ACTA SCIENTIARUM POLONORUM
aspa.sggw.edu.pl
content.sciendo.com/aspa
Acta Sci. Pol.
Architectura 21 (3) 2022, 3–13
ISSN 1644-0633 eISSN 2544-1760 DOI: 10.22630/ASPA.2022.21.3.17

ORIGINAL PAPER

Received: 27.07.2022
Accepted: 09.09.2022

THE INTERDISCIPLINARY DESIGNING IN FORM, FUNCTION, AND STRUCTURE COHERENCY

Małgorzata Kurcjusz[1]✉, Anna Stefańska[2], Saurav Dixit[3], Agnieszka Starzyk[4]

[1, 2] Faculty of Architecture, Warsaw University of Technology, Warsaw, Poland
[3] Division of Research & Innovation, Uttaranchal University, Dehradun, India
[4] Institute of Civil Engineering, Warsaw University of Life Sciences – SGGW, Warsaw, Poland

ABSTRACT

The structural form in the 21st century refers to specific architectural ideas as a strong relationship between ideas, design algorithms, and production processes. Therefore, searching for the relationship between form, function, and structure in the contemporary technological context is essential. The paper analyses the strategies for a holistic understanding of interdisciplinary design through literature review and theoretical case studies on function, shape, and structure. The case study evaluates new possibilities for designers to create objects with a holistic understanding of architectural and structural principles. The key findings show how geometric variables influence the final performance of the shape and the importance of proper topology optimisation at the early stage of the design process. The paper indicates that such an approach enables a better understanding of the structure and leads to designing efficiency.

Key words: structural optimisation, interdisciplinary design, sustainability, architectural form, conceptual design

INTRODUCTION

Structural form in the 21st century relates to specific architectural ideas as a strong link between ideas, design strategies and production processes (Siegel, 2021). Therefore, seeking the relationship between form, function, and construction in contemporary design is essential. This paper explores strategies for a holistic understanding of interdisciplinary design to find a noticeable balance between design features such as aesthetic and mechanical properties. The introduction of such a process enables the creation of crucial determinants of integral performance in areas of interdisciplinary design. The design patterns introduce the importance of a comprehensive approach at an early design stage and the cooperation between the architect and structural designer (Stefańska & Rokicki, 2022).

Due to sustainability, material conservation, and energy-saving assumptions, designers are constantly looking for the right relationship between aesthetics, construction, the form of architecture or its function. Kysiak highlights that the architectural work arise "from need for a simultaneous, rational way of thinking over many seemingly contradictory categories" and that "The extent of integration and mutual compromises in functional, spatial, structural, technological, installation and financial solutions depends on the efficiency of their coordinator [own transl.]." (Kysiak, 1998, p. 96). Rokicki (2006) points out that form and function are extreme premises. The search for the interrelationship between them makes it possible to analyse their mutual impact in each other.

Małgorzata Kurcjusz https://orcid.org/0000-0002-9703-2118; Anna Stefańska https://orcid.org/0000-0002-5070-3877; Saurav Dixit https://orcid.org/0000-0002-6959-0008; Agnieszka Starzyk https://orcid.org/0000-0002-8704-5003
✉malgorzata.kurcjusz@gmail.com

STRUCTURE AND ARCHITECTURE

Architecture and engineering design are constantly intertwined – good design will only emerge when this reaction coherently strives towards a common whole. The boundary between architecture and construction in contemporary design is blurred, "as a result of creative rethinking, structural systems should (...) present a synthesis of technique and architectural form that corresponds to the intended functional goals, documents the correct choice of construction materials and their rational use [own transl.]" (Borusiewicz, 1978, p. 15–16).

One of the main components of architecture is structure, which connects aesthetical design with engineering and technology. The structure has a decisive influence on architecture. Therefore, one of the architect's roles is to understand the engineering fundamentals and follow the logic of the algorithms that create the supporting structures, especially in the curvilinear environment of contemporary spatial forms. Thus, the study poses the following hypothesis:

- Hypothesis 1 – The interdisciplinary approach to design at the early design stage yields numerous benefits in the final facility.
- Hypothesis 2 – The initial design decision on a structure's topology can significantly impact its subsequent performance.
- Hypothesis 3 – Implementing materials with various properties may improve aesthetic and structural efficiency.

Polish structural designer Wacław Zalewski (1917–2016) approached an architectural and structural interdependence. He designed great buildings such as Spodek in Katowice and the demolished Supersam – one of the best examples of post-war modernism in Warsaw (Fig. 1). One of the directions of the so-called the Zalewski School was the search for rational principles of structural design and the development of structural intuition (Sadowski, [n.d.]) His thoughts on shape and structure are worth quoting. "The character of shape determines performance, (…) Finding good shape for a structure should be a major concern of the architect and of engineer. Trust in shapes." (Allen et al., 2010, p. 612).

