Challenges in Survey Methodology Workflows for Complex Geometry Structures. Case study of the Church of Divine Mercy in Kalisz, Poland

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Abstract

The Church of Divine Mercy in Kalisz represents a distinctive post-war architectural specimen, distinguished by its hyperbolic parabolic shell and intricate geometry. This unique design posed a significant challenge in terms of digital documentation. The necessity for accurate measurement data for the purpose of maintenance planning was made urgent by the deterioration of the structure's technical condition. The present article proposes a comprehensive methodology for the documentation of cultural heritage buildings characterised by complex geometry. The proposed methodology integrates terrestrial laser scanning (TLS), photogrammetry utilising unmanned aerial vehicles (UAVs), tachymetry and manual verification. To ensure comprehensive coverage, a total of 455 scan points and over 6,400 images were collected, with precise alignment provided by geodetic control networks. This approach provides a replicable framework for analogous cases worldwide. The data was processed in FARO SCENE, RiSCAN PRO, RealityCapture and PointCab Origins software to generate optimised point clouds, laserscan-based orthophotomaps and 2D documentation, while Rhinoceros/Grasshopper and Archicad software were used for parametric modelling of the irregular shell. The findings underscore the necessity to amalgamate automatic and manual methodologies for the purpose of eradicating discrepancies from theoretical geometry that have been occasioned by primitive construction methodologies. The proposed workflow demonstrates the efficacy of integrating laser scanning, photogrammetry and geodetic measurements in enhancing data reliability, reducing on-site measurement time, and facilitating interpretation. In addition to the creation of metrically accurate digital records, this methodology facilitates structural analysis, maintenance monitoring and the creation of preliminary HBIM models. The present study contributes to the standardisation of digital measurements. The following essay will provide a comprehensive overview of the relevant literature on the subject.

1. Introduction

The Divine Mercy Church in Kalisz is undoubtedly one of the most unusual and visionary religious buildings erected in Poland after World War II. Its spectacular mass is even more impressive when the viewer realises that the first design drawings of this church were made in 1958.

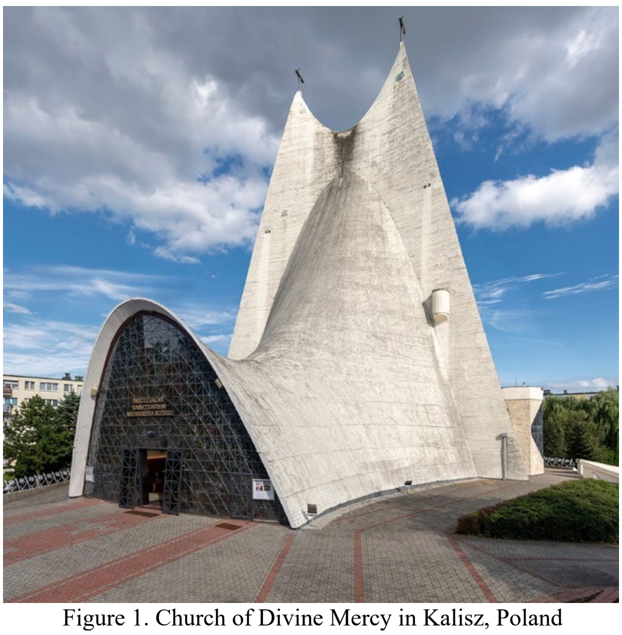

Figure 1. Church of Divine Mercy in Kalisz, Poland (P.Marciniak, 2024).

The building is an example not only of exceptional form and pioneering architectural and structural solutions, but also an example of the extraordinary determination of its investors and authors to complete the building. The church building was designed from 1958 and construction lasted from 1974 to 1993. It took 15 years to complete and was carried out economically seven days a week. The construction teams came from the parish, the concrete was mixed in concrete mixers, poured from wheelbarrows and thankfully vibrated, the joinery and ironwork was done by craftsmen and the stained glass and beautiful ceramic elements by artists. Altogether, the process of preparing the project and its realisation took 35 years.

The complex architectural form is reminiscent of the Philips Pavilion at Expo'58 in Brussels, designed by Le Corbusier and Iannis Xenakis, based on a mathematical formula. In particular, it brings to mind the spectacular realisations of Felix Candela, such as the open chapel at Lomas, the Chapel of Saint Monica, and the restoration at the Oceanographic Park in Valencia, realised many years later. Subsequent years also saw, albeit on a slightly different basis, the Cathedral of the Blessed Virgin Mary in Tokyo designed by Kenzo Tange, the chapel of Our Lady of Fatima and the iconic cathedral in Brasilia, both works by Oscar Niemeyer.

