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The use of 2D vector studies as an architectural research stage in the era of digital spatial models

Introduction

So far, the results of architectural research have been presented by using two-dimensional drawings. Along with the advent of digital documentation and measurement methods, it has become common to analyze architecture with spatial models. Their use significantly increased the information base about the features and context of historic buildings. Thanks to these methods, we can analyze virtual reality by generating moving three-dimensional images which either represent real architectural forms or consist of metrically embedded sets of points [1]. Architecture data can also be transferred by means of techniques such as laser scanning, structured light and photogrammetry [2], [3]. 3D digitization and mapping of monuments is used for comparisons with historical drawings [4]. The successively developed Historical Geographic Information System (HGIS) is also becoming more and more helpful [5].

In this context, it is justified to ask the question whether linear drawings are still needed in architectural research and whether we should apply results for two-dimensional foundations. In the article presented, an attempt at finding the answer to this question was made. The basis for considerations includes materials from the research which was conducted in the years 2017–2022. Most of the said research comprises studies which were carried out by a team consisting of doctoral students and students of the Faculty of Architecture of Wrocław University of Science and Technology (hereinafter: ZWA PWr) under the supervision of the author. Drawings of doctoral students at this university, i.e. Alicja Hoyenski, Franciszek Hackemer and Luba Smirnowa were also used.

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Digitization and preliminary analyses in architectural research

In all the works on conducting architectural research, the importance of carrying out preparatory analyses, which consist in the development of a query of written and iconographic sources and a careful presentation of the state of knowledge on a given topic, is emphasized. This is becoming increasingly easier thanks to the availability of many archives and studies which are posted on digital platforms. However, it is still necessary to remember about materials which are stored in the form of paper printouts and typescripts only. They are very important especially in relation to non-existent objects. Particular attention should be paid to the inventory drawings and their correctness should be assessed. The author's previous experience shows that the measurements which were performed by the State Enterprise Monuments Conservation Workshops at the PP PKZ (Przedsiębiorstwo Polskie Pracownie Konserwacji Zabytków) are most often error-free. The situation is different with the measurements from the period of the mid-19th century to the mid-20th century. They are usually schematic and do not reflect the actual state of affairs; however, they can constitute the starting point for further measurements.

The effect of correctly conducted preliminary analyses should include, among other things, the selection of elements of a building, which should be measured, and what method to use. The choice of method depends on many factors, including the desired measurement accuracy, the availability of an object and its formal complexity. It is equally important to initially determine the range of spatial study, i.e. its 2D, 3D or 4D temporary format.

Before starting the research, as it was mentioned, we make a list of missing measurements and define their scale, adjusting the method of preparation to the intended effects. In the case of monographic studies of objects

of considerable size and complexity, it is worth assuming the maximum spatial scope of the study, i.e. 3D and 4D. The models of St. Elizabeth's and St. Vincent's Church in Wrocław constitute the illustration of this approach (Figs. 1.1, 1.2). This type of study may also be much smaller in scope and on a smaller scale – for example, measurements of the Chapel of the Dead at Wrocław Cathedral (Fig. 1.3).

Preparing vector studies on the basis of digital documentation

The described digital layouts of buildings and the ability to generate various transmitters of information about buildings have changed the perception of drawing, which until now was considered an objective transmission of information. The analysis especially of archival drawings and the comparison of them with current measurements have proved that the drawing which is called vector model today is an interpretation, partly subjective, depending on the knowledge and graphic preparation of the researcher and cartoonist (Fig. 2).

Performing a linear image, e.g. a scan, is not an easy work for people with little experience. It requires not only the skills of digital drawing, but also knowledge about the drawn subject – its construction, types of forms occurring in a given period, etc. It also repeatedly happens that in the scan the density of points is insufficient and during drawing we have to use photographs and a field visit. There are low-density or incomplete scans as well. This is usually connected with the low availability of the developed fragment or the elements which are obscuring it. It often happens when we conduct wall examinations at attics and the building material is covered by a roof truss or shadows formed by it.

Making a selection which scans should be drawn and with what accuracy can be undoubtedly included in the research stage. The basis of such a choice is the specific purpose of the works carried out. If we want to show architectural transformations of a building, it is necessary to make all drawings in which these transformations will be visible. In the case of a fairly complicated building, which is, for example, Świdnica Cathedral, in the years 2019–2022 the following drawings were made: six levels of projections, six cross and longitudinal sections, views of all faces of the walls, selected fragments of the building material layout, all architectural details. Moreover, 3D and 4D visualizations were developed in the video form. Despite the very good and rich output material (scans, archival drawings), photographs were constantly used during drawing and the drawings were checked in the field many times, completing the measurements.