Another designer Pier Luigi Nervi (1891–1979) was an Italian representative of modernism, a structural engineer, designer and architect. In the 1940s, he explored the use of reinforced concrete in structures that were also curvilinear, which helped to rebuild many buildings and factories across Western Europe. Nervi also emphasised that intuition should be used

Fig. 1. Supersam, Warsaw, 1962 – supermarket designed by the Central Office of Studies and Projects for Industrial Construction (*Centralne Biuro Studiów i Projektów Budownictwa Przemysłowego*)

Source: https://sekretywarszawy.pl/sites/default/files/styles/large/public/field/image/supersam_warszawa_1969.jpg [accessed 30.04.2022].

Fig. 2. Palazzo di Torino Esposizioni (Saloni C), Turin, 1948 – art exhibition hall designed by Pier Luigi Nervi (photo by M. Carrieri)

Source: https://s3.eu-central-1.amazonaws.com/pressland-cms/cache/__original__/fd/14942258-pier-luigi-nervi-hala-c-w-turynskim-centrum-sztuki.jpeg [accessed 30.04.2022].

in design like mathematics, especially for thin-shell structures. He combined simple geometry and prefabrication to introduce innovative design. This was due to the increasing number of building projects using concrete and steel in Europe at the time, and the architectural aspect receded into the potential of engineering (Fig. 2). Nervi successfully made reinforced concrete the primary construction material of the time (archINFORM, 2022).

A contemporary architect and designer who has contributed significantly to the development of architectural and structural thought is the Spaniard Santiago Calatrava. His works combine complex structures, giving them an extraordinary aesthetic character. He is famous for his outstanding bridges and designs for railway stations (Fig. 3) and airports (Gov Civ Guarda, 2022).

Fig. 3. Gare do Oriente, Lisbon, 1998 – train station designed by Santiago Calatrava (photo by A. Stefańska)

Calatrava's approach to design is expressed through the seamless integration of architectural design and structural engineering. According to him, the best designs are not superficial decorations but based on a new approach to structural foundations. A strong inspiration for him has always been nature. This is reflected in his practice that buildings must give the impression of living organisms because they expose the attitude of the city, its inhabitants, and its generations. Calatrava's works embody the human being, connect with the soul of a place, and change the centre of gravity of human affairs (Clavijo, 2012).

STATE OF AN ART

Shape

An architectural shape can be defined as a set of features that make up a building object. These include, among others, the shape of the building's body, the canopy's form, the facade's composition, and architectural details. The free-form design, which is not limited by any rules, is often ahead of its time – it happens that there are not yet sufficiently developed technological possibilities to create the one that the designer intends (Rokicki, 2006). The form search can take place thanks to digital technologies and models. Previously, it was done with architectural models like the one of Sagrada Familia by Antoni Gaudi, where sandbags determined the final shape (Fig. 4).

Architecture is an art that represents the essence of human beings because it does not recreate their experiences but reveals people's constructive-perceptual nature (Ingarden, 1996). The assumption that architectural form is an aggregate of shape and functional substance helps to explore its intangible properties provided by geometry. Shape refers to geometrical

Fig. 4. Antoni Gaudi's spatial model – links adapt in shape to the load placed in the pouches (photo by A. Stefańska)

properties, and shape-dependent form references its physical properties, manufacturing and structural--material issues (Asanowicz, 2019).

Form finding

Besides fulfilling physical and mechanical conditions, each structure is an expression of creativity and a work of art, regardless of the automation of the form-searching process. The search for innovative and expressive forms requires experimentation (Rokicki, 2006).

Designing structurally efficient forms using experimental methods has been one of the most interesting ways to develop and seek optimisation of structures. Among the buildings designed by architects who adopted this approach is Eladio Dieste (1917–2000), who created parish church building the Iglesia de Cristo Obrero y Nuestra Señora de Lourdes (known as Iglesia de Estación Atlántida) in Estación Atlántida, Uruguay (Fig. 5). The expressive forms were based on double-curved geometry and were efficient. The baseline is straight, while the top resembles a sine wave. This makes the wall much stiffer and able to carry the load while still being an aesthetically pleasing form (Nazar, 2021).

