Challanges of sustainable development and Building Information Modelling

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BUILDING INFORMATION MODELLING IN THE EDUCATION OF STUDENTS AT THE FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING AND ARCHITECTURE OF BYDGOSZCZ UNIVERSITY OF SCIENCE AND TECHNOLOGY AND SPINAKER 2022 SUMMER SCHOOL – SELECTED TOPICS

Abstract. *The Building Information Modelling is an important part of the training process for future design professionals, construction managers, construction administration and supervision personnel, as well as personnel overseeing the production and maintenance of facilities. The article presents the basic assumptions for the education of students of the Summer School.*

Keywords: construction, innovation, design, Building Information Modelling

1. Introduction

The Building Information Modelling (BIM) is becoming a standard for structural and architectural design, which is being applied to the production of building components and the process of using building structures. The practical application of BIM by engineers includes, among other things, collaborating and communicating with architects, conducting structural analyses using three-dimensional models. BIM also involves simulations of energy consumption and lighting, and, above all, tools that assist in detecting clashes and conflicts in the project at an early stage [1]. The full computerization of construction processes, including construction administration, requires the adaptation of the curricula of construction and architectural studies at universities. Moreover, universities, in addition to being a forge of human resources, are a platform for discussions between researchers and practitioners – engineers pointing out the needs of changing construction technologies, including in the context of the execution time and operation of facilities. The above aspects, supported by examples of applications, were the subject of classes conducted at the 2022 Summer School.

2. BIM application in construction and architecture

As part of the education at Faculty of Civil and Environmental Engineering and Architecture classes are taught in the shaping and design of objects. Issues of project management and preparation of technical documentation are also developed. Academic teachers presented similar issues in the form of lectures and workshops during the summer school, whose participants were foreign students. The students of the 2022 summer school represented various fields of study related not only to the technical industry, hence the program and the way the classes were conducted were adapted to the existing knowledge of the audience. The classes were aimed at broadening the students' horizons and expanding their interests. The summer school also included classes on both theoretical and practical approaches to BIM [2-6]. In the classes, the elements of a three-dimensional model of a building shaped into an arched solid were presented. A model of the object was presented in a native file, i.e. created with Archicad software (Fig.1).

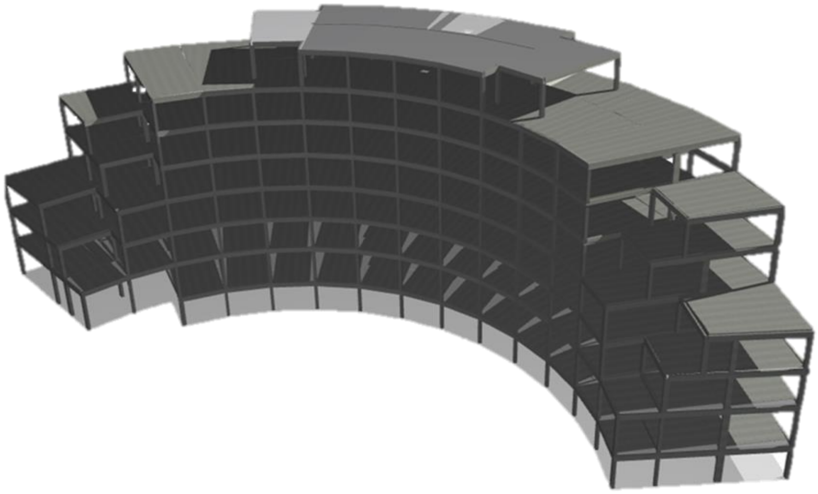

Fig. 1. Illustrative structural model of a public building – Archicad 25 software

The above model consisted of both structural and architectural parts. It was created through the cooperation of students and instructors within the framework of the competition of the 1st edition of the Architecture and Engineering Competition "Two Faces One Future of Cellular Concrete and Precast Concrete". Figure 2 shows the visualization. The students of the summer school were also introduced to the elements of the model, the structural-architectural coordination, the solutions used and the program descriptions. They were also presented with the possibilities of exporting the model from the native file to the open file IFC, which is a BIM standard [2–6]. Then, using the open file, the possibilities of using the file and the project model in other software such as Revit were presented. The mentioned open computer format IFC (Industry Foundation Classes), which is used in the construction industry, serves as a data exchange standard between various software applications used in design. It aims to ensure interoperability and collaboration within the construction industry. Additionally, it seeks to standardize the scope of information transmitted during the creation of a project and facilitate project management in each phase of investment, minimizing issues related to data incompatibility and enhancing efficiency.

Fig. 2. Visualisation of the public utility building

The scope of preliminary conceptual design and the possibilities of generating documentation in the form of drawings are presented. In addition, the advantages of exchanging data through IFC open files and using various capabilities through them to support the design and analysis of structures of objects, which is their most important element ensuring the safety of users and the durability of structures, are highlighted. The advantages that IFC brings primarily include data consistency and compatibility. IFC, as an open BIM standard, has a global character, making international collaboration significantly more accessible. Innovations are an important part of any industry – including construction [2–6]. They set trends in the design and shaping of objects, so students were also introduced to innovative materials used in the construction sector. Discussions have been held on the mechanization of printing concrete structures. Another less popular solution so far is the 3E (ecology, energy efficiency, cost effectiveness) system – it is a system based on specially shaped wall sections made of perlite material. This material ensures appropriate thermal properties of the elements and lightweight construction. One of the many construction systems discussed was also "SMART BRICKS", which resemble the blocks known to all. In turn, this system is distinguished by the ease of connecting elements to each other. These systems shown in Figure 3.

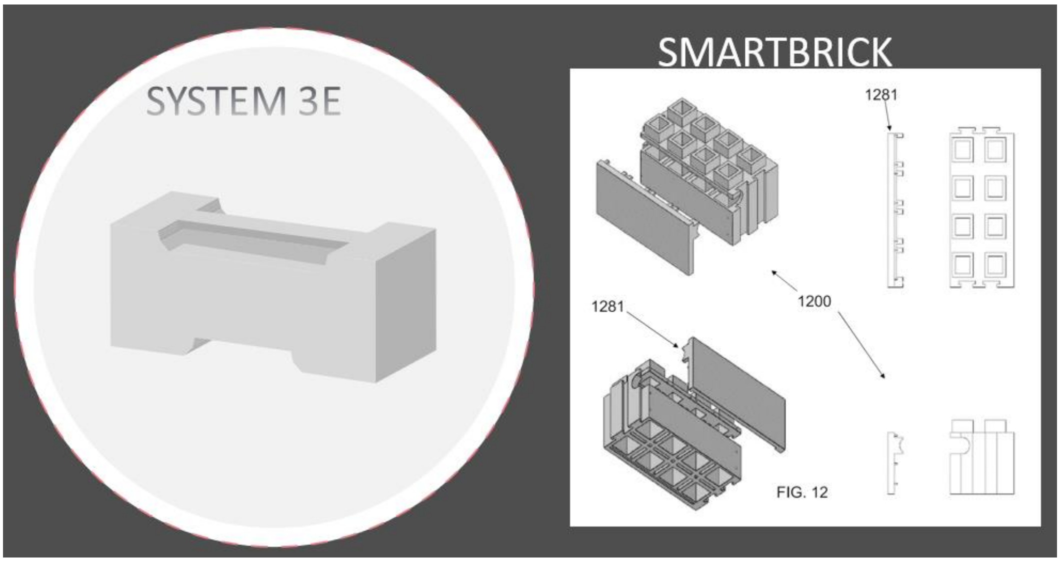

Fig. 3. Abrasive sticks; left 3E SYSTEM [6], right SMARTBRICK [7]

Innovative approaches include also environmentally friendly solutions, so alternatives to the use of concrete are an important consideration. These can include bamboo, which has a high tensile strength. Another material is hemp concrete, which is made of lime-bonded hemp fibres and resembles concrete in its construction. The combination of sawdust and concrete results in a high-performance lightweight material called wood concrete. An innovative idea is brick-shaped elements created from mycelium. In addition, given the use of recycled materials, glass and plastic work well as aggregate materials for concrete. Similarly, blast furnace slag, fly ash, microsilica can be used in the composition of concrete, reducing the amount of cement itself. All of the above materials are alternatives that have a less destructive effect on the environment than classic concrete. An alternative to external concrete structures is the so-called "grasscrete", which is concrete elements with grass slots that cover its outer layer over time [8, 9].

It is important to use BIM in existing structures with regard to structure monitoring and control [10]. BIM allows real-time tracking of changes in existing structures and visually identifies potential issues. This means that any deformations, damages, or abnormalities can be immediately detected and addressed. It facilitates the planning and management of maintenance and modernization work, optimizing the schedule and costs. It is also crucial for ensuring the safety, efficiency, and durability of these structures. It provides engineers and property managers with the essential tools for effective monitoring, analysis, and management of existing buildings. The use of BIM technology by architects and engineers primarily revolves around fostering collaboration between them. This helps in comparing architectural designs with structural considerations. Consequently, it enables the enhancement of design efficiency, reduces the risk of errors and costs, and facilitates better management of the entire building lifecycle. A joint study with students was carried out on the application of BIM to an existing structure. Steel stack structures were taken as a case study. Thanks to this form of study, students had the opportunity to gain knowledge-seeking skills through literature review as well as had the opportunity to model the stack structure in a calculation program, subject it to loads and conduct analyses. This is also a valuable type of knowledge transfer and education that allows the student to be independent and stimulate creativity. An example of the result of the analyses of the stack model is shown in Figure 4.

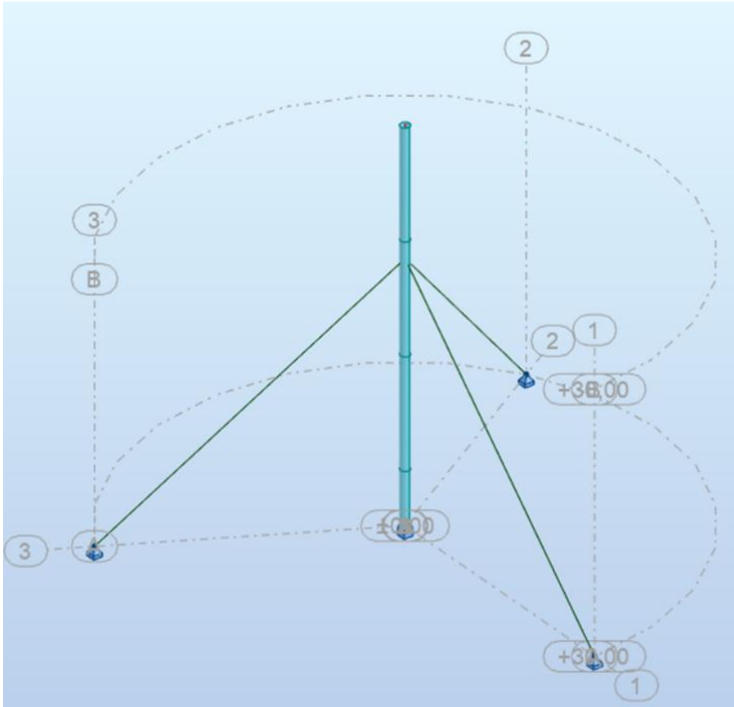

Fig. 4. Illustrative view originating from construction analysis (source: construction analysis made by the authors)

Students from France also participated in laboratory testing, where they made concrete samples, which were then subjected to strength tests – compressive strength testing of concrete.

Education at the summer school took place in a wide spectrum of the use of modern educational techniques [11, 12, 13]. Students participated in lectures and discussions with both the Faculty of Civil and Environmental Engineering and Architecture staff and invited guests. Thanks to this approach, multiple viewpoints and perceptions of construction and architecture were presented. In addition, as mentioned above, they were presented with a lot of modern software for designing both models and analysis of structures of buildings. The students' development was further enriched by visits to, inter alia, the historic Rother's Mills or trips to selected cities in Poland. This enabled students to learn about the broadly understood technical sciences from different perspectives.

3. Conclusions

The implementation of BIM methodology into teaching is a key element of the student educational process at the Faculty of Civil Construction, Environmental Engineering and Architecture at Bydgoszcz University of Technology, including during the Summer School under the Spinnaker project. The importance of the issues raised is related to the increasing use of BIM in the design, execution – implementation of civil structures, as well as their maintenance. Internationalization of the educational process is another goal set for the team implementing the Spinnaker project. The content covered in the classes of the Summer School was also tailored to the broad interests of students coming from different countries, as well as representing different academic backgrounds and using a different system of technical standards for the design of civil structures.