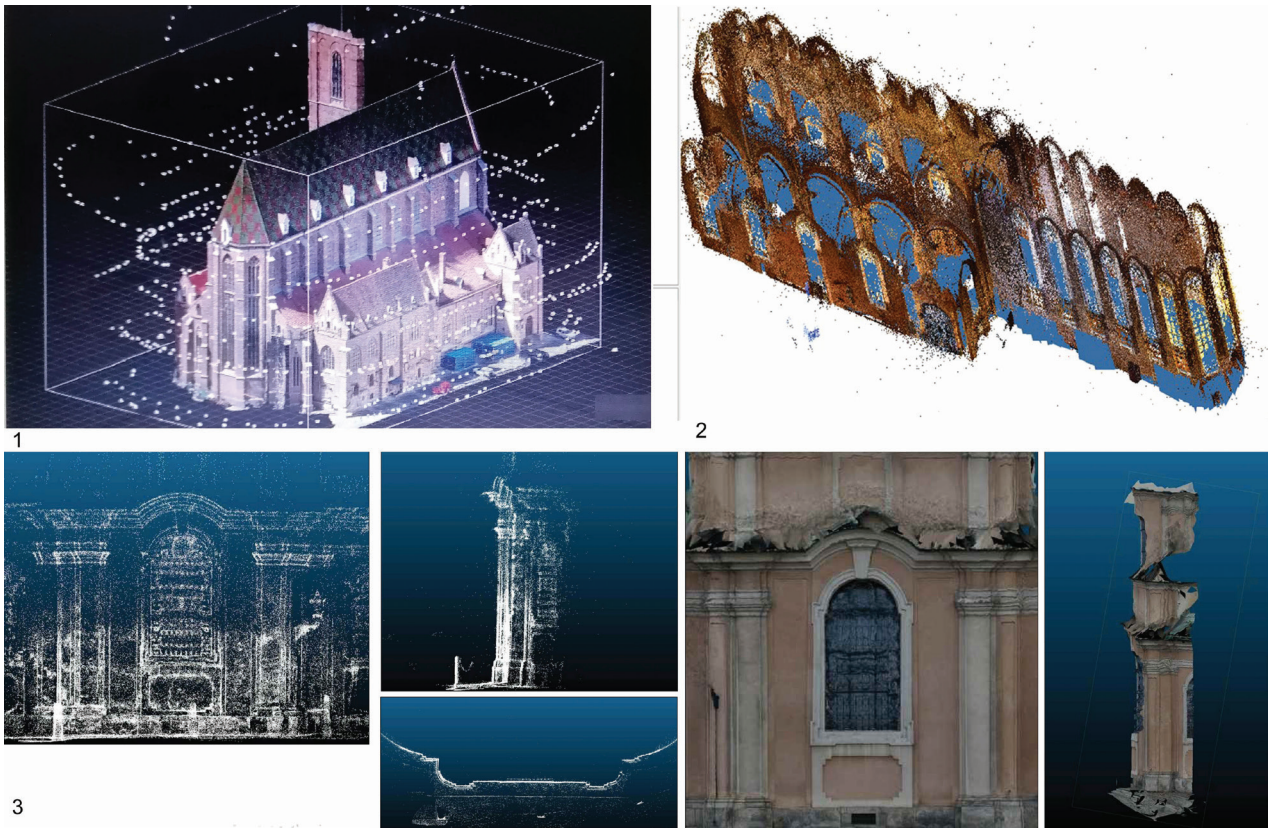

Fig. 1. Examples of measurements of churches in Wrocław: 1 – St. Elisabeth's, model with drone positions (elaborated by F. Hackemer), 2 – St. James' and St. Vincent's, cloud of points in 3D model (elaborated by A. Hoyenski), 3 – Chapel of the Dead at the cathedral, cloud of points and model with texture (elaborated by ZWA PWr)

Il. 1. Przykłady pomiarów kościołów we Wrocławiu: 1 – św. Elżbiety, model z pozycjami drona (oprac. F. Hackemer), 2 – śś. Jakuba i Wincentego, chmura punktów w modelu 3D (oprac. A. Hoyenski), 3 – Kaplica Zmarłych przy katedrze, chmura punktów i model z teksturą (oprac. ZWA PWr)

Two-dimensional linear analyses

Creating two-dimensional linear layouts is therefore the first attempt at systematizing the research problem. It is also for this purpose that we to determine the architectural stratigraphy, i.e. the system of building layers. These layers have spatial character and their adequate model is the layout in 3D or 4D format.