Fig. 5. Iglesia de Cristo Obrero y Nuestra Señora de Lourdes, Estación Atlántida, 1958 – church designed by Eladio Dieste

Source: https://marcapaisuruguay.gub.uy/en/uruguayan-engineer-eladio-diestes-work-has-been-declared-a-world-heritage-site-by-unesco/# [accessed 21.08.2022]

Another crucial experimental designer is Félix Candela, who specialised in concrete as the primary building material. He sought to minimise the thickness of the canopies, as seen in the Los Manantiales restaurant building design in the district Xochimilco of Mexico City, Mexico (Fig. 6), which is only 4.0 cm. He was interested in the parabolic hyperboloid – a double-curved geometry rectified in two directions. He designed saddle forms and their combinations. Contemporary numerical calculations using advanced algorithms confirm the correctness of Candela's designed geometries (Nazar, 2021). It is important to remember to consider the fabrication process of the objects – optimising the technological difficulty also minimises the fabrication time. To fulfil the more straightforward assembly process, the reinforcement for each curvilinear element in the restaurant design follows straight lines in at least one direction.

Fig. 6. Los Manantiales, Mexico City, 1958 – restaurant designed by Felix Candela

Source: https://archive.curbed.com/2018/1/25/16932400/felix-candela-architect-concrete-los-manantiales [accessed 21.08.2022].

Experimental methods on empirical models initiated the development of computer techniques, and computer simulations are the basis of advanced experimental design. Antoni Gaudi experimented on the catenary model of the Templo Expiatorio de la Sagrada Família (known as the Sagrada Família) (Fig. 4). He claimed that surfaces following the shape of free-hanging chains when inverted could be structurally efficient, as compression forces would naturally propagate through them (Rokicki, 2006). Many designers conducted similar research prior the form--finding computational designing. Pier Luigi Nervi worked with reinforced concrete and sought prefabricated modular forms. Heinz Isler designed thin-walled concrete shells experimentally by developing hanging models and then freezing them. Frei Otto dealt with membranes and tensile forces. At the Institute for Lightweight Structures (*Instituts für Leichtbau Entwerfen und Konstruieren*) in Stuttgart, he refined experimental methods using technological advances to get real-time results on how the model changes. Otto's research is an example an experimental approach in architecture. He also worked on soap bubble surfaces inspired by soap film – bubbles adapt to a minimal surface in a state of stress equilibrium (Nazar, 2021).

Function

When talking about the function, one cannot ignore the aspect of space adaptation to new applications (Tarnowski, 2012). It is worth distinguishing the concepts here: multifunctionality, when the building has many different functions, and flexibility – the possibility of transformation. Space adaptation has been crucial recently, as in the hospital facilities during the pandemic. The functional scheme of the building defines the connections and relations between individual areas and the accompanying communication system. On this basis, it determines the area and distinguishes the necessary spaces.

Nowadays, it is believed that the goal of architecture is not only usability but also a few other parallel designing features. These include aesthetic, symbolic, prestigious, political, and environmental processes. At the same time, one cannot forget the materials, structures, cultural and economic limitations. All this may affect the design's final shape to a greater or lesser extent (Tarnowski, 2012).

A functional analysis should be carried out in designing and shaping space and form so that the object corresponds to its purpose. A helpful procedure is the implementation of parametric algorithms. In addition, it is worth optimising the use of space or sunlight. The materials and construction used should be compatible with the assumed function, which will be incorporated into a form after being solved.

Structure

The advantages of the structure lie in the form that makes it stable, and not in the use of accumulated material. The form influences the effectiveness of the structure and allows it to resist the forces acting on it. The search for the arrangement of the elements of the structure in a way that increases the efficiency of the whole is perceived as more valuable than transferring loads by increasing the cross-sections (Allen et al., 2010).

Architecture and engineering constantly interpenetrate – a good design arises if this reaction coherently strives to achieve common ground. The boundary between architecture and construction can be fluid – structure has many architectural aspects, and vice versa. Searching for and creating new, spatial forms causes constant changes in the process of shaping building structures.

Structural design is concerned with more than just engineering (meeting requirements and transferring loads), as it also involves art. Before designing a structural system, the purpose of the building should be analysed in every possible respect. Attention should be paid to the basic concept of the structure before mathematical calculations begin (Rokicki, 2006).

According to Torroja Eduardo, a structure's visible part should be designed with aesthetic aspects in mind. In contrast, the characteristics of the structure that cannot be seen only need to take economic and structural factors into account (Torroja, Polivka & Polivka, 1958). The structural designer must decide between several alternatives, so far existing only in his imagination, but he must fully consider their artistic value. In each case, the designer must rely more on his instinct and artistic past than complex rules. It is much more challenging to formulate regulations for art than for technology. Material and structural design mainly depends on the method of complex spatial forms (Rokicki, 2006).