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TRADITION AND CUTTING EDGE IN THE STRUCTURAL SOLUTIONS OF LONDON STRUCTURES – SELECTED EXAMPLES

Abstract. *The urban development we can observe in cities around the world today is dominated by structures using steel and concrete. These include structures from many years ago as well as structures using modern technology. Water crossings in the form of bridges and footbridges are also an important aspect of urban areas located by watercourses. This paper presents structural solutions observed in London. Selected bridge structures are presented to emphasise their importance as a key element of the city's communication. The importance of combining modern structures while retaining existing buildings was also highlighted, using the ARBOR-Bankside Yards high-rise buildings as an example. Office buildings built with steel and cross-laminated timber were also discussed. The whole is based on the experiences and materials collected during a study visit to London as part of the Spinaker project. The aim of the article is to present the significance of practical knowledge gained during study visits and its further application in the didactic process carried out at the Faculty of Civil, Architecture and Environmental Engineering, the Jan and Jędrzej Śniadecki Bydgoszcz University of Technology.*

Keywords: steel structures, bridges, office buildings, bracing, cross-laminated timber

1. Introduction

Academic staff at the Faculty of Civil, Architecture and Environmental Engineering at the Jan and Jędrzej Śniadecki University of Technology in Bydgoszcz are also expanding their research and teaching skills during study visits. In June 2022, staff from the Faculty of Civil, Architecture and Environmental Engineering (the Faulty) participated in a study tour to London. The major highlight of the programme was a visit to The London School of Architecture (LSA), where they were introduced to the teaching methods and system of building and architecture education at this university, in particular Building Information Modelling (BIM) education. The visit and developing contacts with the LSA is also part of the internationalisation of education at the Faculty. The main goal of the visit was to exchange experiences related to technical education along with getting acquainted with the techniques and tools used in education. During the stay, various forms of teaching were observed in their natural form, and one of the more interesting forms was case discussions between students and the teacher during classes.

2. Examples of structures under study

The impact of weather conditions on building structures makes them vulnerable to corrosion. Because of this, opportunities are needed to discover new solutions to protect structures from this phenomenon. Steel structures are particularly vulnerable to this type of degradation, an example of which is the Southwark Bridge shown in Figure 1. This 100 year old structure is a 5 span steel arch structure resting on concrete bridgeheads and pillars. The arch structure forms the base of the structure, so the pavement layers are supported on these arches. In each span in the longitudinal direction, 7 such supporting arches are designed to provide adequate stiffness and load bearing capacity to the structure [2].

Fig. 1. Southwark Bridge (open in 1921) (source: own study Daria Jasińska (photo taken in June 2023))

At present the requirement is to design structures that are optimised in terms of weight and use of materials. This makes these structures more and more slender, with difficulties or problems encountered during operation. An interesting solution is The Millennium Bridge opened in 2000. This structure is shown in Figure 2. The slenderness of Millennium Bridge refers to the ratio of length to width. The footbridge is characterized by a narrow dimension in the horizontal axis (4.0 m) and significantly greater length (325 m) in relation to the horizontal direction.

Fig. 2. Millennium Bridge (source: own study Daria Jasińska (photo taken in June 2023))

Unfortunately, the Thames crossing had to be closed due to vibrations in its first days of use. It is now a very important facility in terms of bringing the issue of pedestrian traffic to the attention of engineers from all over the world. The footbridge was visited by thousands of people on the very first day, who, unaware of following each other, synchronised their walking pace to such an extent that they caused vibrations with their movement, which at one point equalled the structure's natural vibration frequency causing resonant vibrations. Pedestrians unaware of the structure vulnerability being in the resonance zone panicked and started to walk faster further impacting the footbridge and putting it in a sway. The structure had to be taken out of service and redeveloped. Dozens of vibration dampers were installed, which took about 2 years (Fig. 3–4). Passive damping was selected to fix the bridge: 37 viscous dampers were integrated into the bridge deck architecture or hidden under the deck to reduce sway (Tab. 1) and 50 tuned mass oscillators were added to limit vertical deck deflection under footfalls.

Tab. 1. Viscous dampers integrated into the bridge (source: [2])

Damper Type	Quantity	Description	Use
V1	5	Chevron Damper	Lateral Mode
V2	10	Chevron Damper	Lateral Mode
V3	2	Chevron Damper	Lateral Mode
V4	4	Vertical to Ground Damper	Lateral and Vertical Modes
V5	4	Pier Damper	Lateral and Torsional Modes
V6	8	Pier Damper	Lateral and Torsional Modes
V7	4	Pier Damper	Lateral and Torsional Modes

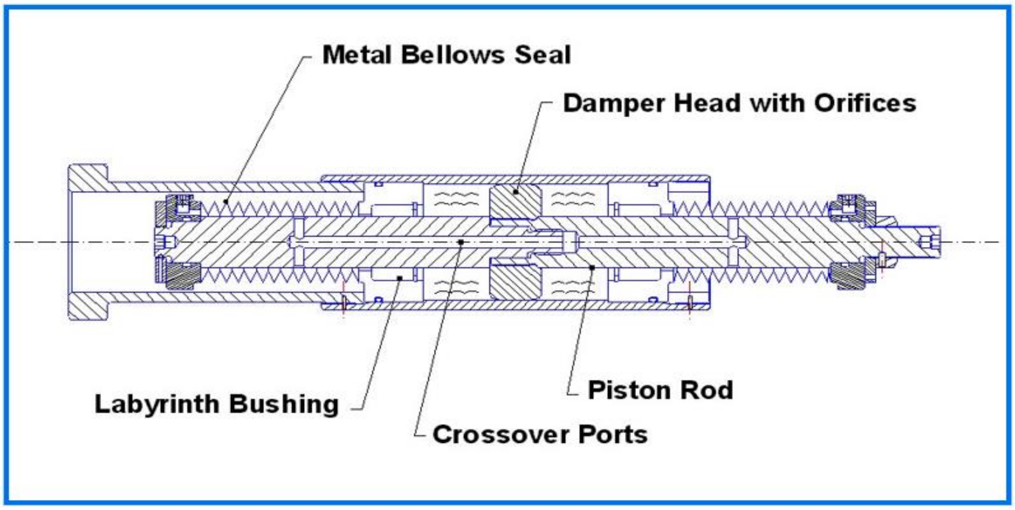

Fig. 3. Hermetic Damper Cartridge [2]

The infrastructure of an urban agglomeration located on a river course requires users and urban planners to plan multiple river crossings in the form of bridges and footbridges. Over the years, less slender bridge structures of concrete construction like The London Bridge, shown in Fig. 5, have also been built. The bridge at this location has taken on different geometric forms as well as different material solutions over the years. In its current form, it has served users for 50 years now. Over the centuries, the crossing at this location has changed its form, starting with wooden structures that, over hundreds of years, were repeatedly rebuilt due to fires. At the turn of the 12th/13th century, a stone bridge was constructed, and over time, multi-story buildings were also erected on it, which later hindered the passage through it. Therefore, it was decided to dismantle the existing one and build a new bridge.

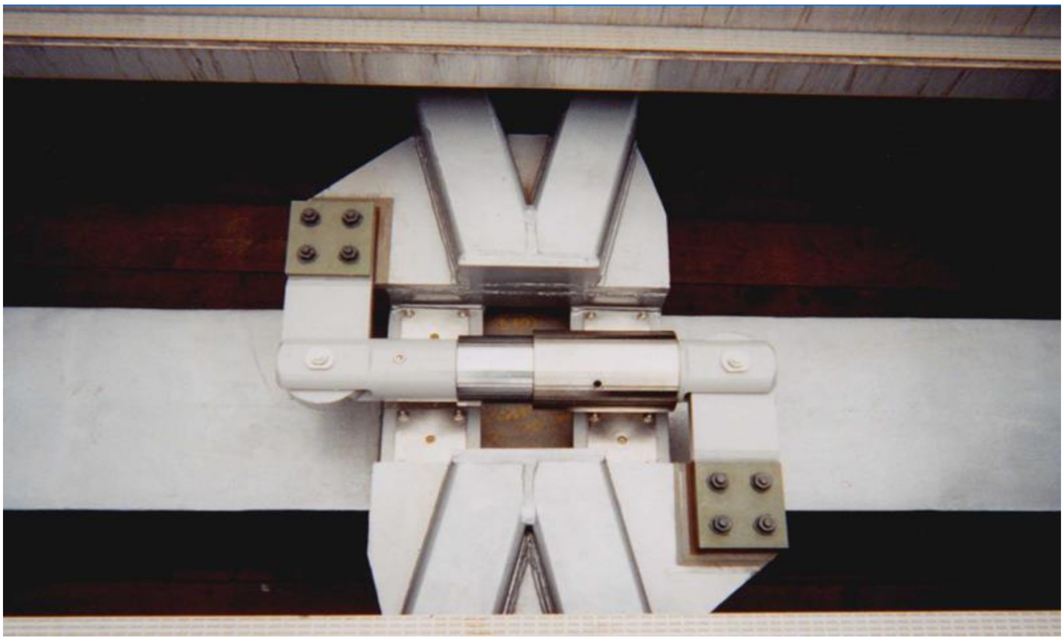

Fig. 4. Installed Damper [2]

Fig. 5. London Bridge (built in 1973 r.) (source: own study Daria Jasińska (photo taken in June 2023))

The design of buildings in a congested urban area forces the construction of structures occupying a small area. More and more constructions are frame structures with system facades – steel structures and glass facades. Objects are designed so that their functionality is adapted to changing trends and user expectations. Frame structures allow the creation of large open spaces – currently one of the most popular office solutions. In addition, these spaces can be easily divided by lightweight partition walls without disturbing the main structure of the building. The building of The London School of Economics and Political Science – shown in Figure 6 – was designed and built in this way. It is a facility adapted for teaching activities, allowing the use of modern teaching techniques. In its functionality, the facility has open zones – spaces for work, study and relaxation spaces.

Fig. 6. The London School of Economics and Political Science (source: own study Daria Jasińska (photo taken in June 2023))

An innovative solution in this building is the issue of the facade. Constructed of glass panels, the facade can generate a lot of inconvenience due to excess daylight making it difficult to work on screens or monitors, for example. However, in order to adapt to each user, electrically controlled façade shades have been installed, which can be operated independently in relation to a particular room – shown in the central part of Figure 6. From an architectural perspective, such a solution also affects the dynamics of the mass of the building.

When observing steel-framed buildings, it is impossible not to mention the important structural issue of bracing to ensure adequate stability of the building and uniform load transfer. Such bracing in many London buildings is located on their exterior side, so one can directly look at the solutions adopted by the engineers (Fig. 7).

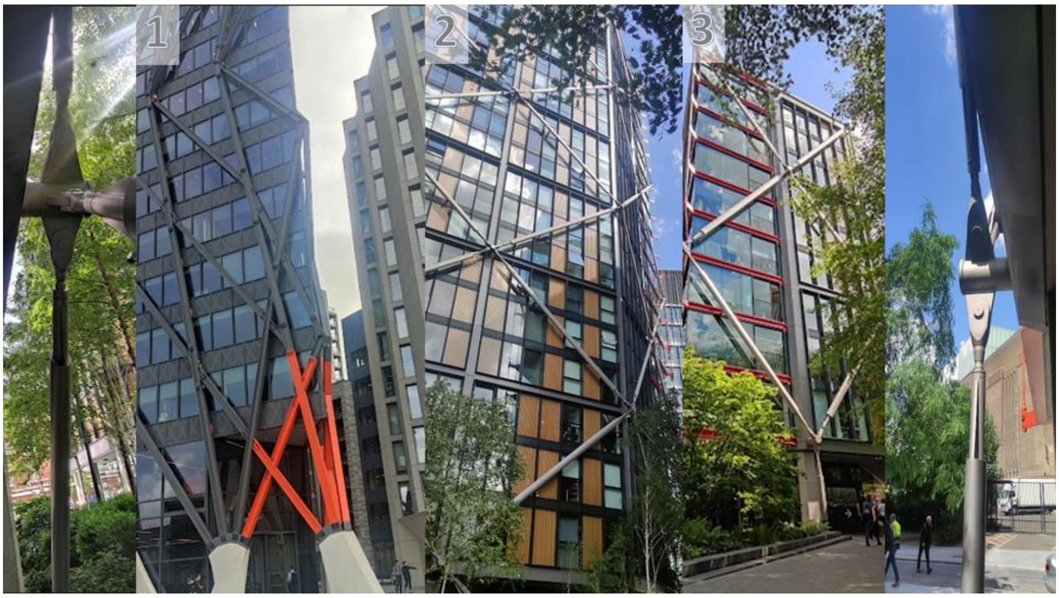

Fig. 7. Steel bracing (source: own study Daria Jasińska (photo taken in June 2023))

It is worthwhile mentioning here the combination of modern steel structures with glazed facades with existing historic buildings made of brick, for instance. A perfect example is the construction of the Arbor-Bankside Yards skyscrapers, which are being built on the site of a historic train station – a visualization of the new building is shown in Figure 8.