The role of the researcher, however, is not only to present the final effect of his/her own analyses, but also to show the transition stages. The presentation of one's own thinking must be readable and consists in removing unnecessary information and limiting to a clear verbal and graphic message. In this case, a very good form of presenting indirect analyses is the two-dimensional registration of stratigraphy. In order to facilitate this, the term "architectural stratigraphic unit" (hereinafter ASU) was introduced. The basis for qualifying various elements (building material, detail) to one unit is most often their combination with one bonding material. It should be added that the condition for determining features of many layer is the availability of the analyzed architectural source. The optimal situation is the ability to reach walls without plasters and well cleaned.

This unit includes all architectural elements – both the building material and other parts of a building. The basic criterion for determining one construction unit is the simultaneous formation of components. Thus, one stratigraphic construction unit will include all building creations which were formed in the same period. So they may be made of various materials, they may also have different formal, construction features, etc. A single stratigraphic unit will be, for example, a stone foundation with several layers of bricks on it, in which wooden window frames are inserted. The unit in the minimum dimension will therefore be, for example, a brick, and in the maximum dimension – e.g. the entire building which was erected simultaneously and was not remodeled.

In discussing this type of unit, the text and graphic part will be of equal importance. Part of the text study includes the examples list of features which can be traced during research (Table 1). It is worth using the same table for each unit, even if in a specific case most of the columns remain not filled. A subsequent comparison of units with a different number of features shows how many authentic elements have survived and what is the size of this building event.

During analyses of units, it is important to trace the metric features of entire objects and their elements. The structure and description of its components are very important. Forms of supports, vaults, ribs, etc. are later helpful in dating. The optimal situation is the case when we have access to all elements, e.g. foundations, walls on both sides, attics. We can then specify, for example, the