Modern digital tools in structural modelling processes

The architectural model has changed over time due to scientific developments and evolving scientific approaches. *In silico* (Latin for flint) is a term describing that the study was done on a computer. Architectural tools for such research are Autodesk Fusion 360, Rhinoceros 3D, Grasshopper 3D, and its plug-ins, i.e. Kangaroo Physics (chain curve analysis) and Karamba3D (finite element analysis).

Parametric models adapt their form and structure to given parameters and relationships with other objects. Generative models are based on algorithms containing feedback loops (each subsequent step depends on the result of the previous one). The automated optimisation process produces a solution space – all the results within the set conditions. Expressive forms are the paradigm of continuity – the form seamlessly rises and extracts; some consider the fold the highest building form that can exist (Nazar, 2021).

In designing, the rational use of material is essential in the search for an efficiently working structure. Thanks to the development of modelling tools, analysis and simulation programmes, and better information exchange, we can gain new structural solutions for form, subdivision structures, materials and connections – thanks to cross-industry collaboration (Stefańska & Rokicki, 2022). The best solutions can be achieved through a compromise between architecture and construction.

MATERIAL AND METHODS

Research methodology

The qualitative research method used in this paper has been explored through a literature review on form, function, and structure. The time range of the literature sources analysed is from the 1960s to the year 2022. The case study analyses the structure topology and geometry of the proposed railway station canopy (Fig. 7). The shape was found based on the architectural function design conducted by the authors. The canopy was designed as a timber structure with the main surface divided into repetitive triangles with two fixed inclinations (29.1° and 21.8°). The main span between the supports did not exceed 15.4 m.

The optimal geometry of the divisions in the triangular flat panels is searched with use of Autodesk Robot Structural Analysis software. The structural analysis consists of three main panels. Hence the canopy covers the railway station, those three panels are not separated from the rest of the structure, and the connection points with other triangular members have X and Y displacements blocked (Fig. 8).

Phase one of the analysis compares the parallel and triangular mesh divisions in the above canopy panels (Figs 8 and 9). The parallel mesh consists of 7 bars of different lengths placed parallel (the distance between the bars is equal to 2.57 m). The pattern is mirrored on every panel. The second structure consists of triangular mesh divisions, with the length of each bar equal to 1.72 and 2.57 m. Total bars length for one of such triangles panel for parallel mesh equals to 128.2 m, while for the triangular sums to 250.9 m.

In the second analysis, the more lightweight structure is further investigated. The technological boundary condition was presumed to easier assembling. Since the structure designed material remains timber, all the bars were designed with the same cross-section, and the various parameter was the class of the

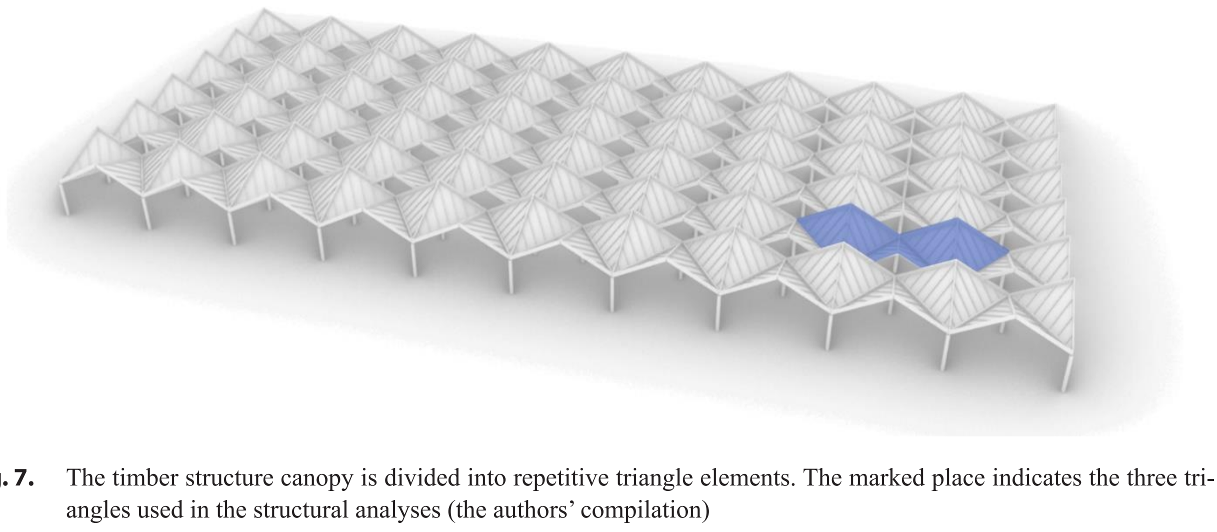

Fig. 7. The timber structure canopy is divided into repetitive triangle elements. The marked place indicates the three triangles used in the structural analyses (the authors' compilation)