The steel structure of the new building rises above the arches of Victorian-era railroad viaducts [4]. The choice of steel as the main material proved to be much more efficient, with less weight and easier to solve the issue of independent foundation with respect to concrete structures. The existing railroad infrastructure will be an active and integral part of the entire complex. The facilities fit into the existing layout of the development. A number of solutions have been adopted here to ensure, independently of the old station structure, the stability of the building (Fig. 9). In Figure 9, on the left side, work is being carried out on the elevator near the existing portion of the historic building. In the central part of the illustration, there is a depiction of the separation of the new structure from the existing one, with a new steel column passing through the opening in the arch. On the right side of the graphic, you can see elements of the new structure, including columns, beams, and the terrace roof.

Fig. 8. Visualisation of Arbor, Bankside Yards [3] (originally built in 1864, reconstruction in progress – as of June 2023)

Fig. 9. Arbor, Banside yards (source: own study Daria Jasińska (photo taken in June 2023))

Although many modern buildings in London are based on steel construction solutions, we can also find examples of buildings with equally lightweight and efficient structures made of other construction materials, yet innovative in relation to the solutions most commonly used in this type of building. The building shown in Figure 10, which is the headquarters of The London School of Architecture, is a 2017/2018 redevelopment that is predominantly CLT cross-laminated timber construction [5–7]. It is a 6-storey building and is located in the immediate vicinity of the canal, which determines the choice of structural and material solutions due to the structure lightness [6]. The optimum solution chosen is a made of cross-laminated timber core: the main walls, stairs and even the ceilings. Only the latter were reinforced with openwork steel uprights supported on columns. Visually, however, the colours of these additional steel beams were made to blend in with the timber solutions.

Fig. 10. The London School of Architecture (source: own study Daria Jasińska (photo taken in June 2023))

Sustainable construction primarily involves maximizing the utilization of existing resources while making sustainable choices in selecting new materials. Durability and the potential for renovation or further use of elements or entire structures are crucial considerations. Many construction investments are subject to a balance of environmental, spatial, and economic objectives. The importance of this issue, particularly in the context of educating engineers to reflect on these matters, is also addressed in the literature, as referenced in [8]. Sustainable development, in the context of the discussed structures and construction solutions based on concrete, steel, or wood, should entail finding an optimal balance between the benefits of construction methods using these materials compared to the current construction resources. When engineers engage in sustainable construction, they are compelled to reconcile forces, displacements, dimensions of structures, and the systems of solutions they can employ. This requires them to expand their skills and competencies by looking at structures beyond conventional frameworks and standard solutions. Various methods for implementing alternative solutions to typical materials are studied and presented. Examples of alternative materials to concrete can be found in references such as [9, 10]. Sustainable constructions involve not only the appropriate choice of materials but also making numerous decisions within the complexity of structural solutions that directly impact material choices.

3. Conclusions

Study visits allow staff to develop their own photographic documentation and collect data, which influences their ability to implement these materials in their teaching activities. Enriching the classes with real-life examples supported by the instructor's own experience certainly arouses greater interest in the students and allows them to observe the practical application of many solutions presented in the educational process (Fig. 11). Elements of software supporting both design and education also play an important role in technical teaching [11].

Fig. 11. Modern educational methods (source: own study)

All elements from the graph were taken into account during the activities carried out at the summer school in August and September 2022. The results of the trainer workshops and site visits, as well as the experiences gained during the workshops, were also applied in the student training system undertaking their education at Faculty of Civil, Architecture and Environmental Engineering.

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APPLICATION OF BUILDING INFORMATION MODELLING IN ANALYSIS OF STRUCTURES EXPOSED TO STATIC AND DYNAMIC LOADS

Abstract. *The following paper presents the application of IT tools to develop a complete building model based on Building Information Modelling technology, using the example of a building exposed to high winds. The software and its use will be briefly discussed. In conclusion, the collaboration between the software and their practical application will be demonstrated. Finally, the need for further development will be pointed out, an example of software development will be given.*

Keywords: Building Information Modelling, advanced software, building design, structural analysis, failure analysis, wind load

1. Introduction

Building Information Modelling (BIM) is the process of creating and managing information about a facility under construction. This information is used in the design, during construction and also during the service life time of the facility. BIM technology, based on an intelligent model and available on a cloud-based platform, integrates structured multi-discipline data, enabling the creation of detailed digital representations of a resource throughout its development cycle – from planning through design to construction and operation.

Building Information Modelling is a digital record of a building's physical and performance characteristics, in parametric form, for generating and using data about a building as a source of multidisciplinary knowledge, fully available to those involved in the development process or during the use of the building and providing a basis for making decisions throughout the life cycle, from initial conception, through design, construction and operation, to demolition of the building. The full process is illustrated in Fig. 1.

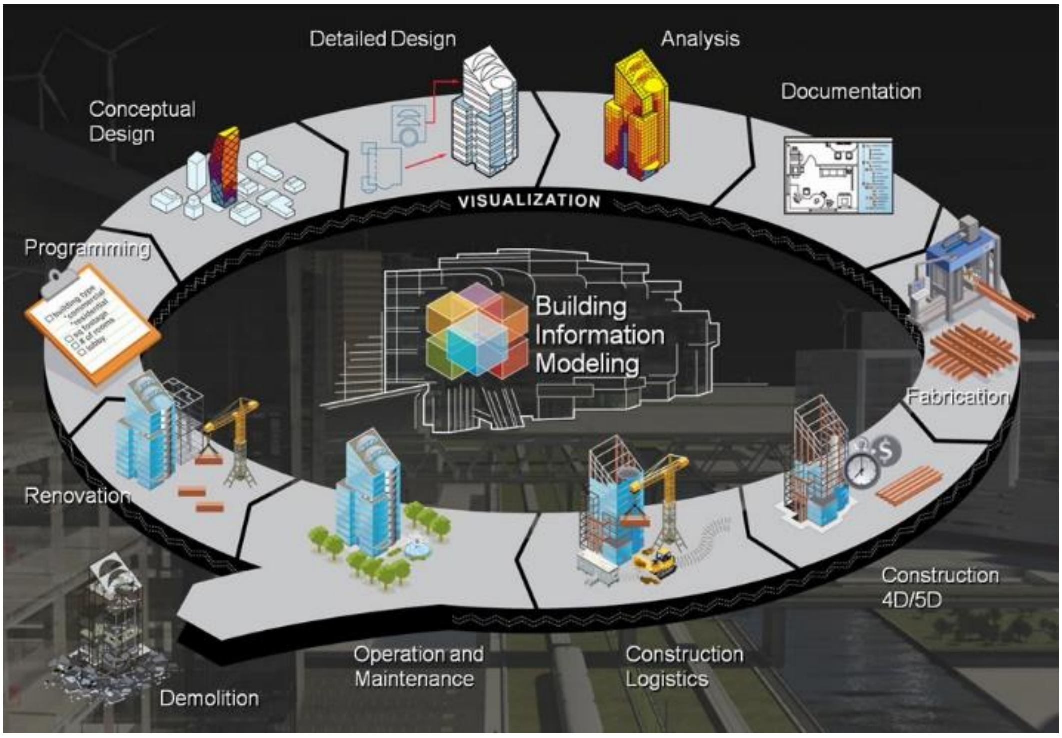


Fig. 1. Building Information Modelling process (source: [1])

There are many software suites that allow to carry out specific activities, as well as to streamline and accelerate work in certain areas. A selection of BIM-related software is presented below, and please note that these are just a few examples. The most popular Building Information Modelling (BIM) software is Revit, it helps teams in the fields of architecture, engineering and construction to create high quality models of buildings and infrastructure. The software supports:

- modelling shapes, structures and systems in 3D with parametric accuracy, precision and ease;
- streamlining documentation work with instant corrections to plans, elevations, statements and sections as designs change;
- streamline multi-disciplinary teams with specialised toolkits and a unified design environment.

Another example is Smath and Mathcad software. These are software suites that support the design process. They allow calculations to be streamlined thanks to automatic calculations. Although at first glance these text programs are not strictly related to modeling, it should be remembered that BIM technology is not only a numerical model of an object but, according to the definition, modeling information about a building, so the recording of any information will be part of it. It is worth emphasizing that, unlike purely text-based programs (Word/NotePad), Smath/Mathcad programs allow for much more. We can distinguish specific values (object parameters) such as dimensions, material strength, etc., along with their units. Additionally, these parameters can be easily extracted by referring to them later in the file. The most important convenience, however, is the ability to enter calculation formulas that retrieve data from a previously entered database, taking into account units. Finally, it is worth mentioning that changing the parameters in the first part automatically affects the results updates.

Another group of programs that play an important role in BIM design are calculation programs such as Robot or Ansys, but also 2D drawing programs (AutoCad) and 3D (Advance Steel). All these programs, despite their similarities, have slightly different applications and we can distinguish them as follows:

- Robot is one of the key calculation software suites and ensures that the load-bearing capacity of all structural components is checked. It is particularly suitable for checking the overall structure as well as individual main load-bearing components.
- Ansys is an analysis system with functions analogous to Robot, but more advanced and extended with analyses covering more areas of scientific analysis. A more specialised software, it is aimed at the detailed examination of individual components related to the operation of a structure, such as wind flow, dynamic vibrations, etc.
- Once the calculations have been made, it is time for the drawing documentation. An invaluable tool here is AutoCad, a piece of software that allows us to produce detailed drawings in both 2D and 3D. AutoCad allows us to draw everything from scratch (of course there are ready-made blocks, but someone must have prepared them beforehand), but you can speed up the documentation process by using Advance Steel software.

At this point, it is also worth mentioning another modeling program, this time a detailed one. This is IdeaStatica, a program for creating and calculating connections, especially steel ones. It is obvious that a program intended for a narrower area will be much more accurate and easier to use, so it is worth using programs dedicated to specific issues.

An important issue is the fact that IdeaStatica, like Robot, directly uses the applicable standards – Eurocode 1993 and proposes ready-made solutions compliant with it, while Ansys bases its calculations first on complex laws of physics and then on the standards. Therefore, it is mainly used to check the stresses inside each connection element and to check the cooperation of the structure.

When talking about working in different programmes, we cannot ignore the aspect of collaboration between them. The most important function is the import/export of an object or its part between programmes. An example of this would be to prepare a 3D model in Revit then send it to Robot to check the load-bearing capacity of the main structural elements, in the next stage we send the model to Advanced Steel to obtain the connections between the elements, which we will finally check in Ansys suite.

Curricula at the universities should be carefully prepared and arranged in a non-accidental way. Students have to gain in-depth knowledge of a particular area during the programme, which lasts from 7 to 12 semesters in immediate succession. In each semester, they take courses in various subjects to increase their knowledge and prepare them for work. The aim is to continuously learn more and more advanced functions and programmes to facilitate future work

In the following, the educational process of BIM design will be presented using selected subjects from the Construction course as an example. The steps in the structural modelling of a simple hall building will be discussed.

2. Application of BIM to the analysis of building structures

There are many opportunities to discuss the application of software to work improvement, starting with a theoretical introduction, followed by a discussion of diagrams and ending with a presentation of design practice and application to the implementation and use of structures under design. In this paper, the issue will be demonstrated using the design of a simple hall building as an example. The learning process at the different stages of the construction course will be discussed, preparing for the submission of the design of a structure under construction

2.1. General diagram of facility design based on hall example

The building in question is constructed from a series of frames with a structure consisting of two reinforced concrete columns topped by a steel lattice girder. The frames are connected by beams of smaller cross-section in relation to the columns. The girders are connected by a series of purlins. In addition, there are bracing elements. The whole is topped with a lightweight structure consisting of prefabricated wall and roof panels. A diagram of the solution is shown in Fig. 2.