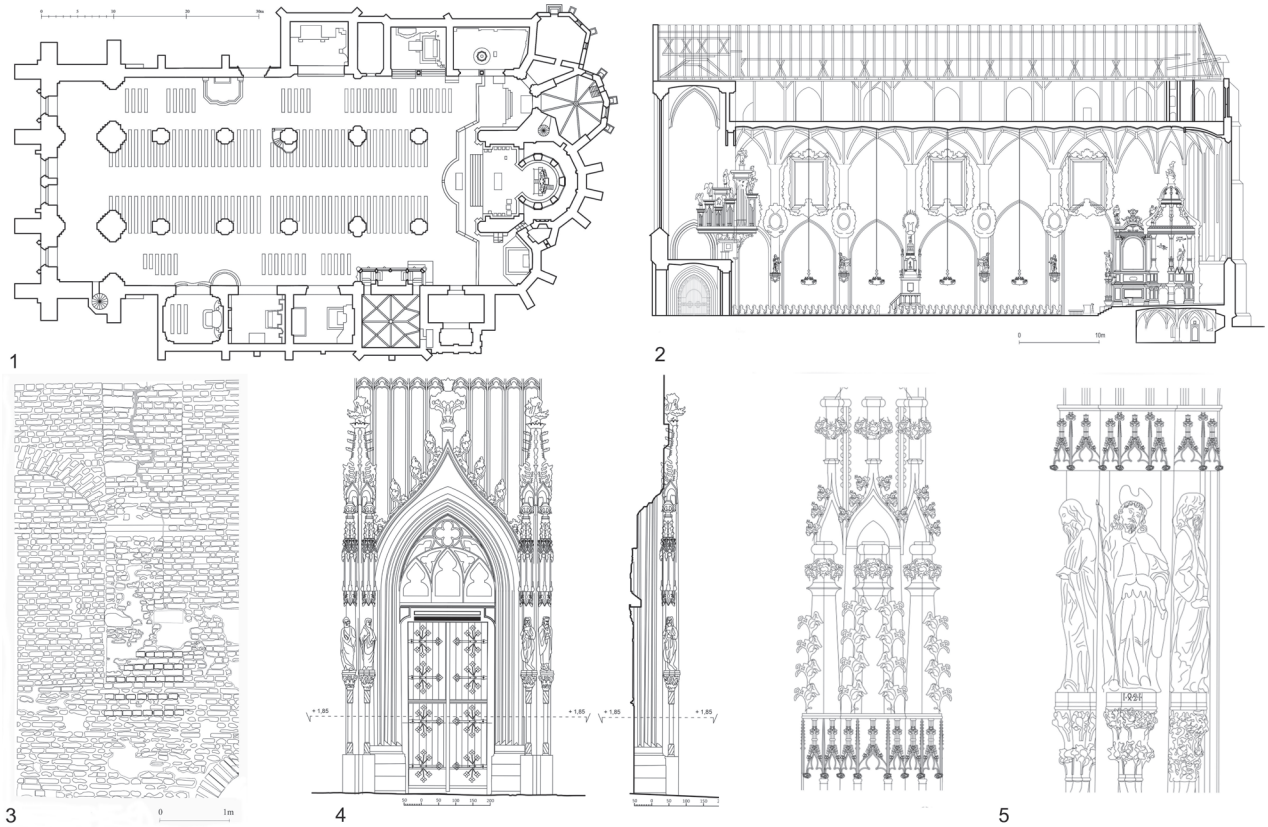

Fig. 2. Vector layouts of the cathedral in Świdnica during the research in the years 2021–2022:
1 – basement projection, 2 – cross-section, 3 – building material of the northern wall, 4 – central western portal,
5 – portal pinnacles (elaborated by ZWA PWr)

Il. 2. Opracowania wektorowe katedry w Świdnicy podczas badań w latach 2021–2022:
1 – rzut przyziemia, 2 – przekrój, 3 – budulec ściany północnej, 4 – środkowy portal zachodni, 5 – sterczyny portalowe (oprac. ZWA PWr)

Table 1. ASU characteristics, sample issues (elaborated by E. Łużyniecka)
Tabela 1. Charakterystyka AJS, przykładowa problematyka (oprac. E. Łużyniecka)

AJS 1	METRIC FEATURES					CONSTRUCTION - GENERALLY			
	Building	Elements	Maximum size			Element		Type	
	FOUNDATION					WALL			
	Structure	Building material	Grout	Excavation		Structure	Building material	Grout	Plaster/polychrome
	ARCADES					VAULT			
	Components	Form	Building material	Profile	Coatings	Structure	Building material	Rib profile	
	GABLE					ROOF			
	Location	Form	Building material	Plaster/polychromy		Location	Form	Truss	Coating
	SUPPORT					PORTAL			
	Location	Components	Building material	Other features		Location	Components	Building material	Other features
	WINDOW					OTHER/SEDILLA, SACRAMENTARIUM/			
	Location	Components	Building material	Other features		Location	Components	Building material	Other features
	SOCLE					CAPITAL			
	Location	Components	Building material	Other features		Location	Components	Building material	Other features
	CANTILEVER					KEYSTONE			
	Location	Components	Building material	Other features		Location	Components	Building material	Other features
	FRIEZE					CORNICE			
	Location	Components	Building material	Other features		Location	Components	Building material	Other features

type, layout, dimension, color, texture, technique of the building material. Details such as arcades, portals, brackets, keystones, socles, friezes, cornices, etc. can be subjected to a similar analysis.

If a construction relic is small, e.g. a fragment of the foundation discovered during excavations, then the analysis of macro- or microscopic raw materials used to produce individual elements may be helpful in the establishment of units. It may be useful to determine the amount of clay, sand or cement in the cross-sections of the analyzed bricks. It is equally important to determine whether the brick was made by hand or industrially by means, for example, a forming press. The analysis of mortar components, i.e. grout and framework grains, can also help in determining units. The distribution of aggregate grains will indicate the fact of riddling or not riddling the sand added and the low or high presence of lime clouds in the grout indicates the quality of the process of its firing and seasoning.

The analysis of the building described above, which was conducted during vector studies makes it possible to separate ASU border lines emerging wherever there are building irregularities (Fig. 3). Therefore, it seems more readable to apply lines to vector development and resignation from the undercoat, e.g. photomaps.

By determining the boundaries of units, we will deal with, among other things, straight lines. Horizontal straight lines will be usually connected with physical features of a building, i.e. the principle that a building is erected from the bottom, starting from the foundations up to the roofs. There are also exceptions related to remodeling and subsequent functional changes. Vertical lines will be usually caused by the extension of objects, i.e. the formation of new elements. Broken lines and curves will often result from renovations and additions. Drawings of the border lines should be supplemented with the numbering of architectural elements which are important for the analysis such as windows, bricked up openings, or damaged details.