The church's importance for the development of Polish architecture is remarkable, and references to the achievements of world architecture increase its range and significance.

Pre-design work related to the poor technical condition of the object was the direct cause of undertaking inventory work. Using the case study of the Church of the Divine Mercy in Kalisz as an example, the challenges posed to documentation and inventory processes by architectural objects with complex geometry are discussed.

The text highlights the need for advanced technologies and precise data interpretation to address such challenges, using the example of the complex spatial form of the Church of the Divine Mercy in Kalisz. The article aims to discuss the issues involved in documenting structures with unusual geometry and to propose a standardised workflow for such cases.

2. Framework

The church in Kalisz has a hyperbolic paraboloid roof, which has found use in the construction industry due to its favourable static properties and versatility. A hyperbolic paraboloid has two planes of symmetry. Depending on the shape of the horizontal projection of the object to be covered, it is possible to distinguish between hyperbolic paraboloid surfaces with rectilinear and curvilinear edges. By selecting the coordinate system accordingly, the form of the paraboloid can be written as an equation in canonical form (3) as well as (4):

$$\left(\frac{x}{a}\right)^2 - \left(\frac{y}{b}\right)^2 = z \tag{3}$$

$$x \cdot y = z \tag{4}$$

The hyperbolic paraboloid also belongs to the group of translation surfaces. This surface can be created by moving the parabola transversely parallel to the dorsal parabola. At the same time, the convexities of the two parabolas are opposite. If one is directed upwards, the other must be directed downwards or vice versa. (Przewłocki, 1997) (Nahmias, Smith, 1993) (Pottmann et al. 1995)

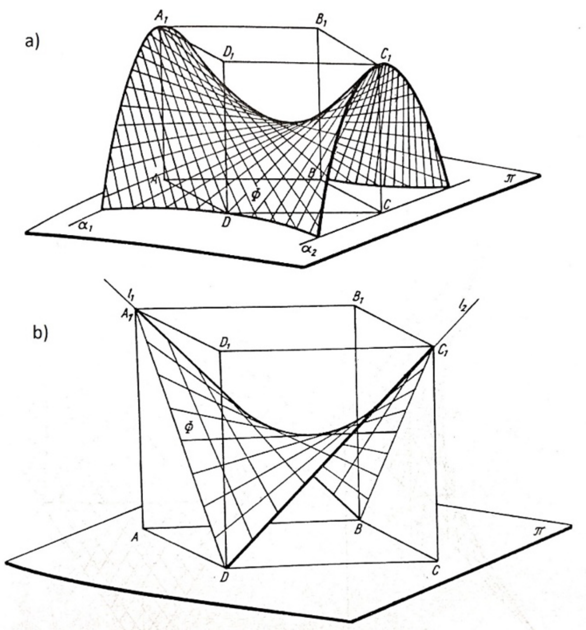

Figure 2. Theoretical model of a hyperbolic parabola (S. Przewłocki, 1997).

Three types can be distinguished in compound roofs, including those obtained by juxtaposing several surface sheets. This arrangement of parabolas was used in the construction of the shell of the Church of the Divine Mercy in Kalisz. This arrangement of parabolas was used in the construction of the shell of the Church of the Divine Mercy in Kalisz. An analogous combination of parabolas can be seen on the church towers.

This church is a building whose complex plane consists of three basic hyperbolic paraboloids which form: the tower, the main part and the front part of the church. In addition, three smaller paraboloids with equal equations form the lunettes, located at the back of the church. With such a rigid geometry, measurements may seem very simple. In reality, significant inaccuracies in the workmanship and primitive techniques of construction resulted in a slight deviation from the ideal shape. (Quintilla-Castán, Agustín-Hernández, 2022).
The digital survey of the church building was an opportunity to verify the chosen measurement methods for the analysis of complex geometric structures and to verify the accuracy of the analytical and measurement methods used. Van Mele et al., 2012)

3. Methodology

Key methodological aspects addressed in the research include:

- **Analysis of measurement methods:** suitability of laser scanning, photogrammetry and total stations in the context of surveying structures with complex geometries. The advantages of these technologies, such as high measurement accuracy and the ability to capture complex details, are highlighted along with their limitations. One of the main challenges in documenting constructions with complex spatial forms is to provide complete coverage of the building while minimising data gaps in hard-to-reach areas. The combination of laser scanning and photogrammetry provided a comprehensive data set that allowed for accurate 3D modelling. The decision to prioritise these technologies was based on their ability to effectively capture both large-scale geometry and fine architectural detail.