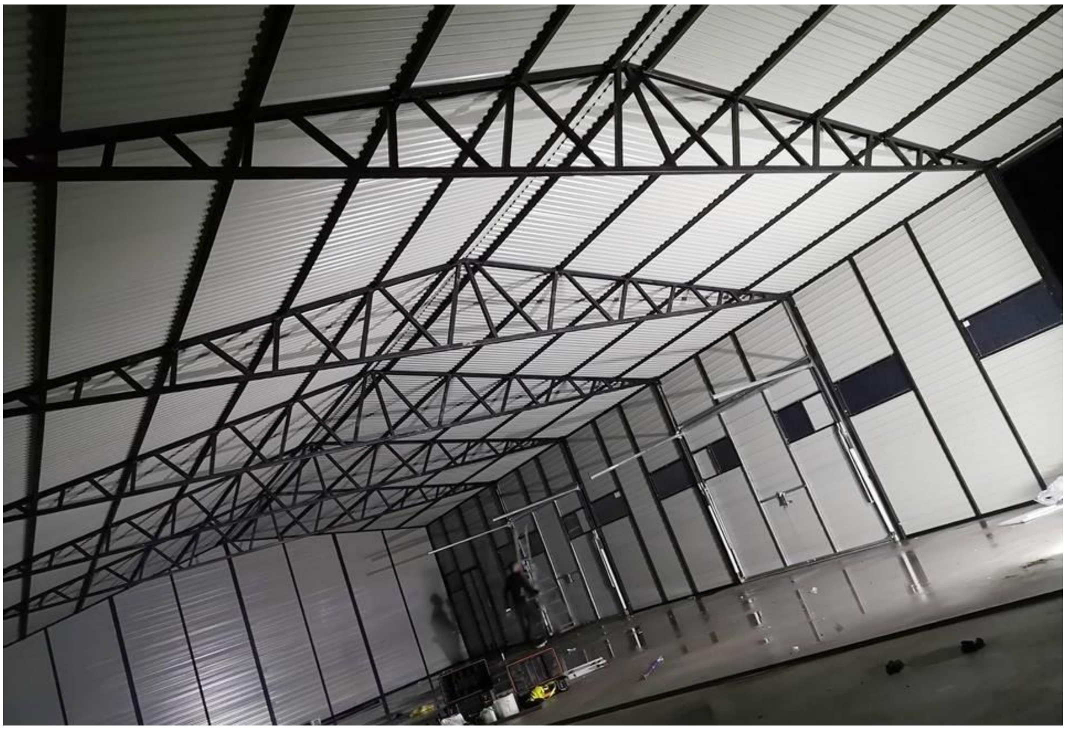


Fig. 2. Construction diagram for a sample hall with lattice girder (source: [2])

In order to carry out the project, the following roadmap can be followed:

a) Facility concept

The first phase when the structure is only in the designer's mind, must choose the intended purpose, shape and layout of the structural elements and the entire facility. In addition, it should be noted that the concept must coincide with the investor's vision and be created in collaboration with the architect.

b) Selection of materials

It is important to select both structural (e.g. concrete, steel) and non-structural materials (e.g. insulation, doors, windows).

c) Type of structural solution, e.g. floor, truss/roof girder

Developing the initial concept by reconciling the client's vision with structural realities. It should be a compromise between the available investment budget and the load-bearing capacity, by selecting the most economical solution for the structure.

d) Check of situational and thermal conditions

In addition to the general guidelines laid down in the technical conditions, an important aspect is also the fulfilment of local requirements depending on the location of the building. The conditions are described in the local zoning plan, in which you can find, among other things, what can be built on the site, how high the building can be, where the access to the property is, what can be built next to the property in the future.

e) Preliminary technical description

All of the above information should be included in a concise note containing information on the requirements and how to meet them. This function is fulfilled by the technical description, and it is good practice to complete it from the initial phases. It should be noted, however, that at this stage any assumptions are preliminary and will be subject to detailed static and strength analysis which may result in changes.

f) Collection of loads

The pre-selection of structural elements and finishing materials as well as the choice of building location makes it possible to clearly determine the loads acting on the building. This is necessary to check the load-bearing conditions

In addition to collecting the loads at this stage, attention should also be paid to the combinations of these loads in accordance with formulas 6.10a and 6.10b of the PN-EN 1990 standard showing the correlations of the occurrence of individual loads. It should also be emphasized here that the calculation of loads includes not only aspects visible from the outside, such as climatic loads or self-weight, but also what we cannot see, such as the load-bearing capacity and internal stresses of the soil or seismic loads related to earthquakes. Therefore, it is necessary to study the location of the object, whether it is located in post-excavation areas.

g) Development of a simplified 2D model to check the load capacity of individual straight elements, e.g. a beam

There are several ways of checking the load-bearing capacity of a structure, one of which is to carry out manual calculations of successive elements according to the guidelines of the applicable regulations. However, it is also possible to use calculation programmes, for which a calculation model must be created. This solution speeds up the calculation process and reduces errors. Calculation models can be accurate and complex, e.g. solid, or partially simplified – 3D. The maximum simplification is in the 2D calculation, which, when used correctly, allows individual elements to be calculated over a short span, but the interactions between the elements must be taken into account.

h) Development of a 3D model to check the overall stability of the facility

The spatial solution allows the interaction of elements between planes to be taken into account, and represents a compromise between working time and the accuracy of the structural model.

i) Development of a detailed model of the roof girder, checking the load capacity of selected profiles

Once the general stability has been checked, it is possible to proceed to detailed calculations. Depending on the solutions adopted, different elements and their interaction are considered. The structure is usually calculated "from above", starting with the climatic loads, so the first element in the case of the hall will be its roof. In the case under consideration, the supporting structure of the roof consists of a steel truss.

j) Checking the load capacity of a reinforced concrete column

The steel truss is supported on columns, in this case of reinforced concrete. The static scheme of the two elements is significantly different, so this has been broken into two subsections

k) Checking the load-bearing capacity of the foundation and the substrate

The last area is the foundation and the substrate immediately beneath. Both should be checked taking into account all the loads above

l) Import of the girder model in order to create connections

A lattice girder is composed of top and bottom chords, posts and diagonals. The profiles used can be round, square or e.g. I-sections, or a mixture of solutions is possible. Depending on the choice, the appropriate connections between the profiles must be selected. Suitable programs with a built-in connection database can help with this, such as Robot, Advance Steel or IdeaStatica.

m) Checking of connection details

Once the connections have been selected, their load-bearing capacity should also be checked; as with general stability, standards or software can be used.

n) Execution of complete implementing documentation

The final element is the execution of full documentation, an extensive and completed technical description, all calculations as well as drawings of each component

2.2. Chronology of the curriculum

Below, the range of subjects taught during the Construction Course will be briefly discussed in a chronological order. Primarily those aspects that overlap with the diagram in subsection 2.1 will be highlighted. In addition, the learning of the software will be shown together with examples of their application.

a) Building materials (semester I)

A subject directly linked to the aspect of "selection of materials". It discusses possible solutions and the conditions they must meet.

General design

The most important early subject consisting of several cycles run in different semesters. It discusses structure concepts (starting from the completed ones), types of structural solutions and how loads are collected. Towards the end, simplified calculations of the individual elements are also presented. Figure 3 contains a diagram showing the collection of loads on a lintel, one of the aspects covered in the general design subject. The course also provides an introduction to the AutoCad drawing software using the example of plans and sections of a single-family house.

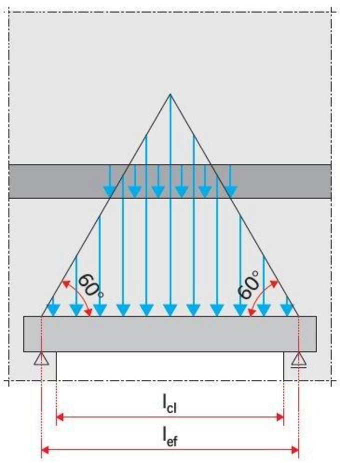


Fig. 3. Diagram showing the collection of loads on the lintel (source: own study)

a) Construction law (semester II)

At this stage, it is important to learn the applicable standards and design guidelines, as well as the conditions that must be met. In order to fulfil the situational conditions, it is first necessary to know where to look for them.

b) Structure physics (semester III)

The thermal aspect is becoming increasingly important in the design process, and every few years the requirements for the thermal insulation of buildings and the energy balance are increased. The calculations presented here enable thermal conditions to be met.

c) Theoretical mechanics (semesters I, II, III)

The next phase, when all the assumptions and the initial selection of materials have been made, is to perform the calculations of the individual components. The subject is extensive and is also spread over several semesters, this is due to the multitude of structural solutions that need to be understood from the ground up, starting with the working diagrams, through to the determination of internal forces. Figure 4 shows a static diagram of a two-span beam for the determination of internal forces. The course introduces the basics of simple models in the Robot software.

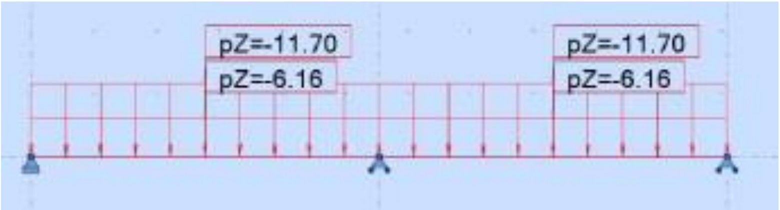


Fig. 4. Static diagram of a double-span beam (source: own study)

d) Soil Mechanics and Foundations (semesters IV, V)

The basis of any structure is the foundation and the ground beneath it. The ground is a continuous and isotropic medium, but understanding the distribution of stresses and strains is an important aspect of structural stability

e) Concrete structures (semester IV)

The subject launches a series of courses related to reinforced concrete structures. In the first phase, the design of a rib-and-slab floor is presented. The calculations are carried out in stages, each successive element separately calculated on a 2D plane. Fig. 5 shows the static scheme and the loads on the floor grid. The calculations and technical description are carried out using Smath software, where calculation formulas and load-bearing conditions in accordance with standards are introduced. The program is used to speed up calculations and facilitate possible changes to the adopted solutions.

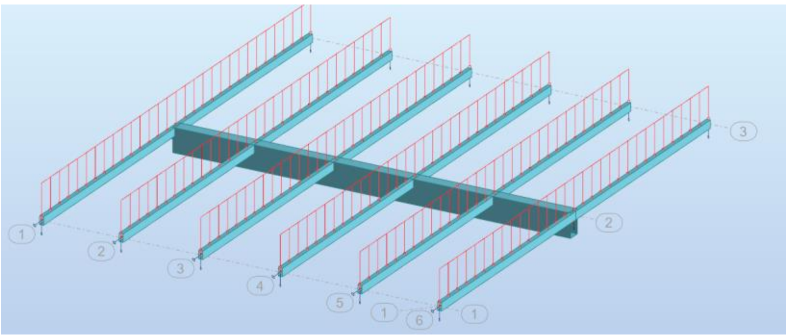
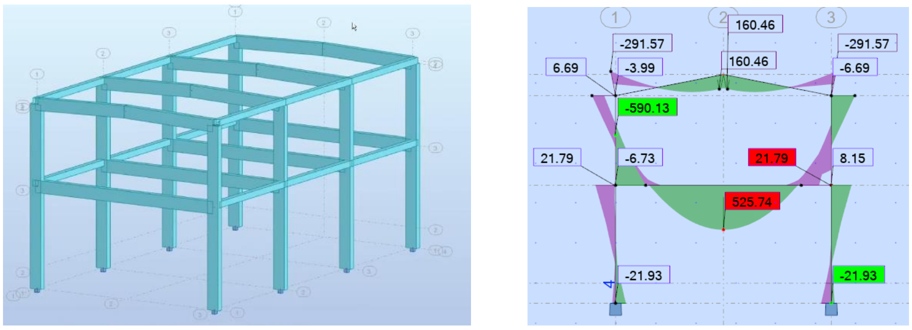


Fig. 5. Static diagram and loads of the rib-and-slab floor grid (source: own study)

f) Building concrete structures (semester V)

The next in the series of subjects develops skills in the design of reinforced concrete structures. The calculation of a warehouse hall is presented, with the entire structure calculated in 3D space. Fig. 6 shows a diagram of the warehouse hall columns and beams, as well as the internal forces in the main frame.

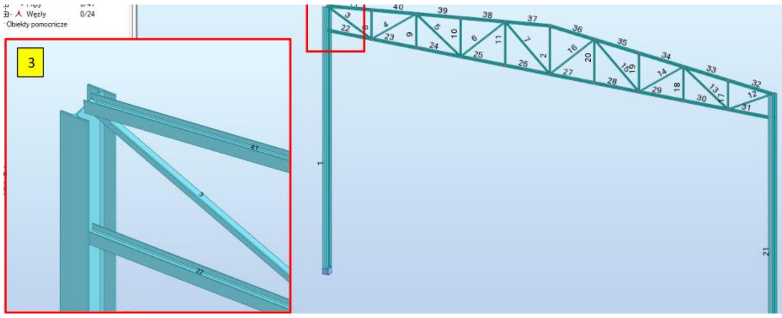


(a) (b)

Fig. 6. Warehousing facility, (a) column and beam diagram, (b) internal forces present in the main frame (source: own study)

g) Building steel structures (semesters V, VI)

A follow-up subject in steel object course. The model to be calculated is similar to the one already learnt on building concrete structures, however, it deals entirely with steel. It shows an example of a steel hall with a lattice girder. Fig. 7 shows the main load-bearing frame of the structure.

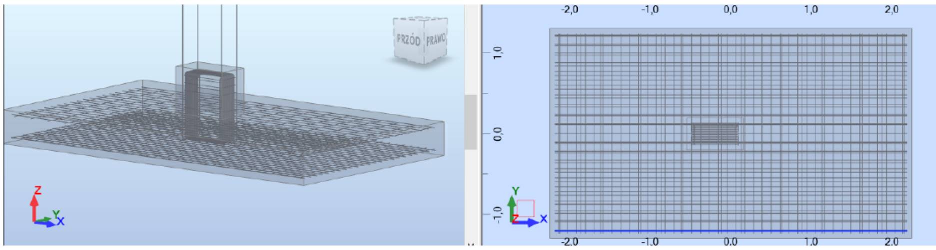


(a) (b)

Fig. 7. Main support frame of the steel hall structure, (a) zoomed-in photo showing profiles, (b) a view from a distance (source: own study)

h) Complex concrete structures (semester VII)

Development of the subject concerning building concrete structures. A similar hall structure is calculated during the course, but some of the calculations are simplified by using advanced functions of the Robot software. Fig. 8 shows the automatically generated reinforcement for the foundation footing of a reinforced concrete hall.