During conservation works connected with the removal of plasters, border lines are often covered by mortar. They should be then made more readable by clearing thoroughly the building material and the borders between it. In places where layer systems are blurred by e.g. color merging, it is worth using the effect of chiaroscuro. During the research on the abbey in Ląd, which was conducted in the years 2019–2022, the impediment to the determination of border lines was the mortar strongly adjacent to the bricks as well as the scaffolding obscuring the view of the building material. In this case, the use of a drone and photo-

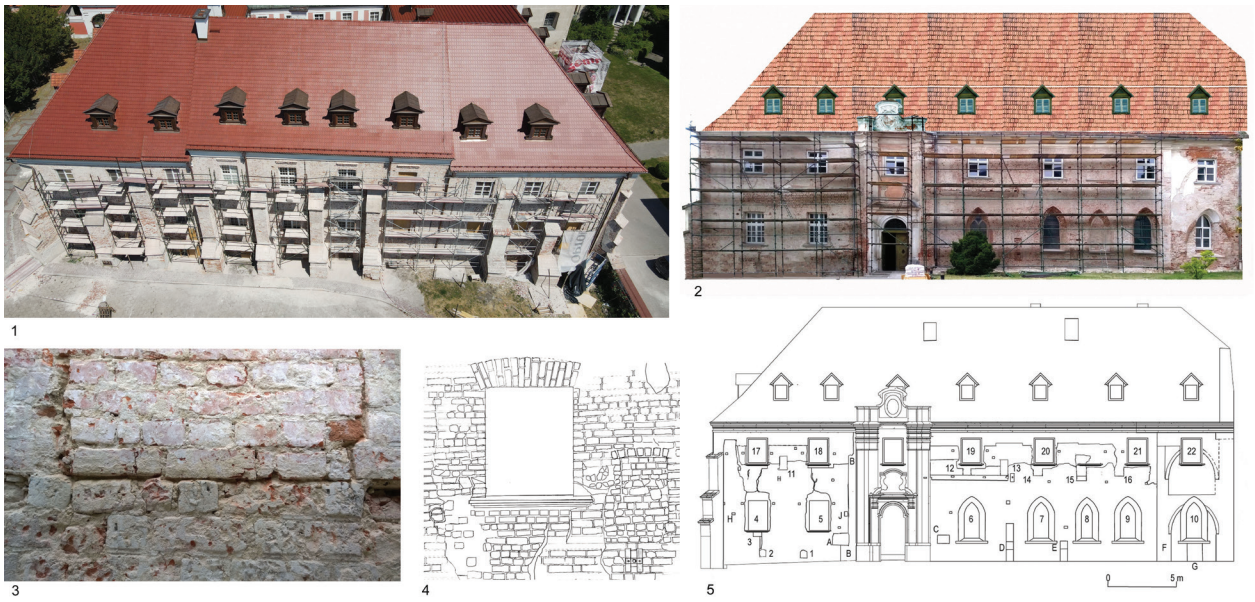

Fig. 3. Determining border lines of architectural stratigraphic units during the research on the abbey in Ląd (2019–2022):
1 – southern façade, view from the drone (photo by F. Hackemer),
2 – eastern façade: photogrammetry (elaborated by L. Smirnowa),
3 – eastern façade: clearance of lines in wall changes (photo by E. Łużyniecka),
4 – eastern façade: drawing of the building material (elaborated by ZWA PWr),
5 – eastern façade: vector development with lines and numbering (elaborated by E. Łużyniecka)

Il. 3. Wyznaczanie linii granicznych architektonicznych jednostek stratygraficznych w czasie badań opactwa w Lądzie (2019–2022):
1 – elewacja południowa, widok z drona (fot. F. Hackemer), 2 – elewacja wschodnia: fotogrametria (oprac. L. Smirnowa),
3 – elewacja wschodnia: uczytelnienie granicy przemurowań (fot. E. Łużyniecka),
4 – elewacja wschodnia: rysunek budulca (oprac. ZWA PWr),
5 – elewacja wschodnia: opracowanie wektorowe z liniami i numeracją (oprac. E. Łużyniecka)

graphs taken at different times of the day with different lighting were very helpful.