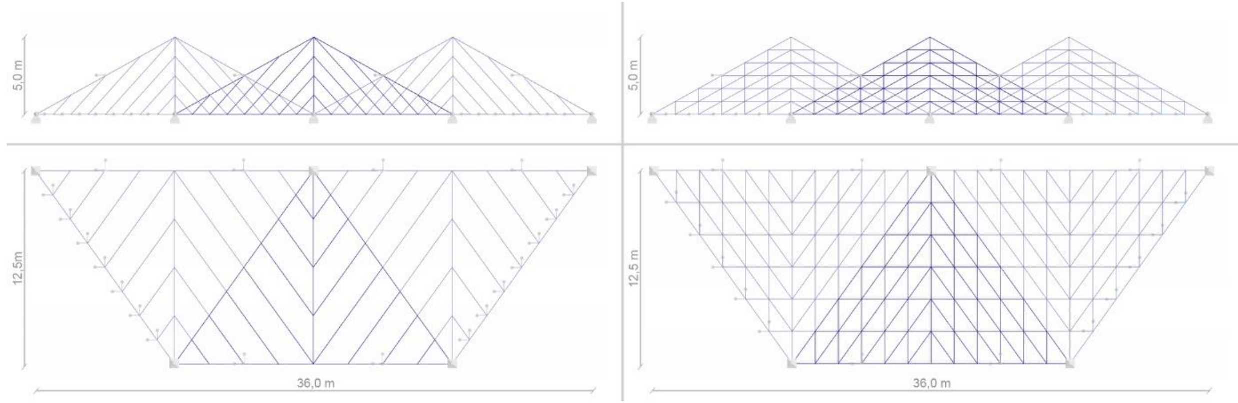

Fig. 8. The plan and elevation of the analysed canopy, left: parallel mesh divisions, right: triangular mesh divisions (the authors' compilation)

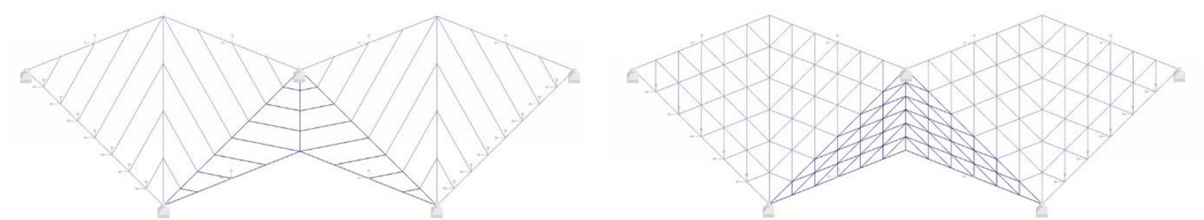

Fig. 9. The three-dimensional view of the analysed canopy, left: parallel mesh divisions, right: triangular mesh divisions (the authors' compilation)

material (where greater stresses of deflection occur, the class of the material was higher). The obtained results are investigated regarding structural stability, where max stress and deflections were not exceeded (Fig. 9).

Case-study form-finding factors

The case study consists of two study steps and is conducted based on the following assumptions (Fig. 10).

Boundary conditions to all variants:

- canopy, which was based on three repetitive triangles planes (Fig. 7) with an area of 136.34 m^2 each (409.01 m^2 in total);
- the structure is supported at the corners of each triangle segment (two planar triangular panels);
- the connection point with other triangular segments is taken into account by blocking the directions of X and Y displacements;
- following the functional requirements, the height of the canopy was 5 m above the level of the supports;
- the analyses were performed according to the dead loads, loads of canopy covering layers, wind loads and snow loads. Model tests were carried out with consideration to standards such as PN-EN 1991-1-3:2005, PN-EN 1991-1-4:2005, PN-EN 1991-1-3/4:2005/2008 and PN-EN 1991-1-4:2008/NA:2010 (Polski Komitet Normalizacyjny [PKN], 2005a, 2005b, 2010) (snow/wind loads), and PN-EN 1990:2004 (PKN, 2004) (code combinations);
- the classes of timber bars used in the structures were C35, C27 and C22;
- the allowed global deformation between the supports was set at L/250, which means that the maximum possible deformation is 6.2 cm.