(a) (b)

Fig. 8. Automatically generated reinforcement of the reinforced concrete hall foundation footing, a) 3D view, b) top view (source: own study)

i) Metal structures II (semester VIII)

Development of the subject cubic steel structures. The design of a telecommunications tower with steel lattice girder-like walls is presented. The structure is considered in terms of the load-bearing capacity of the individual elements; the use of advanced functions of the Robot programme allows the cross-sections to be easily optimised by iterating the calculation results. Fig. 9 shows a diagram of a telecommunications tower.

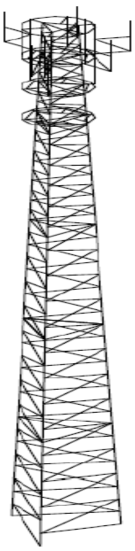


Fig. 9. Telecommunications tower diagram (source: own study)

j) Computer-aided design (semester IX)

The course combines all the previous units, additionally introducing an advanced 3D drawing tool called Revit. The course introduces the 3D drawing of the hall structure, its import into the connection modelling program and then into the calculation software. Please remember that depending on the university and the program in force in a given academic year, courses may have different names and appear in different semesters. The examples described above concern the 2015–2021 cycle. A summary of the names of subjects and semesters in which they may appear and their uses is presented in Figure 13.

3. Possible consecutive development paths

The curriculum has been developed in detail, but it can be developed further. Students are introduced to the calculation of structures and the applicability of various programmes, but this is only a small part of the technology available on the market.

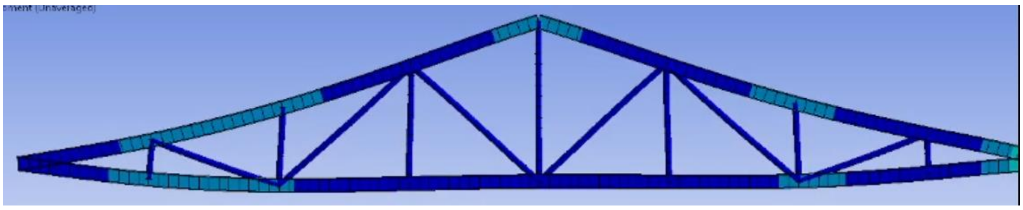
Two examples of additional subjects will be presented below, together with an example of the use of the latest software. These could be taken at the very end of the programme, due to the level of sophistication and theoretical preparation required. Please remember that at this stage, students have already obtained their first diploma (bachelor degree – semesters I–VII) and started advanced studies (masters degree – semesters VIII–X).They are ideally suited to specialisations

a) Structural vibrations [3–7]

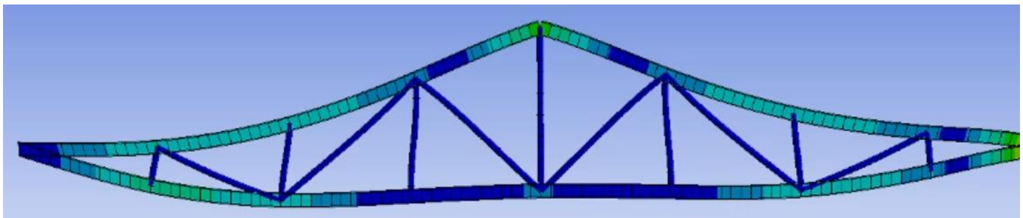
The course may show how to design structures under dynamic loading.

The design comprises a model of the structure under static and dynamic loading, representation and comparison of internal forces. The ideal tool in this case is one of the modules of Ansys – Dynamics software suite.

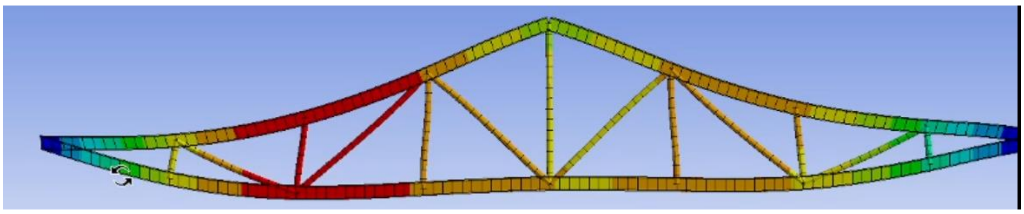
The deflection of a steel truss in different phases of loading is shown below (Fig. 10).



(a)



(b)



(c)

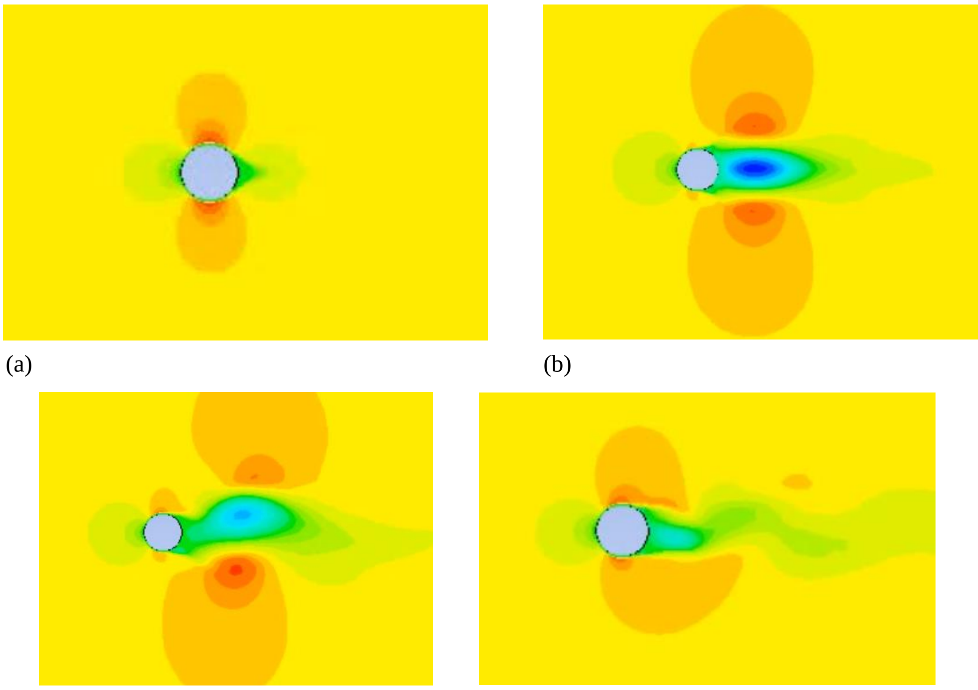
Fig. 10. Example of deflection of a lattice system over time, (a) 1 second, (b) 2 seconds (c) 3 seconds (source: own study)

b) Wind engineering [8–11]

The course introduces wind models, wind scales, strong wind, the phenomena of flow around bodies with different geometries, the use of CFD in wind engineering, discusses how to design buildings exposed to strong wind, the effects of wind on different structures and people, and wind comfort.

The underlying design idea, could be to create a model of the wind enveloping a body-building, both in plane and in space. The ideal tool in this case is one of Ansys' Fluid (CFD) modules. It not only uses the laws of physics describing the complex behavior of wind, but also uses calculation standards such as PN-EN 1991-1-4. However, it should be remembered that the wind aspect is still being developed and the guidelines go beyond the design standards (especially in the case of strong winds with a speed of v>50 m/s, which corresponds to the second category on the improved Fujita scale). Design should often be supported by recommendations from the literature, such as articles on wind comfort, laboratory tests describing wind models in close proximity to the structure or the impact of these models on other structures (e.g. tandem buildings).

Figure 11 shows an example of air flow around the cylinder depending on the duration of the load. The individual parts of Figure 11 (a to d) show the wind speed in different areas around the cylinder.



(a) (b) (c) (d)

Fig. 11. Example of cylinder flow over time, (a) 1 second of movement, (b) 2 seconds of movement (c) 3 seconds of movement (d) 4 seconds of movement (source: own elaboration)

4. Conclusions

This paper presents the process of building information modelling, the different phases and their scope. In order to work correctly and quickly, appropriate computer software should be used.

A summary overview of the selected software with the assignment of the phases of the building information modelling process is presented in Figure 12.

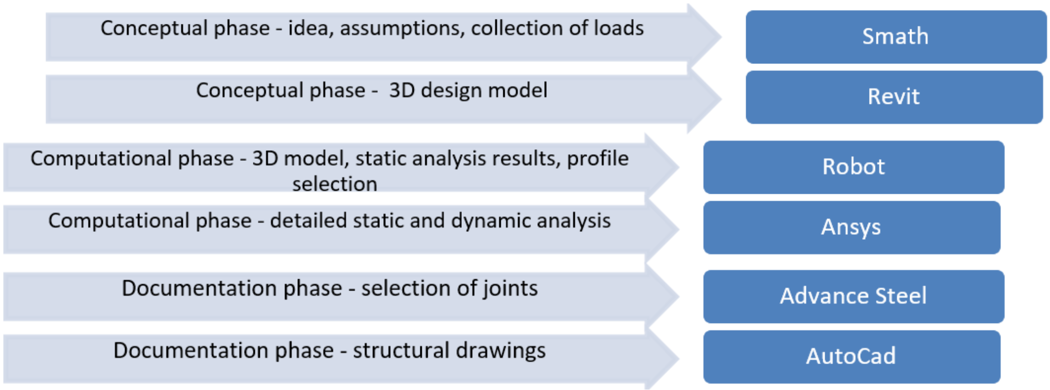


Fig. 12. Summary overview of the selected software suites with the building information modelling process phases assigned to them

The most important aim of this paper is to compare the general design scheme with the curriculum of a technical university. The comparative diagram is shown in Figure 13, it shows the selected subjects of the curriculum in chronological order and shows the key aspects covered by them. The entire curriculum is also compared with the general diagram of facility design.

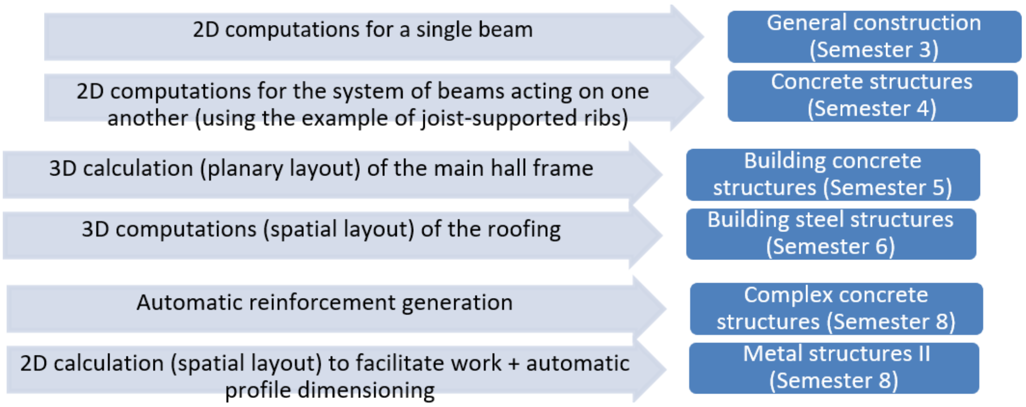


Fig. 13. Schematic comparison of the general design diagram with the technical college curriculum

A key aspect of studying is continuous development, and possible development paths are presented below – a summary of new subjects together with the software application. Of course, you should remember that there are also other programs not mentioned in the text, such as Sap2000 (Fig. 14).

Fig. 14. Schematic comparison of possible new subjects with the software applied to them

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SUSTAINABILITY DEVELOPMENT AS A PILLAR OF ECO-CONSTRUCTION

Abstract. *The paper emphasizes that the principles of EU environmental policy indicate, among other things, the need to take into account environmental considerations and effects in all types of economic activity and in all phases of its operation. The construction sector has a highly advanced relationship with environmental problems. The erection of building structures means direct interference with the natural environment. Sustainable development, meaning a balance between the environment, society and the economy, is currently noted as very important.*

Keywords: eco-construction, Ecological Maturity of Construction Enterprise – EMCE, sustainable development

1. Introduction

The construction sector has an extremely high relationship with environmental problems. The erection of building structures means direct interference with the natural environment. The interaction between construction objects and the environment continues throughout the life cycle of the objects. They are influenced by decisions in the investment programming phase, planning the course of construction projects, in the execution phase, as well as in the operational processes. Pro-environmental awareness of the entities involved in the tasks of the subsequent phases of the life cycle of construction objects determines their correct coexistence with nature [1].