- **The role of surveying matrices:** the establishment of a precise surveying matrix was a key initial step in the documentation process. The framework served as a reference point for all subsequent surveys, ensuring the consistency and accuracy of the integration of data from multiple sources. The geodetic network enabled precise alignment of datasets of point clouds, reducing measurement errors and increasing the reliability of the final documentation.

Figure 3. Digital survey process of Church’s interior (K. Argasiński, 2025).

- **Challenges in data interpretation:** the paper over-emphasises the complexity of processing and interpreting point cloud data, especially in the context of constructions that

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deviate from their theoretical geometric models. A comparative analysis of different data acquisition techniques was carried out to assess their effectiveness in capturing deviations from the expected shape. In addition, in-situ manual measurements were carried out to verify sections that were difficult to document and to check the accuracy of the final data set against actual conditions. This verification phase was particularly important to ensure the completeness and usability of the resulting documentation.

- **Standardised workflow:** the study proposes a structured approach to documenting structures with complex geometries, outlining a model-based workflow that includes the selection of measurement tools, guidelines for data recording and recommendations for interpreting the results. By integrating laser scanning, photogrammetry and direct manual measurements within a standardised framework, the methodology provides a balance between precision and efficiency. In addition, the combination of automatic data acquisition and manual verification reduces processing time, making the workflow more suitable for conservation-oriented research.

4. Digital Survey Processes of the Church

For the development of the digital model of the church, detailed inventory documentation was carried out using laser scanning and photogrammetry technology (by K.Argasinski/BIMfaktoria). The graph below is explained later in this paragraph (Argasinski, 2025).

The survey process included: (1) terrestrial scanning with FARO Focus S and Premium series scanners and RIEGL VZ-400i scanner - both point cloud-based methods (Cloud2Cloud) and grid-based systems (Top View and characteristic geodetic points aligned with Tachymetry done with Trimble S7) and a geodetic grid were used. A total of 424 survey color and 31 intesity value based positions (455 in total) were taken with different graduality of quality and resolution. The fieldwork lasted 3 days. This was followed by (2) photogrammetric documentation taken from a DJI drones Mattrice 300 with connected Zenmuse P1 Camera (for outside) and DJI Air 2s for interior of main church (with SONY A7 R IV cameras. The overall number of used pictures is 6460. Next, (3) integration of scanning data in scan registration software (including FARO SCENE, RIEGL RiSCAN PRO). Using native data from both companies, all pintclouds were in final step (after registration, cleaning and optimisation combined using FARO SCENE software (native for FARO Focus Scanners + .PTX based format exported from RiSCAN PRO. After that step, all information regarding geodesy (geodetic control grid) was implemented after combining both datasets.

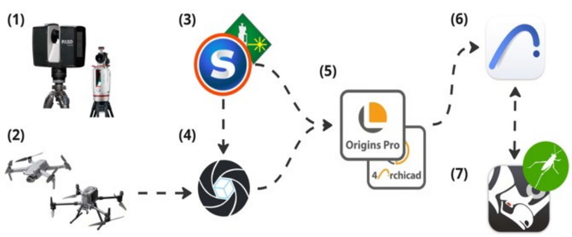

Figure 4. Method of acquiring a digital measurement and creating initial inventory documentation (K.Argasinski/BIMfaktoria 2025).

At a further stage, the (4) RealityCapture tool was used to develop the photogrammetric model, and spatial data from various sources was integrated and processed in the (5) PointCab Origins 3D software - enabling the generation of orthoplans, projections, sections and preliminary vector drawings for 2D documentation and 3D modelling. The software allowed to organise all point cloud-based data in a practical way – by creating mentioned view cuts (layouts, sections, elevations) as well as creating manually segmented parts of the Church – logically divided by floors and in/out groups of scans.