Study 1 analysed the differences in topology, where a comparison of the system of parallel bars and the tri-

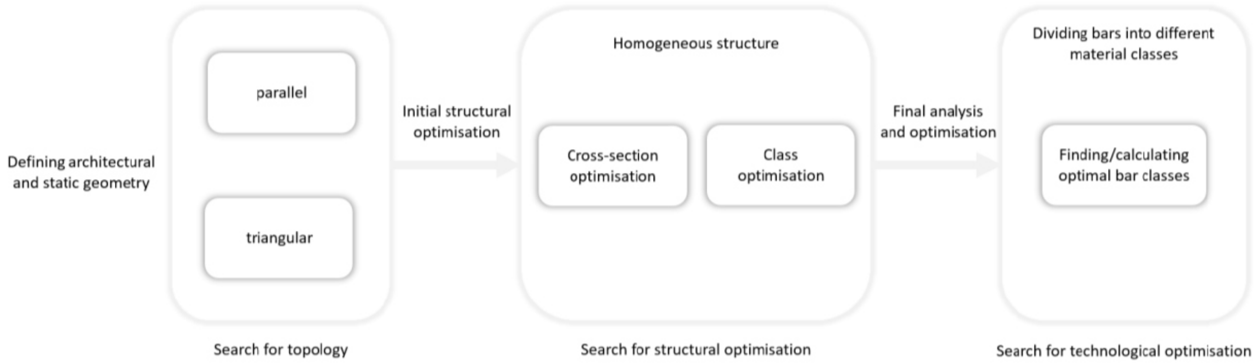

Fig. 10. The methodology flowchart of conducted theoretical studies (the authors' compilation)

angular mesh in terms of the load transfer properties was conducted.

Study 2 analysed the selected more lightweight mesh to change the timber class while having fixed bar cross sections.

RESULTS AND FINDINGS

The comparison of the two variants in Study 1 indicates the better structural efficiency of the triangular mesh in terms of stresses and deflections (Table 1). In terms of total weight, both meshes have similar total weight; the one with parallel divisions is 6,921 kg, and the one with triangular divisions is 6,774 kg. The mesh with parallel beams requires bigger cross-sections (150 × 320 mm) than triangular (150 × 150 m).

Since triangular mesh allows further optimisation (smaller stresses and deformations), Study 2 was based on this bar geometry. Further canopy development is conducted to decide between variable timber classes based on the same cross-section (150 × 150 mm).

The bars were divided into three groups by their ratio. The group of the most used bars remained with the timber class C35, while the class of the middle and the less used bars were changed into C27 and C22, respectively. That modification resulted in better structure effectiveness and better cost of the whole structure. Further optimisation performed in Study 2 showed that the structure's weight can be reduced with different classes of timber used following their effort (Table 1).

Besides the economic advantage, timber class optimisation enables the use of the same nodal connections due to the same cross-section. That allows for further cost reduction, prefabrication solutions and faster assembling. Such an interdisciplinary approach at an early stage of architectural design minimises the energy usage and carbon footprint, which is particularly important in the construction sector in terms of sustainable strategies for minimising the amount of carbon dioxide (Stefańska et al., 2022). This area of research requires further in-depth analysis, so that the issue of benefits is comprehensively confirmed by direct results. The further investigation may include comparative cost analysis, considering the life cycle of the designed structures.

Topology and material optimisation are crucial in the preliminary design process as they can impact the structure's efficiency. The study shows that the various meshes' divisions behave differently; thus, the arrangement of the beams is crucial. The topology decision should be made in the design's early stage as it influences various variables in the later stages. The result shows that using different meshes leads to better lead carrying capacity. Individual treatment of structural elements allows for their more effective use. The result shows that the interdisciplinary approach from the beginning of the structural and architectural design may lead to more efficient behaviour of the canopy. Various aspects should be considered in different configurations to determine the best possible solution. It often requires additional time and effort. However, the optimisation and the structure's logical design enable

Table 1. The results of Study 1 – topology analyses and Study 2 – material class analyses

Mesh type	Cross-section [mm]	Timber class	Deflection [cm]	Max. stress [MPa]	Min. stress [MPa]	Max. ratio [-]	Min. ratio [-]	Bars length [m]	Structure weight [kg]
Study 1 – topology analyses									
Parallel	150 × 320	C35	5.5	19.01	–19.01	–	–	384.5	6 920
Triangular	150 × 150	C35	3.6	18.95	–18.95	0,44	0.02	752.7	6 774
Study 2 – material class analyses									
Triangular with different classes of timber	150 × 150	C22 C27 C35	4.1	20.60	–20.60	0.56	0.02	752.7	5 982

a better solution with less material and a reduced carbon footprint.

The result shows that using different timber classes improves the effectiveness of the structure. The total weight of the structure is also smaller, although the equal cross-sections were used.