Construction activities shape the human environment throughout the life cycle of construction investment projects. Therefore, problems related to the environmental quality of the solutions used require special attention. The way these problems are solved can be linked directly to the entities involved in the projects. It is important to see the role of the construction company, in the course of solving decision-making problems in projects and, in particular, their ecological responsibility. Linking the ecological maturity of actors, involved in the implementation of construction projects, taking into account the ecological approach, is related to the management of limited resources and the possibility of reducing their impact on the environment. Among the most serious impacts are carbon emissions released due to use of concrete, steel, cement and other construction materials. For instance, concrete contributes significantly to the greenhouse gas (GHG) footprint, leading to significant effects on the Earth's climate. According to data published in 2012, the production of concrete accounted for around 8.6% of all human-caused carbon dioxide (CO_2) emissions during only that specific year [2]. Typically, the manufacturing of a single ton of cement clinker results in the creation of roughly an equivalent amount of carbon dioxide [3]. Therefore, this situation puts significant pressure on decision-makers to decrease an energy consumption and a CO_2 emissions in production processes of construction materials.

However, the problem lies not only in the production of the materials, but also in the way they are used by contractors. Consideration of the environmental behaviour of enterprises is a starting point not only for researchers of the environmental maturity of construction enterprises and the sensitivity of the idea of environmentalism in projects, but also for professionals and public administration. The articulated factors of ecological maturity can be used to measure the degree of implementation, in construction enterprises, of the principles of greenness of implemented projects throughout their life cycle.

The need to build the environmental maturity of construction enterprises is emerging.

The ecological maturity of an enterprise can be defined as the ability to manage professionally with ecological factors in mind.

It is of great importance to disseminate the concept of EMCE (Ecological Maturity of Construction Enterprise) among construction entrepreneurs. Continuous improvement in the operation of construction enterprises should take into account the concept of the EMCE as a determinant of their development. A high level of the EMCE is the achievement of economic goals, meeting environmental requirements and social expectations. It is conducive to achieving investor satisfaction, which builds a good image for contractors of construction projects. In a construction company, EMCE maturity means equivalent treatment of business and technological-organizational problems both at the level of positions, processes and the entire organization. It is an important determinant of the success of a construction company that participates in shaping the environment.

The building contractors perceive the need to strengthen the EMCE. They allowed to articulate the ecological maturity factors of enterprises, operating in the construction market.

The EMCE can be seen as a driver of the success of investment and construction projects. It can be a significant differentiator in the competitive construction market, determining the success of construction investment projects. This concept holds the potential to bring about substantial benefits for nature and the environment. By aligning construction practices with ecological principles and sustainability, EMCE can contribute to several positive outcomes for nature. First of all, the EMCE emphasizes the efficient use of resources, including raw materials, energy, and water. By adopting practices that minimize waste and optimize resource utilization, construction enterprises can reduce the overall environmental impact of their operations, helping to conserve natural resources. As a matter of fact, the EMCE can encourage the use of cleaner technologies, materials, and construction methods that produce fewer pollutants and greenhouse gas emissions. This helps in minimizing air, water, and soil pollution, leading to improved air quality and healthier ecosystems. Besides, the EMCE may promote the use of sustainable and eco-friendly construction materials, such as recycled materials, locally sourced resources, and renewable materials. This also reduces the demand for raw materials and minimizes the environmental impact of material extraction and processing. Additionally, the EMCE, implemented as a part of the corporate DNA, can emphasize considering the entire life cycle of a construction project, from design and construction to operation and potential decommissioning. This holistic approach helps identify opportunities for reducing environmental impacts over the project's entire lifespan. In summary, exploiting the concept of the EMCE can benefit nature by promoting sustainable construction practices that conserve resources, reduce emissions, preserve biodiversity, and integrate nature into the built environment. This approach contributes to a healthier planet and enhances the long-term well-being of both human and natural systems.

While developing the EMCE, it is vital to take into account the problems of forming enterprise maturity in different dimensions of its functioning.

Attention can be paid to the experience of building project maturity [4] or process maturity [5].

Undertaking projects in construction enterprises involves deep and long-lasting interference with the environment, and is a nuisance to the surroundings, both at the stage of erection of buildings, as well as their operation and decommissioning. This is due to the nature of the outcome of construction activities.

It should be noted that there is an option of making assessment of the quality of construction solutions of investment projects by analysing their environmental performance, also formulated as ecological quality. The concept of environmental performance of a construction project is defined as the adaptation of the solutions used throughout its life cycle to perform in accordance with respect for the environment. The life cycle of a construction project begins with the articulation of construction needs, followed by the concept and feasibility study of the project throughout its life cycle. This is followed by the design of the construction facility and execution processes. The consecutive phases of the project life cycle are the implementation of logistics and construction processes, which ends with commissioning. Next the structure operation takes place and ends with its decommissioning. The processes of shaping the structure in the programming, design and implementation phases are connected with the operational processes and the decommissioning phase.

It is also necessary to emphasize the need to take into account the subject perspective in the assessment of environmental performance. This is due to the fact that each stakeholder should perceive all phases of the construction project cycle.

It should be noted that in the area of construction enterprise management, it is worthwhile to disseminate the responsible partnership of science and business, as a manifestation of sustainable development of theoretical and practical knowledge.

The current trend in the preparation of construction investment projects is to take into account the environmental performance of construction sector products. The challenge in this field is to take into account the principles of Circular Economy (CE). CE implies minimizing the environmental impact of the products of anthropogenic activity by using technological and material solutions to minimize environmental risks.

At the theoretical layer, the circular economy is based on the assumption of the limited resources and environmental capacity of the globe.

CE comes along with the concept of cradle-to-cradle ("cradle to cradle"), or Design for Deconstruction as a way of designing and erecting buildings in accordance with the concept of sustainability so that once the buildings are out of use and demolished, the materials used can be put back into circulation. CE promotes the 4xR concept: Reduce, Repair, Reuse and Recycle.

The practical side of the circular economy aims to reduce waste, take care of the environment, and efficiently and cleanly manage energy in conjunction with economic growth [6].

The principles of the EU's environmental policy indicate, among other things, the need to take into account environmental considerations and impacts in all types of economic activities and in all phases of their operation.

Construction is a very complex and heterogeneous sphere of activities. There are several major classifications of building structures, which vary widely: residential, non-residential, highways, industrial and public buildings, and structures. Construction projects include new construction, renovation and demolition of both residential and non-residential structures. They also include public works projects, such as streets, roads, highways, utility greens, bridges, tunnels and overpasses. The success parameters for each project are in the category of time, within a certain budget and required performance. The main barriers to success are changes in the project environment. The improvement of construction project management processes and the efficient use of resources is positively influenced by risk management [7]. The development of a new building structure, as well as its renovation, modernization or restoration of its original condition, requires a number of conscious actions and decisions. The sequence of these coordinated activities and actions of a technical, technological, organizational, legal, financial, etc. nature, which lead to the realization and operation of the planned construction project within a certain time and cost, is called the construction investment process. On the other hand, the full life cycle of an investment is the time from the idea of realizing the investment until the decommissioning of the investment along with the effects of its existence, for example, on the environment [8].

2. Eco-construction underlying assumptions

Criteria used for assessment of the environmental quality of construction projects can be generally divided into: criteria of a general nature, taking into account the adopted construction-material and technological solutions, and specific criteria relating to the subsequent phases of the life cycle of a construction project.

The problems included in the criteria for assessing environmental performance have a variable impact on the interests of individual participants in a construction project.

The evaluation of each criterion must be done individually in the perspective of the stakeholders, e.g.: investors, designers, construction contractors, suppliers of construction materials, users of the facility, local community, construction administration.

The specification of these criteria is shown in Table 1.

Tab. 1. Criteria for assessing the ecological quality of a construction project (source: the own work according to [9])

O.n.	**Criteria**	**Description of the criterion**	**Stakeholders**
I general criteria			
I.1	construction and material solution of the building with regard to CE	design of the building structure and building materials should meet the requirements of CE	all participants of the project
I.2	the method of constructing the building with regard to CE	technological processes of the construction phase of the building should be susceptible to the use of CE	all participants of the project
I.3	the exploitation of the object including the CE	operating processes should meet the CE requirements	all participants of the project
II detailed criteria			
II.1	formulated construction requirements	in the course of formulating this criterion, there are premises for choosing specific solutions (related to structural design or materials used) for a building or a non-building structure	investors, designers, facility users, local community, construction and environmental administration
II.2	concept and feasibility study	features of a building or a non-building structure, a feasibility study should signal problems within the entire project life cycle and its relationship with the natural environment	investors, designers, facility users, local community, construction and environmental administration

O.n.	Criteria	Description of the criterion	Stakeholders
II.3	design of the building and building processes	functional and utility solutions, methods and techniques for the implementation and operation of the facility environment-friendly	all participants of the project
II.4	logistic processes	logistic details including solutions for the supply of resources, including means of transport, routes of transport and place of delivery, compliant with the requirements of the natural environment	investors, designers, contractors of construction works, suppliers of building materials, local community, construction and environmental administration
II.5	construction processes	presentation of technological and organizational variants, including respect for the natural environment	investors, designers, contractors of construction works, suppliers of building materials, local community, construction and environmental administration
II.6	exploitation	problems of environmentally safe operation of the facility, maintenance of the facility in full usability, principles of environmental control of the building	investors, designers, contractors of construction works, suppliers of building materials, facility users, local community, construction and environmental administration
II.7	liquidation	methods of demolition work, material recovery including CE	investors, designers, local community, construction and environmental administration

The implementation of ecological strategies for environmental management is possible provided that the environmental information processing system is adequate to reality. This applies to both modelling, i.e. the creation of a mapping of component production systems, and the quality of input data, mainly the specification of the appearance of environmental hazards. Also important are the ways of presenting the processed information and interpreting the results. In particular, we can mention: how to build a model of the impact of manufacturing processes on the environment (the model's compliance with reality), the complete specification of hazards, taking into account the risk of variability, the importance of the impact of hazards on individual characteristics of ecosystems, how to estimate the magnitude of the accuracy of critical data (accuracy of measuring devices, accuracy of readings). It should be borne in mind that small changes gradually accumulate in trends, so any restoration of reality for greening decisions should be dynamic.

The progress of civilization comes along with a number of potential environmental hazards. The resulting production facilities operating in the environment, on the one hand, benefit from environmental goods and, on the other hand, are a source of emissions and waste. The products of manufacturing processes are also a conundrum for the environment. From the point of view of the manifestation of hazards that cause environmental risks, it is possible to classify the factors of environmental hazards from production systems. The relationship of production systems and the environment is shown in Figure 1.

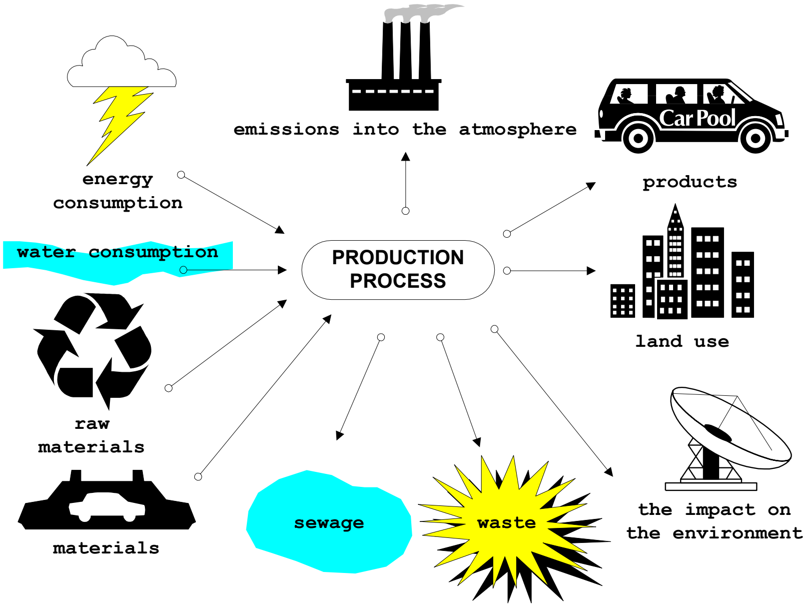

Fig. 1. Diagram of the environmental impact of the production process (source: the own work according to [10])

Enterprises, in search of success, are incorporating current market trends into their management philosophy. An example is the noting of the idea of the EMCE as a challenge, resulting from the growing environmental awareness of societies around the world. Researchers' inquiries into ecological problems have led to the formulation of the Ecodesign Maturity Model (EcoM2) [11, 12].

The development of the EMCE involves the implementation of an environmental strategy based on continuous, integrated preventive measures for processes, goods and services, aimed at increasing the efficiency of production and services and reducing risks to people and the environment [13].

In a construction company, the production process is combined with the concept of reducing the use of resources and the environmental impact of the product.

This applies to all stages of the life cycle of construction facilities.

3. Sizing of the sustainable development in the investment and construction projects

The limited capabilities of the environment when it comes to providing natural resources and dealing with pollution are the basis for introducing sustainable development [14].