Determining the border lines of units is the output guideline of the presentation of individual stratigraphic units. The boards, in which we place the location of the unit and images of its features on a smaller scale, constitute an important element of the presentation. The components of boards may take the form of parts of photomaps (e.g. studies of Saint Jame's and Vincent Church in Wrocław) or vector developments (e.g. research of Świdnica Cathedral) (Fig. 4).

The order of separating and, as a result, numbering of stratigraphic units is free. Most often they are connected with the time of conducting research, if, for example, it is caused by dividing renovation works, which are planned for several years, into stages. Then we number units according

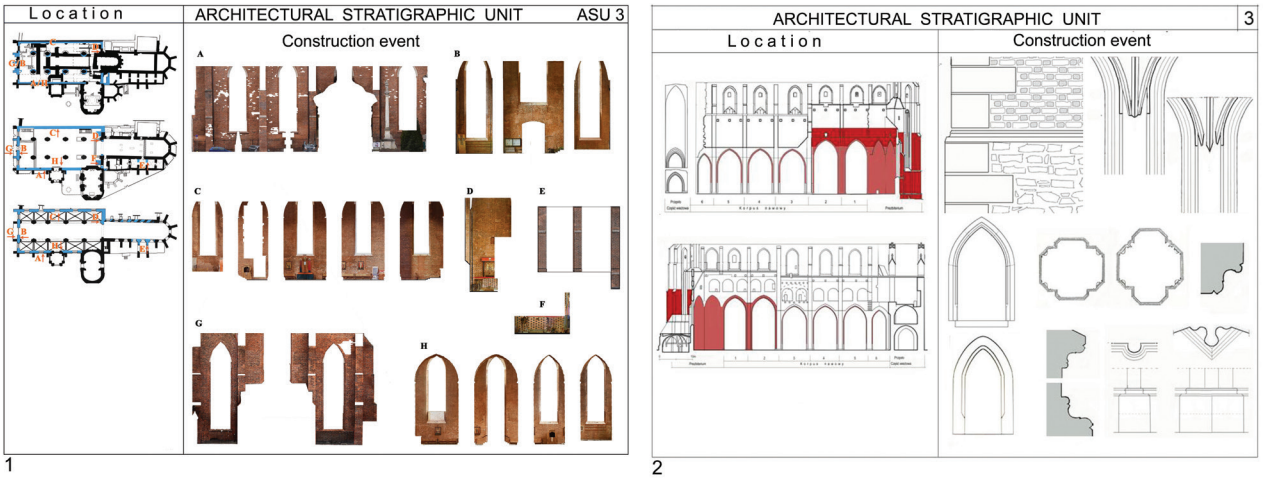

Fig. 4. Boards with a graphic illustration of the description of the architectural stratigraphic unit:
1 – fragments of the photomap (elaborated by A. Hoyenski),
2 – vector developments (elaborated by E. Łużyniecka)

Il. 4. Tablice z graficzną ilustracją opisu architektonicznej jednostki stratygraficznej:
1 – wycinki fotomapy (oprac. A. Hoyenski), 2 – opracowania wektorowe (oprac. E. Łużyniecka)

to the renovation schedule. When making analyses, it is preferred to start from the youngest units, i.e. the last repairs from the 20th and 21st centuries as well as from the 19th-century conservation works. These units are relatively easy to define due to the available iconographic material – archival measurements and photographs. This order helps to avoid mistakes in distinguishing authentic elements from their copies or reconstructions.

The described method was adopted during the research on the eastern, southern, and northern façades of the abbey clause building in Ląd. The presented comparison of architectural stratigraphic units was made according to the order of the analyzed façades. Initially, the youngest units were separated, later others – nine such units were described in total. Their graphic performance makes it possible to assess both the location of construction events and their range, size or characteristic features (Fig. 5).

The final part of the architectural analysis of units is to determine the stratigraphy of the entire object. It is also the next stage of the interpretation which consists in presenting relations of all units within subsequent parts of the building in 2D format, e.g. in the eastern façade of the abbey enclosure building in Ląd (Fig. 6.1).

After developing this type of stratigraphic comparisons, we move on to the definition of the main directions of transformations. They are designated by contractual cesuras which are understood as breaks in construction and determined after selecting the most important ASU border lines. Architectural transformations have long been connected with the concept of the "construction phase". One phase will be understood as a collection of construction works, as a result of which a fragment of the building was created functionally and structurally completed, i.e. ready for use. In determining the order of phases, we use the knowledge from the preliminary stage as well as historical and stylistic methods.