DISCUSSION AND CONCLUSIONS

The basic principle in design can be described as the rule of unity of function, form, and structure. The relationship between these three elements should be balanced, often achieved due to a compromise. That consists of the interdependent shaping of structural solutions, functional systems, and spatial forms.

The architect takes responsibility for the designed objects. This involves finding the proper relationship between many aspects such as aesthetics, construction, the form of architecture and its function. The classical principle of mutual balance of the elements determining the value of architectural work arose from the necessity of a simultaneous, rational way of thinking over many seemingly contradictory categories. The scope of integration and mutual compromises in functional, spatial, structural, technological, installation and financial solutions depends on the efficiency of their coordinator.

Such a holistic point of view enables the designer to create objects with the integrity of form, function, and structure. The form optimisation meets the need for aesthetic architecture in logic and beautiful structural forms. The intuitive layout of functions and analysis of the user's behaviour in the building make the architecture functional. The logic structure is responsible for its efficiency and the rational usage of materials.

There are many directions for further development, as the design process is complex. The scope of integration and mutual compromises in functional, spatial, structural, technological, installation and financial solutions depends on the efficiency of the architect. For instance, the comparative cost analysis could be conducted, considering the life cycle of the designed structures. Another area of investigation might be the optimization study of installation and prefabrication.

There is an approach to finding a balance between architectural design's spatial, aesthetic, and mechanical problems. The introduction of such a process enables the creation of crucial determinants of integral action in architectural design. The presented design patterns for constructing architectural objects introduce the importance of a comprehensive approach at an early design stage.

Hypothesis 1 stated in the paper says that "The interdisciplinary approach to design at the early design stage yields numerous benefits in the final facility". The paper challenges knowledge of the relationship between form, function, and structure. It contains relevant information that shows that an interdisciplinary approach is beneficial in the design process. These advantages are among others the efficiency of the structure, the consistency of form, function and structure, the aesthetics of the design and the design quality that does not overlook any essential aspect. Thus, Hypothesis 1 is confirmed. "The initial design decision on a structure's topology can significantly impact its subsequent performance" – this Hypothesis 2 is confirmed with the results of the conducted study. The presented different structural topologies (parallel and triangular mesh) analyses proved that this decision affects the further results such as maximum deflection and leads to better lead carrying capacity. Hypothesis 3 – "Implementing materials with various properties may improve aesthetic and structural efficiency" – is confirmed by the included analyses of the application of different classes of timber. The effectiveness of the structure is improved, and the total weight of the structure is smaller with the same cross-sections used.

The knowledge contained in the paper is intended for anyone interested in architectural-structural optimisation and interdisciplinary approaches in design. It can benefit researchers and practitioners, whether they are architects, designers or others involved in these industries. This will allow them to find a common design language.

Modern design, unfortunately, is a reflection of an individual approach. The analyses should be conducted with specific boundary conditions. These conditions can change the outcome of the investigations and the final geometry of the objects. The studies were conducted for a finite number of cross sections and timber classes. The research conducted could be further developed. For instance, the canopy geometry could be tested for various angles, spans, materials and their classes, cross-sections and the technology of an assembly.

Authors' contributions

Conceptualisation: M.K., Anna S., Agnieszka S. and S.D.; methodology: M.K. and Anna S.; validation: M.K., Anna S. and S.D.; formal analysis: M.K. and Anna S.; investigation: M.K. and Anna S.; resources: M.K. and Anna S.; data curation: M.K. and Anna S.; writing – original draft preparation: M.K.; writing – review and editing: Anna S., Agnieszka S. and S.D.; visualisation: M.K.; supervision: Anna S. and Agnieszka S.; project administration: Anna S.; funding acquisition: Anna S.

All authors have read and agreed to the published version of the manuscript.

REFERENCES

Allen, E., Zalewski, W., Foxe, D. M., Anderson, J., Hriczo, K., Ramage, M. H., …, Iano, J. (2010). *Form and Forces. Designing Efficient, Expressive Structures*. Hoboken, NJ: John Wiley & Sons.

archINFORM (2022). *Pier Luigi Nervi*. Retrieved from: https://www.archinform.net/arch/2.htm [accessed 30.04.2022].

Asanowicz, A. (2019). *Recenzja pracy doktorskiej pt. "Modelowanie parametryczne obiektów architektonicznych o formie swobodnej" autorstwa Karola Kowalskiego*. Białystok: Politechnika Białostocka. Retrieved from: https://bip.zut.edu.pl/fileadmin/pliki/wbia/zalaczniki/Awanse_naukowe/architektura/karol_kowalski/Kowalski-rec_prof_Asanowicz.pdf [accessed 24.05.2022].

Borusiewicz, W. (1978). *Konstrukcje budowlane dla architektów*. Warszawa: Wydawnictwo Arkady.