A holistic view of an investment and construction project requires seeing the perspective of sustainable development. A sustainable development approach should focus on social, economic and environmental problems [15].

The concept of sustainable development establishes a balance in respect for the natural environment, as well as the anthropogenic (including economic) and human environment. It ensures a lasting improvement in the quality of life of present and future generations through the proper shaping of the proportions between the various types of capital: economic, human and natural. Sustainable development is social and economic development, in which there is a process of integrating political, economic, social activities with preservation of natural balance and sustainability of basic natural processes in order to ensure the possibility of satisfying the basic needs of individual communities or citizens of both the present and future generations [16].

The constrained ability of nature to supply natural resources and dealing with pollution are the basis for introducing sustainable development [1].

A significant part of investment and construction projects are large projects, often carried out in international cooperation. The specificity of such projects is due in particular to the nature of the products. Construction facilities are most often products with a significant range of tasks set, a long implementation and product life, a significant cost of production and use, and, above all, are characterized by a significant impact on the environment – in principle, they shape the human environment. Hence the large number and variety of stakeholders in investment and construction projects – from the traditional for projects: the sponsors (investors) of the project and its implementing bodies (the project team with the project manager) to the local community (in the immediate vicinity of the implemented project) and also societies in the broader sense, exposed to the consequences of the existence of erected buildings. Interaction of investment and construction projects with the environment depends on the type of structure, its size, location and a number of other general and specific conditions for such projects.

The long life cycles of investment and construction projects, counted from the idea, through its materialization, maintenance to the stage of decommissioning of the erected objects, make it necessary to take into account the philosophy of sustainable socio-economic development, harmonized with respect for the environment. Adherence to the principles of sustainable development in relation to construction means designing solutions of construction objects (buildings and structures) and ways of their implementation in a way that is friendly to humans and their environment, taking into account the economic calculation [17].

Construction has a negative impact on the environment. With the continuous increase in pressure for sustainable development, it is extremely important to take steps to reduce the amount of waste generated by the construction sector [18].

To reduce significantly the level of ecosystem degradation, construction waste management must be optimized. To this end, a model was analyzed to benchmark the performance of construction waste management.

The results of the Hong Kong researchers are optimistic. The use of this model is also recommended in Poland. It gives a strong tool for the government body and entrepreneurs themselves to control activities in Construction Waste Management (CWM). A contractor can compare his performance against his peers or against his past performance and mark his practices as "good," "average," or "not so good. This allows them to optimize their CWM practices to improve their performance. In addition, the government, or the authority in charge of waste management, can spur those companies labeled as 'not so good' in the analysis to improve their CWM performance, such as by imposing fines on them.

4. Conclusions

The peculiarities of construction activities have a significant impact on shaping the nature of investment and construction projects. Their undertaking is associated with deep and long-lasting interference with the environment, is burdensome for the surroundings, both at the stage of erection of objects, as well as their operation and decommissioning. It requires the consumption of considerable material resources, as well as the involvement of a number of specialists and institutions that make decisions in the subsequent phases of the life of the erected facilities. Therefore, these projects have many stakeholders – stakeholders with varying degrees of involvement in their various stages.

Sustainable development, meaning a balance between the environment, society and economy, is currently noted as very important.

When analysing investment and construction projects from the point of view of environmental protection, it is necessary to take into account such factors as:

– the consumption of non-renewable raw materials and the energy required for their processing, especially in the phase of erecting construction objects,
– the amount of emissions of harmful substances, especially in the phase of operation of objects,
– an option of recycling during the decommissioning phase of the facilities.

Construction facilities should be carried out using such technical solutions that, in an energy-efficient manner, will allow the lowest possible consumption of natural resources during the construction and use phases, and at the final stage will allow the facility to be easily disposed of.

When choosing construction technology and the shape of the structure, it is necessary to take into account the economic aspect, related to the operation of the object and the demolition of the object.

The long life cycles of investment and construction projects, counting from the idea, through its implementation and maintenance to the decommissioning stage, make it necessary to consider the principles of socio-economic sustainability.

The main idea behind the above considerations is respect for the environment. Adherence to the principles of sustainable development in relation to construction means designing solutions of construction objects (buildings and structures) and ways of their implementation in a way that is friendly to humans and their environment, taking into account the economic calculation. Therefore, the main factor determining the planning of implementation activities is the design documentation, the purpose and the object of the planned investment project.

Consideration of the problems of environmental quality of construction projects should take into account general criteria, describing the characteristics of a particular type of project of interest to all project participants. On the other hand, a number of specific criteria, relating to individual phases of the project's life, must be considered individually from the perspective of a particular project stakeholder.

The analysis of the environmental performance of design solutions, allows individual stakeholders to use the assessment of ecological quality in deciding on the choice of design solutions (e.g., by the investor), or to engage in given construction projects (e.g., by the contractor of construction tasks).

In the assessment of environmental performance, depending on the entity under consideration, the choice of specific criteria may vary, as well as the weights assigned to each criterion, valued according to selected parameterization principles, such as the adopted point scale.

A significant factor in the success of investment and construction projects is the EMCE. An increase in the level of ecological maturity, through the development of rational thinking and good ecological practices in the enterprise, means greater efficiency in its operation.

In particular, to minimize the environmental impact and support the EMCE, the selection and use of materials play a crucial role. Employing sustainable and eco-friendly materials can significantly reduce resource consumption, pollution, and overall environmental harm. Primarily, it is vital to use materials with a high recycled content, such as recycled steel, concrete, and glass. Also, choosing materials that are sourced locally to reduce transportation-related emissions and support the local economy can be an effective way to minimize the ecological footprint associated with long-distance transportation. It may be useful to incorporate materials that are renewable or have minimal ecological impact, such as bamboo, straw, cork, and responsibly sourced wood. These materials have lower embodied energy and contribute to a smaller carbon footprint. Besides, using insulation materials that provide effective thermal and acoustic parameters, reducing the energy required for heating and cooling buildings may become a practical way to support sustainability solutions in the construction industry. Ultimately, opting for natural and non-toxic finishes such as low-VOC paints, stains, and sealants to improve indoor air quality can be a solution to minimize the environmental footprint of the building sector. By incorporating these and other principles and materials into construction projects, enterprises can reduce their environmental impact, promote sustainability, and contribute to the ecological maturity of the whole construction industry. It's important to approach material selection holistically, considering factors such as energy efficiency, durability, local context, and overall environmental performance.

All in all, the maturity of a construction company in terms of environmental sustainability, described as the EMCE, is manifested in the understanding of the close interdependence of its success and respect for the environment through the implementation of environmental knowledge in the company. At the same time, the idea of the EMCE in an organization must be implemented at both the strategic and operational levels, including with regard to individual, on-going construction projects. This approach creates success factors for the enterprise.

Project implementation requires the adoption of implementation strategies in the design of production system structures, based on specific criteria. The set of tasks posed to the organization by decision-makers constitutes the palette of strategies, while the operational level resolves how to implement these tasks. Problems of the operational level can contribute to strategy revision. Hence the coherence of activities at the strategic and operational levels.

The strategic management in an enterprise mainly refers to capacity building to achieve the set goals, in line with the adopted vision and mission of the organization. The strategic level provides a platform for generating internal projects, with objectives leading to the concretization of the adopted goals of the enterprise. Environmental management at the strategic level promotes the creation of an innovative organizational culture. Projects of a strategic nature most often lead to restructuring towards a strategic resource orientation. They adapt the organization to undertake green investment and construction projects.

Management at the operational level, first and foremost, requires the alignment of corporate goals and the project goals under implementation, ensuring mutual benefits. At the operational level, project management should be viewed primarily as organic management. This applies to both the manner of involvement and the project portfolio, and in particular to the distribution of the company's project activity as a function of time. The selection of the project portfolio, including the schedules for the implementation of individual tasks, should take into account the use of environmentally friendly resources of the enterprise. Mention can be made of having low-energy equipment, the use of which in individual projects depends on the schedule of project implementation.

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DRIED SLUDGE AND BIOMASS AS RENEWABLE FUEL

Abstract. *The paper presents some of the issues arising from the implementation of policies to enhance the share and application of biomass and dried sludge with 90% dry matter content in the thermal and energy management. The application of gasification and pyrolysis techniques in the thermal conversion of chemical energy of renewable fuels including straw and bark is feasible. The gas produced is burned in the boiler's combustion chamber, and the heat produced through thermal processes, can be used for heating purposes. The use of renewable fuels in the power and district heating sector can contribute to the waste recycling implementation. The replacement of hard coal in the district heating sector will reduce dust emissions, harmful compounds into the atmosphere through the use of waste-free and low-emission biomass combustion using pyrolysis and burning the gas produced. The application of organic waste and biomass as fuels is possible and desirable for many reasons. New technologies for the processing and combustion of renewable fuels, especially gasification technology, are safe for the environment due to the low level of pollution of flue gases with harmful sulphur and nitrogen compounds. The high efficiency of energy conversion ensures the profitability of investments in the production of fuels from biomass and the combustion of generator gas to generate heat or electricity. Burning renewable fuels produces a negligible amount of ash, which can be used as fertilizer. Processing biomass into pellets, briquettes or wood chips not only facilitates the transportation and distribution of these fuels but also stabilizes their quality. Processed fuels are homogeneous, have similar dimensions, stable properties such as calorific value, and this makes it easier to operate boilers and automatically regulate the course of thermal processes. The use of this type of fuel is intended to increase the possibility of obtaining additional renewable energy sources. Research results are presented.*

Keywords: biomass, dried sludge, co-firing, gasification, thermal processes, heat

1. Introduction

Poland's signing of the Kyoto Protocol in 2002 introduces the obligation to reduce greenhouse gas and dust emissions. These issues are supported by the European Union through the introduction of Directive 2001/77/EC on the electricity generated from renewable energy sources. The Ordinance of the Minister of Economy, Labour and Social Policy of 30 May 2003 *on the detailed obligation to purchase electricity and heat from renewable energy sources and electricity co-generated with heat*, giving an opportunity of co-firing.

Globally, biomass resources are calculated at 280 EJ/year and are about 6 times higher than their utilization rate. On the other hand, biomass production growth involves the need to allocate large areas of land for growing energy crops. Global biomass resources currently account for 9 to 13% of energy demand [1–4].

Implementation of technologies for combustion of unconventional renewable fuel, such as biomass, will contribute to reducing environmental pollution by waste and harmful combustion products containing harmful nitrogen and sulphur compounds. On-going research is increasing the body of knowledge about the course of thermodynamic processes during biomass combustion, while leading to improvements in combustion equipment.

In order to achieve high combustion efficiency, pressure agglomeration of biomass, commonly referred to as briquetting, is necessary. This procedure, although energy-intensive, at the same time increases the energy efficiency of such a form of fuel as a result of increased density, lower moisture content, storage and the possibility of combustion in conventional furnaces.

Biomass in the form of briquettes is homogeneous, has stabilized thermal parameters, density and moisture content. Combustion of briquettes proceeds smoothly under established conditions with high thermal efficiency of thermal processes and conversion of chemical energy of the fuel into heat.

2. Sludge

Drying of sludge is a prerequisite for its eventual utilization as fuel. Incineration of dewatered sludge after pressing, with a moisture content of 75÷84%, is practically a technologically impossible and economically inefficient process.

Sludge drying is an extremely energy-intensive technological process. Heat for drying can be obtained by burning biogas from wastewater digestion. By treating part of the sludge as biomass and subjecting it to thermal conversion, additional energy will be obtained. From the sludge, which is subjected to water evaporation in the dryers, we obtain organic fertilizer in granular form with a dry matter content of 90%. The dried sludge can be reused for co-firing as a fuel mixture with waste wood, straw or coal in various mass proportions. The calorific value for dried sludge is about 14 MJ/kg, and containing about 35% ash [Own research].

Co-firing of dried sludge with biomass can be a form of alternative fuel. This form of fuel can be subjected to the gasification process, which will increase the efficiency of combustion [5–9].

3. Bark

The term ”bark” is used to describe all primary and secondary tissues located on the cross-section of the plant outside from the pulp. The problem of using waste bark arose first in America, then in Europe with the introduction of mechanization of the debarking process. The proportion of bark to the total weight of the trunk varies depending on the species of tree, ranging from 10 to 17% for pine. Bark is superior to wood in ash content, and its content in the SLR of young trees is about 3.5%, and in the deadwood 1.7% [1–4].

Bark is not a valuable, in terms of energy, waste of the timber industry, accounting for 10 to 15% of the weight of harvested wood. Its calorific value is 18.5÷20 MJ/kg, its moisture content is 55÷65%, and its ash content, which tends to slag, is 1÷3% of dry mass. [Own research].

Bark pyrolysis (decomposition distillation) should be understood as thermal decomposition of bark with limited access to air. Decomposed bark, with low moisture content, is relatively easy to thermally decompose at a temperature of 270 to 400°C, using a fluidization technique with nitrogen.