One phase will include one stratigraphic unit, e.g. in the southern façade of the enclosure in Ląd, phase VI corresponds to ASU 2 unit. However, phase I includes two ASU 3, 4 units (Fig. 6.2). Thus, we eliminate slight building interference which did not have any significant impact on the transformation of the building.

The last stage of using a stratigraphic unit is connected with the dating of individual phases. It is worth presenting them in the projections of building levels. This makes it possible to show elements which are connected with one another or attached to each other (Figs. 6.3–6.5). When determining the duration of individual phases, stylistic terms can be used (early Gothic, Gothic, Renaissance, Baroque, etc.) or specific time intervals (e.g. the 1st half of

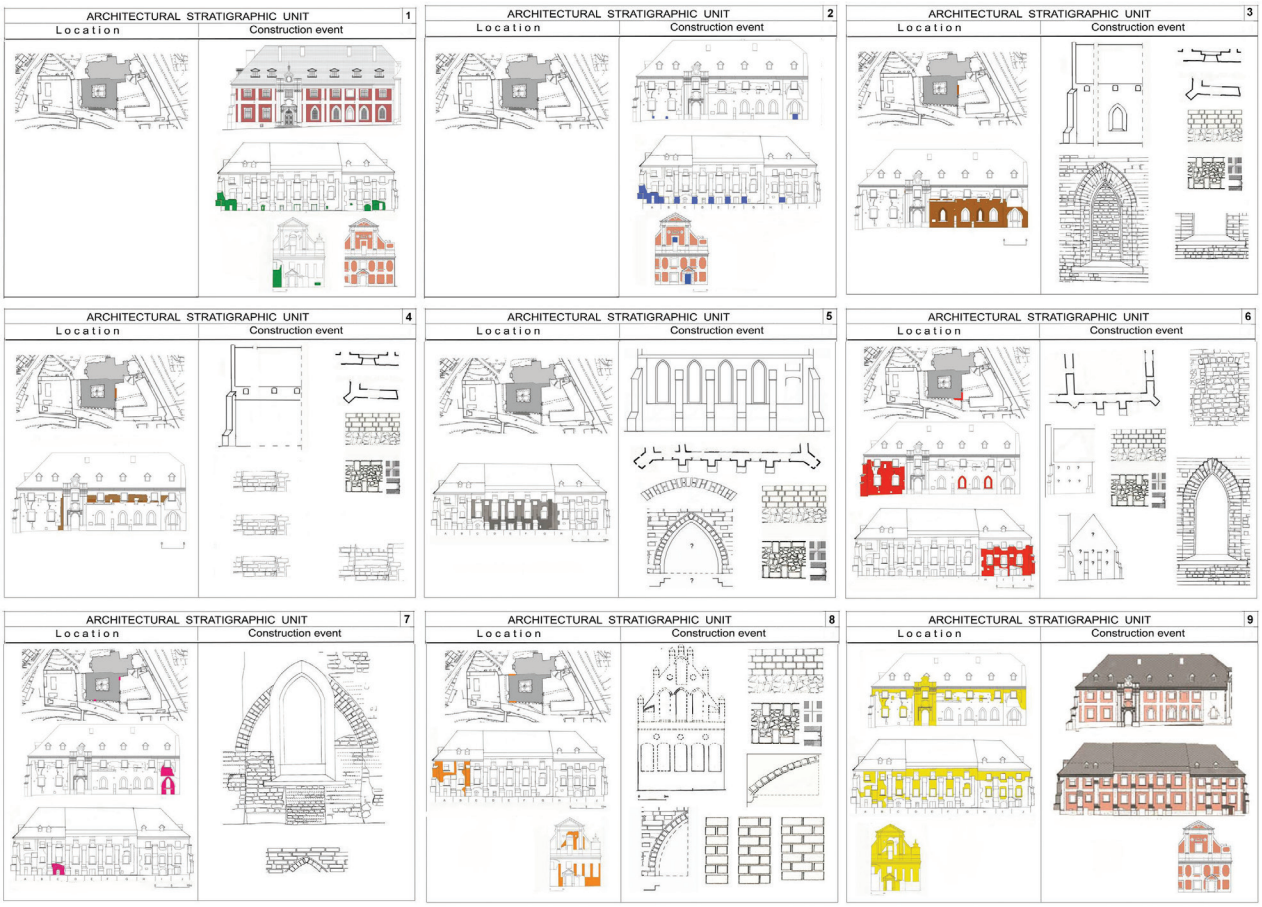

Fig. 5. The list of stratigraphic units during the eastern, southern, and northern façades of the abbey enclosure building in Ląd (elaborated by E. Łużyniecka)

Il. 5. Zestawienie jednostek stratygraficznych w czasie badań wschodniej, południowej i północnej elewacji budynku klauzury opactwa w Lądzie (oprac. E. Łużyniecka)

the 14th century). Sometimes current dating methods do not allow us to strictly determine the construction time and an additional division into stages resulting from the order of appearance of ASU should be applied.

