: lack of appropriate knowledge of this technology. The result of these studies indicate how important it is to educate all parties involved in the investment process about the benefits of prefabrication technology. Guidebooks and instructions on how to implement prefabrication and what are the changes for all the participants throughout the entire process can be of great help. Mentioned report also investigated the main reasons for using prefabrication - in the first place, especially for general contractors, was placed the increase of the whole process productivity, and in one of the last places was listed the investment requirements regarding prefabrication implementation. Increasing investors' awareness of the advantages offered by prefabrication technology and how its use significantly lowers the risks associated with completing time schedules and budget might therefore significantly increase the degree of the method usage on the market.

Finally, remarkably important aspect of prefabricated technology is its minimized environmental impact compared to traditional technology. Environmental issues are priority in context of the implementation of the sustainable development strategy, reduction of energy consumption and reduction of the carbon footprint, implemented not only within the European Union, but also globally. Prefabrication, already taking into account the need to transport ready elements from the factory to the construction site, significantly limits the environmental impact of the entire production process. Production wastes are generated in the factory conditions in an incomparably smaller amount compared to traditional methods, and what is more, they can be controlled or even recycled. The amount of electricity consumed on the construction site is limited, the total amount of transports to the construction site is reduced

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<sup>36</sup> Ibidem

as well. Environmental aspect should be especially highlighted at the central and governmental level, which should support environmentally friendly technologies - it could be possible to implement tax reliefs or other preferential settlement conditions for companies applying modern technologies, like prefabrication.

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