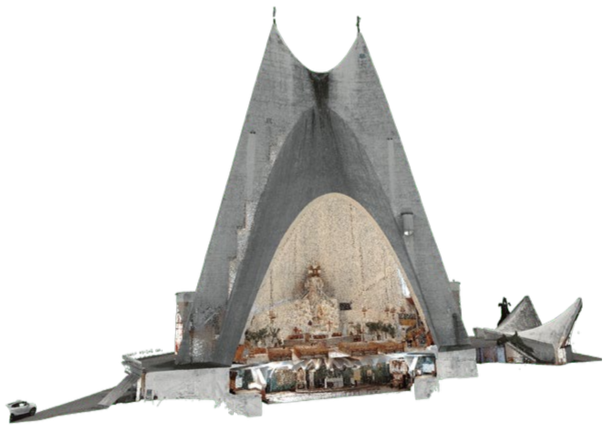

Figure 5. Divine Mercy Church in Kalisz (cross-section through a point cloud) (K.Argasiński/BIMfaktoria, 2025).

The architectural model of the building was developed using (6) Graphisoft Archicad, a BIM software used to create precise architectural documentation. However, one of the key structural features of the building - a complex shell of varying thickness - required a different approach. To accurately represent the irregular and curved form, modelling was carried out in (7) Rhinoceros 3D (Rhino), a design software known for its ability to handle free geometry using NURBS (Non-Uniform Rational B-Splines), a mathematical method for creating smooth, curved surfaces.

To support this process, (7) Grasshopper, Rhino's built-in visual programming tool, was used. With Grasshopper, the contours and shape of the shell were defined and generated using a series of scripts, and the surface was then formed using techniques such as lofting (stretching the surface between curves), swipe (extruding along a path) and creating NURBS curves. The final step - encapsulating the shape into a solid - was done in Rhino or Grasshopper and exported to Graphisoft Archicad for further documentation.

5. Discussion

The results of the research carried out for the Church of the Divine Mercy in Kalisz confirm the necessity of combining measurement technologies and applying an interdisciplinary approach in order to obtain accurate and functional documentation. The methodology for working with such objects requires proper planning, discipline during the work performed, and the next necessary steps can be demonstrated in order to obtain precise inventory measurements |(**Skrzypczak et al.2021)**:

- the first, often underestimated, step should be to obtain materials documenting the history of the creation of the object under study. This may include archival design documentation, inventory cards held at the conservation office, and other available source material. In the case of objects with a particularly complex geometry, this will allow sketch drawing primers to be obtained, giving an indication of the approximate scale of the object under study. It will be helpful for the technician carrying out the measurements to be familiar with the specifics of working with archival sources.

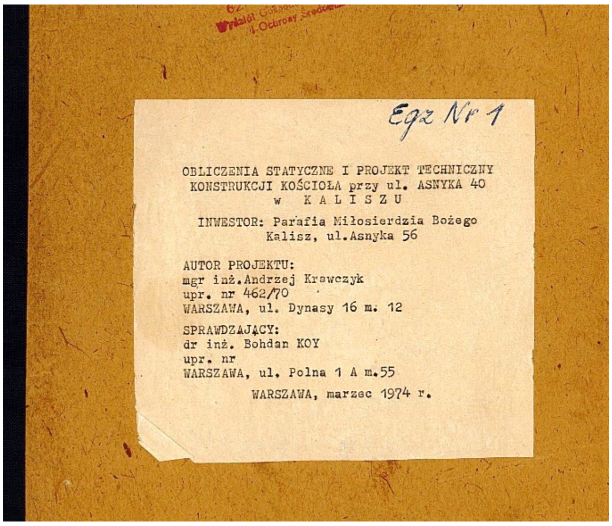

Figure 6. Archive documentation including original drawings of the church project (P.Marciniak, 2025).

- another indispensable element in the preparation of the inventory is the in-situ inspection, the thorough familiarisation with the object and the programming of the surveys. Only the precise programming of the planned measurements, in the context of the conditions found, can result in a final and correct picture of the surveyed object.
- establishment of a detailed geodetic control grid using classic surveying techniques (e.g. total station) in the PUWG 2000, zone 6 Global coordinate system. The detailed geodetic matrix consists of points established in reference to the basic geodetic matrix. The degree of density of points of the detailed geodetic matrix depends on the degree of land development (urbanisation). When carrying out situational and altimetric surveying, it is necessary to refer to the local coordinate system, for which the materials of the state geodetic and cartographic resource are used. During the fieldwork, a geodetic control network was carried out in a detailed, folded system located from eleven control points around the church and designated numbers which were tachymeter stations. These points were stabilized main sidewalks using discrete metal pins and, in the lawn, using wooden stakes.

  Additionally, the final discrete reflective discs were glued to the building, which were measured with a tachymeter from the control network points and which were used as reference points in the laser generator measurement. The last element of the measurement network were 12 temporary photo points that solve the entire church.