As a product of bark pyrolysis, we get a gas containing carbon monoxide and dioxide, methane, hydrogen, liquids, consisting of 20% methanol and acetic acid and acetone, as well as tar and thermal decomposition products of resin in the case of pine bark. Instead of the pyrolysis process, we can carry out bark gasification, which is thermal decomposition with a supply of air with steam. As a result of such combustion, a gas is formed and minerals are produced in the form of ash. The components of the gas are hydrogen, carbon monoxide, methane, and the non-flammable components carbon dioxide and nitrogen. The calorific value of the gas obtained increases with the proportion of combustible gases. In the case of gasification of bark admixed with wood waste, about 4m3 of gas can be obtained from 1kg of absolutely dry substance, which can also be used for combustion in an non-treated condition [5–9].

4. Straw

Agricultural output in Poland yields a grain straw harvest of 25 million tons per year, but a sizable portion is used as mulch, fodder or a component of manure. If about 50% (12.5 million tons) of the previously mentioned 25 million tons of straw were used for energy purposes, it would be possible to save about 5 million tons of coal per year, assuming a calorific value of 16 MJ/kg of straw. The benefits of reduced environmental nuisance should also be taken into account. Straw also has a neutral balance of carbon dioxide emissions, sulphur dioxide emissions are much lower than for fossil fuels, and nitrogen oxide emissions are at comparable levels.

The calorific value of straw depends on factors such as moisture content, type of grain, type of soil and method of fertilization. The maximum moisture content should be in the range of 18%÷22%. The total use of excess straw production can cover 4% of primary energy needs. The chemical energy of 1 kg of straw with a moisture content of 15% is 14.3 MJ, which is equivalent to the chemical energy contained in 0.81 kg of firewood or 0.41 m^3 of high-methane natural gas [5, 6, 8, 9].

5. Research on the use of biomass

Co-combustion tests of straw, bark with dried sludge of 90% dry matter were carried out for different percentages of biomass. The measurements were carried out in a VIGAS-25N air heater with a 57 x 5 mm double-row flame heat exchanger with 6 units in each row. The following percentages of dried sludge were assumed: 20% i 40%. Portions of fuel with a total weight of 5 kg were taken for testing, taking into account the percentages for each biomass. The following were determined for the proposed biomass fuel proportions: heat of combustion, calorific value, ash content, moisture content, volatile content. Temperature measurements were taken simultaneously in the biomass combustion chamber, gasification chamber and behind the air heater. Flue gas analysis measurements were made. The results of the measurements are presented in Tables 1 to 3 and graphically shown in Figure 4 [8, 9]. Figure 1a shows the form of the sludge after the drying process in the dryer. And figure 1b illustrates the ash after combustion and gasification of the dried sludge with biomass.

Fig. 2 shows the course of temperature changes during the combustion and gasification of biomass in the form of bark, straw and dried sludge. Figure 3 shows the temperature changes during the combustion and gasification process of bark, straw for different proportions of dried sludge.

a) b)

Fig. 1. Sludge: a) dried, b) ash after incineration and gasification of dried sludge with biomass (source: own analyses.

The research was carried out by the author of the publication. The results were partly used in the following articles: [1, 3, 4].

Tab. 1. Heat from gasification of rapeseed straw, bark and dried sludge with the 90% dry matter content (source: own analysis)

Type of biomass	Heat kJ	Heat flow kJ/h
Rapeseed straw 100%	6943.710	1.5107
Bark 100%	6287.89	1.6668
Dried sludge with 90% dry matter content	5257.090	0.4867
Rapeseed straw and dried sludge 80%/ 20% ratio	2275.255	0.2632
Rapeseed straw and dried sludge 60%/40% ratio	1910.555	0.2033
Bark and dried sludge 80%/ 20% ratio	2520.14	0.3965
Bark and dried sludge 60%/40% ratio	1819.28	0.2862

Tab. 2. Results of flue gas analysis during combustion of biomass and dried sludge (source: own analysis)

Parameter	Unit of measure	Fuel						
		Rapeseed straw	Pinebark	Sludge	Straw 80% & sludge 20%	Straw 60% & sludge 40%	Bark 80% & sludge 20%	Bark 60% & sludge 40%
O_2	%	10.7	16.8	15.9	16.8	15.1	13.0	17.4
CO	ppm	3654	1560	2776	3725	3509	3198	4037
NO	ppm	30	24	169	115	232	242	100
NO_2	ppm	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NOx	ppm	27	27	169	113	230	241	98
SO_2	ppm	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Flue losses	%	15.3	14.3	19.1	25.9	25.5	20.1	20.5
Λ		6.7	6.32	4.11	4.95	3.55	2.63	5.85
CO_2	%	1.4	3.1	3.3	2.8	3.9	5.2	2.3
H_2S	ppm	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H_2	ppm	2850	3657	1369	3633	3638	2771	2908
E	%	77.6	80.9	80.9	74.1	74.5	79.9	79.5
Combustion air temperature	°C	16.9	17.8	19.5	17.9	18.9	23.3	25.7
Flue gas tem-perature	°C	231.1	243.6	169.6	189.0	241.6	254.60	137.30

Tab. 3. Technical analysis of fuel from rapeseed straw, bark and dried sludge with 90% dry matter content (source: own analysis)

Type of biomass	Moisture content %	Ash content %	Volatiles %	Heat of combustion kJ/kg	Calorific value kJ/kg
Rapeseed straw	15.05	1.97	69.71	15880	14495
Bark	7.95	5.40	67.79	19122	17877
Dried sludge 90% dry matter	10.90	32.80	53.29	13350	12401
Rapeseed straw – dried sludge 80% /20% ratio	7.12	10.64	73.63	14422	13251
Rapeseed straw – dried sludge 60% /40% ratio	6.50	16.54	68.85	13656	12564
Bark – dried sludge 80%/ 20% ratio	7.60	8.40	64.85	17756	16552
Bark – dried sludge 60% /40% ratio	7.20	14.90	61.36	16574	15453

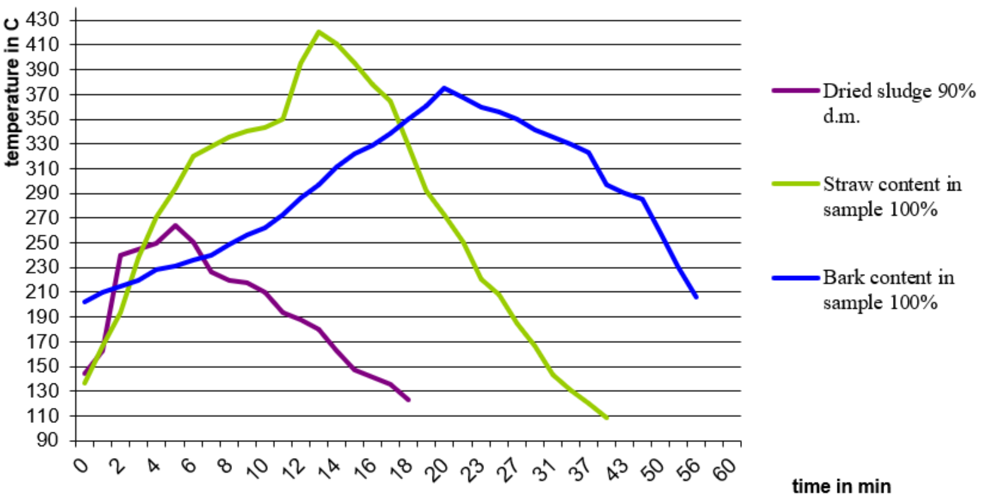

Fig. 2. Graph showing temperature dependence in the furnace used for combustion of biomass and dried sewage sludge (source: own analyses)

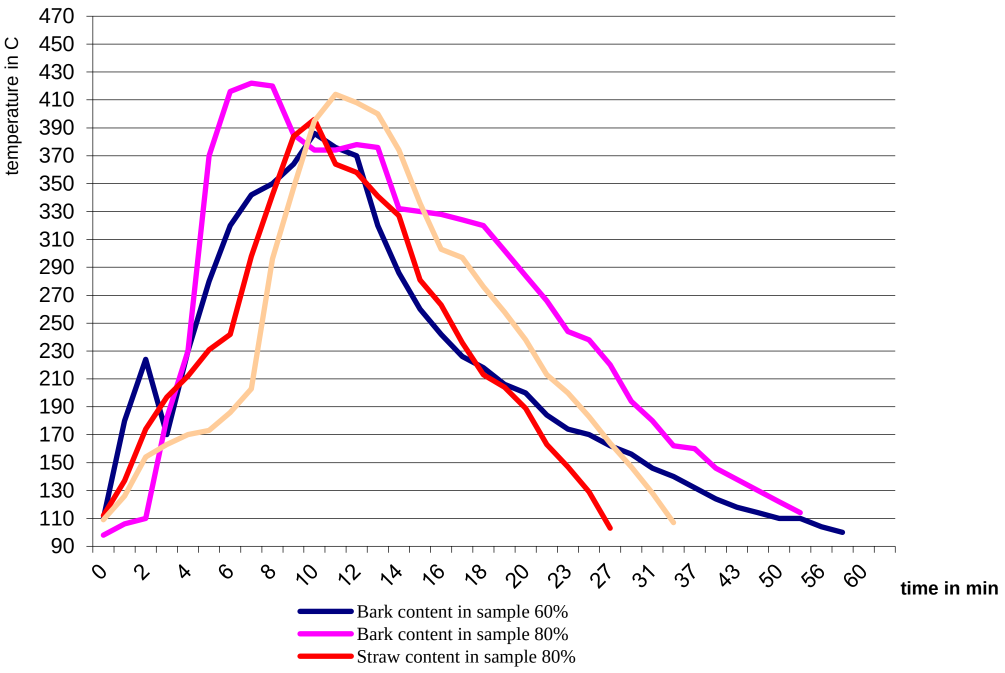

Fig. 3. Graph showing temperature changes in the furnace used for combustion of bark and rapeseed straw with dried sludge using 80%/60% ratio (source: own analyses)

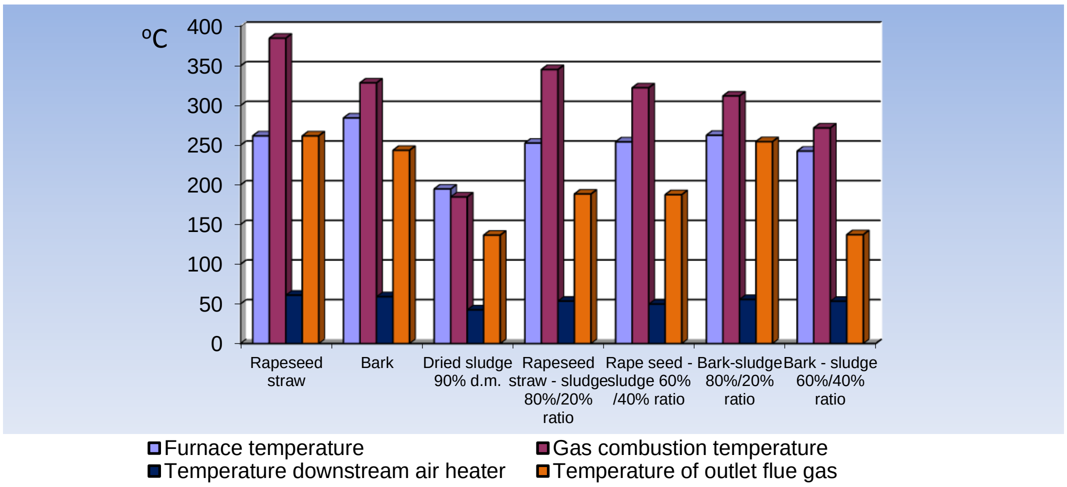

Fig. 4. Temperature dependence of the percentage of rapeseed straw, bark and dried sewage sludge with 90% dry matter (source: own analyses)

6. Conclusions

Surplus biomass and sludge will act as a catalyst for the search of new solutions for their proper management and use. The directive adopted by the European Union on the share of renewable energy in total energy production will force Poland to take measures aimed at more effective use of the energy potential of straw and dried sludge.

The research presented here shows the possibility of using straw, as well as bark and dried sludge for co-firing at a ratio of 20% to 40%. At higher proportions, co-firing is not favourable due to low calorific value. Co-combustion of such fuels is advantageous when the moisture content of straw and bark is below 15%, and that of dried sludge is 10%. However, it should be remembered that the process of drying sludge to obtain such parameters is an energy-intensive process. Straw or bark after pressure agglomeration is a full-fledged and environmentally friendly fuel that can be used in heating and heating applications using dried sludge with 90% dry matter content.

The proposed co-firing and gasification techniques are safe for the environment due to the low degree of pollution in flue gases with harmful sulphur and nitrogen compounds. Processing biomass with dried sludge and its use as renewable fuel in the form of pellets or briquettes is rational because such fuels are homogeneous, have similar dimensions, stable energy properties.

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