Clavijo, L. A. (2012). *Santiago Calatrava: structure as attitude*. Retrieved from: https://luissioamclavijo.blogspot.com/2012/09/santiago-calatrava-structure-as-attitude.html [accessed 30.04.2022].

Gov Civ Guarda (2022). *Santiago Calatrava*. Retrieved from: https://pl.gov-civ-guarda.pt/santiago-calatrava [accessed 30.04.2022].

Ingarden, R. (1966). *Studia z estetyki* (Vol. 2). Warszawa: Wydawnictwo Naukowe PWN.

Kysiak, M. (1998). *Architektura pawilonów wystawowych: funkcja, forma, konstrukcja*. Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej.

Nazar, K. (2021, January 7). *'Form finding' w poszukiwaniu synergicznych rozwiązań strukturalnych*. Warszawa [unpublished academic lecture].

Polski Komitet Normalizacyjny [PKN] (2004). *Eurokod. Podstawy projektowania konstrukcji* (PN-EN 1990:2004). Warszawa.

Polski Komitet Normalizacyjny [PKN] (2005a). *Eurokod 1. Oddziaływania na konstrukcje. Część 1–3: Oddziaływania ogólne. Obciążenie śniegiem* (PN-EN 1991-1-3:2005). Warszawa.

Polski Komitet Normalizacyjny [PKN] (2005b). *Eurokod 1: Oddziaływania na konstrukcje. Część 1–4: Oddziaływania ogólne. Oddziaływania wiatru* (PN-EN 1991-1-4:2005). Warszawa.

Polski Komitet Normalizacyjny [PKN] (2010). *Eurokod 1: Oddziaływania na konstrukcje. Część 1–4: Oddziaływania ogólne. Oddziaływania wiatru* (PN-EN 1991-1-4:2008/NA:2010). Warszawa.

Rokicki, W. (2006). *Konstrukcja w aeurytmicznej architekturze*. Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej.

Sadowski, K. [n.d.]. *Prof. dr inz. Wacław Zalewski*. Retrieved from: https://web.archive.org/web/20110821000927/http://www.architekci.pl/konstrukcje/index.php?id_dzialu=50&id_fragment=757&od=0 [accessed 30.04.2022].

Siegel, C. (2021). *Structure and Form in Modern Architecture*. Hassell Street Press.

Stefańska, A. & Rokicki, W. (2022). Architectural Design Optimisation in Reticulated Free-Form Canopies. *Buildings*, *12* (8), 1–16.

Stefańska, A., Kurcjusz, M., Cygan, M., Buczkowska, J., Szmołda, K. & Morawska, P. (2022). The Interdisciplinary Approach to Free-Form Canopies Optimisation in Terms of Geometrical and Structural Logic Design. In *Proceedings of the 7th International Conference on Architecture, Materials and Construction* (pp. 110–119). Cham: Springer.

Tarnowski, J. (2012). Jeszcze o funkcjonalizmie w estetyce architektury: od Sokratesa do idei budynku totalnie ekoprzyjaznego. *Estetyka i Krytyka*, *1* (24), 183–204.

Torroja, E., Polivka, J. & Polivka, M. (1958). *Philosophy of Structures*. Berkeley, CA: University of California Press.

INTERDYSCYPLINARNE PROJEKTOWANIE SPÓJNOŚCI FORMY, FUNKCJI I KONSTRUKCJI

STRESZCZENIE

Forma strukturalna XXI wieku odnosi się do konkretnych założeń architektonicznych jako silnego związku między ideami, algorytmami projektowymi i procesami produkcyjnymi. Poszukiwanie relacji formy, funkcji i konstrukcji we współczesnym kontekście technologicznym staje się niezbędne. W artykule przeprowadzono analizę holistycznego rozumienia projektowania interdyscyplinarnego poprzez przegląd literatury i teoretyczne studia przypadków dotyczące funkcji, formy i konstrukcji. Studium przypadku ocenia nowe możliwości dla projektantów w zakresie tworzenia obiektów z całościowym zrozumieniem zasad architektonicznych i konstrukcyjnych. Kluczowe ustalenia pokazują, w jaki sposób zmienne geometryczne wpływają na końcową wydajność formy oraz znaczenie odpowiedniej optymalizacji topologii na wczesnym etapie procesu projektowania. Artykuł wskazuje, że takie podejście umożliwia lepsze zrozumienie konstrukcji i prowadzi do efektywności projektowania.

Słowa kluczowe: optymalizacja konstrukcji, projektowanie interdyscyplinarne, zrównoważony rozwój, forma architektoniczna, projekt koncepcyjny