- A direct inventory of the Divine Mercy Sanctuary in Kalisz was carried out using terrestrial laser scanning technology, which was the primary method for capturing the complex spatial geometry of the building. This technique made it possible to acquire high-density point clouds, thus providing precise spatial information on the morphology of the building, including its complex details and irregular geometries. This would otherwise have been difficult to document using traditional survey methods. A critical aspect of the methodology involved strategically planning the placement of scanning stations to ensure optimum line-of-sight coverage and minimise occlusion. The density and distribution of survey points was determined in accordance with the architectural articulation of the site, thus enabling both macro and micro scale features to be captured.

- Furthermore, the rationale behind the acquisition of the scans was based on the need to ensure a comprehensive overlap of the individual scan positions, which was a prerequisite for accurate registration and spatial consistency of the dataset. Emphasis was placed on areas of architectural articulation, structural irregularities and zones of heritage value, with higher resolution scans prioritised in these regions. This level of methodological rigour facilitated the creation of a geometrically consistent and metrically reliable three-dimensional representation of the entire sanctuary, both externally and internally. All-important zones of structure were scanned with additional (RGB) data layer which was an aid in creating photogrammetric alignment and mesh model creation base – both for exterior and interior.

- The implementation of terrestrial laser scanning facilitated a capture of the physical condition of the building, and provided a solid database for subsequent modelling, analysis and conservation planning. This underscores the pivotal function of 3D scanning in the documentation of architectural heritage, particularly in scenarios where accuracy, thoroughness and digital continuity are of the essence.

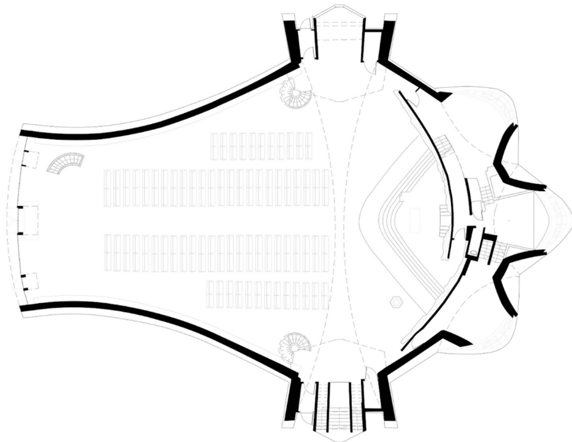

Figure 7. Divine Mercy Church in Kalisz (CAD-based survey floorplan cut of Main Church) (K.Argasiński/BIMfaktoria, 2024).

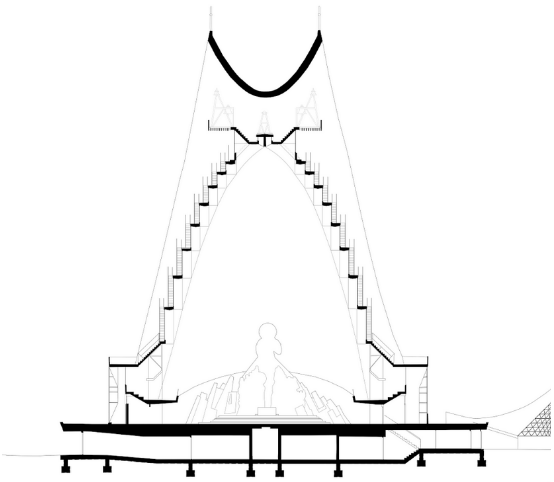

Figure. 8. Divine Mercy Church in Kalisz (CAD-based surveysection cut through whole structure) (K.Argasiński/BIMfaktoria, 2024).

- photogrammetric surveys performed by drone. Proper programming of the aircraft overflight is key, as well as mandatory reporting of flights to the PANSA UTM local airspace control system. By utilising UAVs, it was possible to gather additional photographic layer of information, which wouldn't be possible to gather with TLS or LiDAR (Colomina, Molina, 2014) (Shults, Annenkov, 2023). Drone data was used to fly outdoor to capture whole object with surroundings, optimising time of TLS measurement, mostly focusing on steep outdoor staircases which were problematic to capture. Since monolithic structure of those staircases serves as structural joint, it was crucial to measure it with different possible equipment. Here, again – due to logistics and problematic structure – an indoor flight was established to capture not only mentioned structure, but also details of stained-glass windows as well as all interior-based cracks on the Church's shell.
- processing the results using the software indicated earlier and combining the fragments obtained by the various measuring techniques. Combination of field measurements with scanners, drone and supplemented by manual and check measurements. Point cloud transfer sequence and its transfer to the 3D model (Rodríguez-Moreno et al., 2018) (Banfi et al. 2019) (Andriasyan et al, 2022) using available software. One of the key parameters is to clean up the resulting point cloud and segment it manually in order to bring logic to surveyed shape.
- crucial for the correct elaboration of the final survey inventory is the knowledge of the construction techniques with which the surveyed object was built. The association of the measurement results obtained with the analysis of those techniques allows the correct interpretation of the drawing record. In particular, this applies to complex structures, such as wooden objects, but also to objects of mixed construction or subject to numerous transformations.

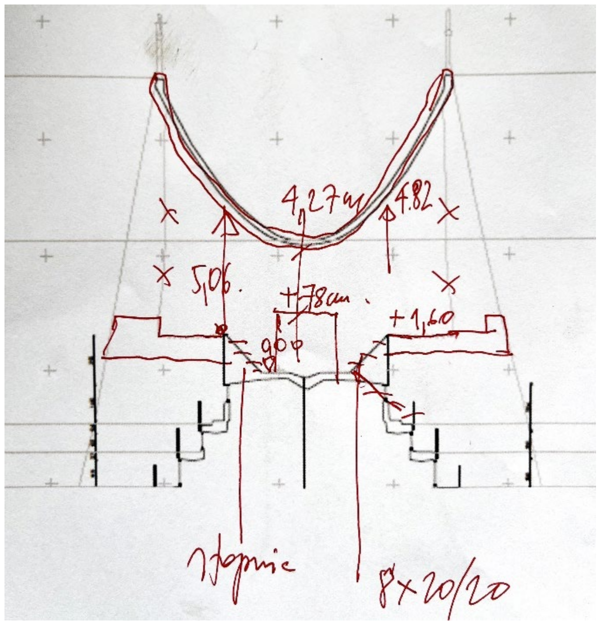

Figure. 9. Natural correction of a measurement drawing produced as a result of 3D scanning (P.Marciniak, 2024).

- After the initial preparation of the measurement drawings and their editing (preferably on physical medium i.e. paper documentation, but depending on a user), **it is necessary to re-verify** the results obtained and compare them with the existing state. In many cases, the automation of the scanning process will unfortunately not provide an unambiguous drawing record, which is particularly the case for details and parts of components lying close to each other. Manual checking of the obtained measurement drawings and their verification with the actual state allows the correct interpretation of the obtained measurement information. (Rodríguez-Moreno et al., 2018)

6. Conclusion

The results show that the combination of different surveying techniques, including the unconventional application of precision 3D scanners to reinforced concrete structures, opens new possibilities beyond the construction of HBIM models. These results can facilitate the analysis of structural deformations and enable continuous monitoring of the building's condition. In addition, the optimisation of the documentation process significantly reduces the time required for in-situ measurements and data processing, which in turn increases the efficiency of conservation research. The ability to generate highly accurate data sets in a shorter time supports decision-making in the field of historic preservation and allows necessary interventions to be implemented more quickly.

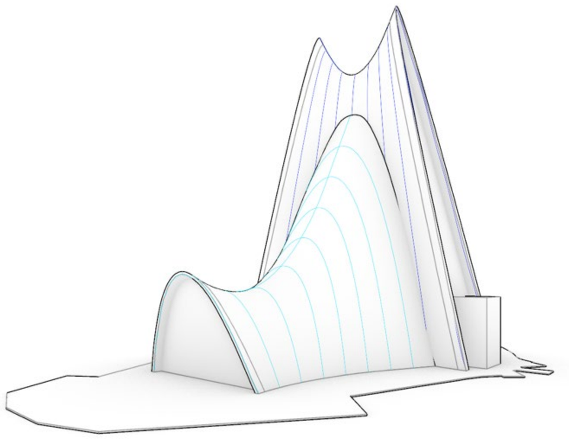

Figure 10. Preliminary geometrical BIM model of the church shell as part of the outcome documentation (K.Argasiński/BIMfaktoria, 2024)

The subject of this presentation is to present the methodology of the research carried out and the interpretation of the results, mainly in the context of assessing the accuracy, stability of long-term point cloud readings and the basic evaluation of the complex structure of the building block.

We would also like to draw attention to the wide possibilities of using the developed method for measuring complex buildings with complex geometry and undetermined construction history.

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