The dating of the first buildings is usually a real difficulty. This situation occurred, for example, in Ląd, because we had historical mentions and stylistic comparisons only [6], [7]. In the eastern house, the dating elements are the Slavonic and Gothic brick layout and the ogival form. According to current knowledge, the Slavonic bond appears in Greater Poland buildings at the end of the 12th century, and Gothic at the earliest in the last quarter of the 13th century. Therefore, when determining phases I and II, the specification connected with stages was introduced (end of the 12th – 3rd quarter of the 13th century). The next Gothic phases were associated with the 1st and 2nd half of the 14th century. Dating the Baroque reconstruction was easier because it could be connected with the events which were mentioned in the documents, i.e. the rule of Opat Antoni Mikołaj Łukomski (1697–1750) and the construction of a new part of the church designed by Pompeo Ferrari in the years 1728–1736. On the basis of written and iconographic sources, it was also possible to specify the duration of renovations, namely those conducted by the Capuchins in the years 1850–1852 and by the Salesian Society from 1921 to the 1990s.

Conclusions

The presented analyses, which were carried out during architectural research and presented in two-dimensional drawings, can be then showed by means of spatial models [8]. However, not all detailed information can be placed in these models so that they are readable. Assuming that in scientific research the basis for the message should be a communication skill, it is necessary to state that the understandable publishing of indirect stages of research seems fully justified.

Obtaining understandable messages is only one of the advantages of using two-dimensional drawings. A researcher who performs drawing works or supervises them, thanks to the necessity to perform linear drawings, gets to know the building thoroughly. She/he must see and analyze many features of architecture in order to draw them schematically. Thus, the contact time with the researched source – architecture is extended, which has a positive influence on the formulation of research questions.

Another benefit of two-dimensional vector developments is the opportunity for other researchers to verify interpretations which are presented by the author. It should be emphasized that the examples presented in the article constitute an interpretative part of the research only. The documentary part should be clearly separated and much

Fig. 6. Research on the abbey in Ląd – dependence between the unit, phase, and dating.
Façades: 1 – eastern, 2 – southern.
Projections: 3 – cellars, 4 – ground floor, 5 – first storey (elaborated by E. Łużyniecka)

Il. 6. Badania opactwa w Lądzie – zależność między jednostką, fazą i datowaniem.
Elewacje: 1 – wschodnia, 2 – południowa.
Rzuty: 3 – piwnice, 4 – parter, 5 – piętro (oprac. E. Łużyniecka)

more extensive. The richer the documentation material, the greater the research value.

In our considerations, it is also worth raising the problem of understanding concepts of architecture and its documentation. The point is not to use these terms interchangeably. Some scientists are aware of this [9], but it is not common knowledge. Documenting by means of 3D and 4D models constitutes a small part of the research only.

Hence it seems that in architectural research we will still use two-dimensional linear drawings for some time. For now, they are irreplaceable also in the design of contemporary architecture and constitute the main part of conceptual and implementation projects. It is possible that in the future we will provide all information about planned and historical buildings by means of digital models and we will use the achievements of geomatics to a larger extent than today [10]. The condition for the effectiveness of such actions, however, will be appropriate content-related preparation of recipients.

Translated by
Bogusław Setkowicz

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Abstract

The use of 2D vector studies as an architectural research stage in the era of digital spatial models

The article tried to prove that in architectural research we will use two-dimensional linear drawings for some time. The considerations were based on materials from research conducted in 2017–2022. Most of them are studies made under the author's direction by a team consisting of doctoral students and students of the Faculty of Architecture of the Wrocław University of Science and Technology.

The summary states that in scientific research the basis of the message should be communicativeness and understandable publication of intermediate stages of research. In this case, avery good form of presenting indirect analyses is a two-dimensional recordingof stratigraphy. To facilitate this, the term "architectural stratigraphic unit" was introduced.

Such a unit includes all architectural elements – both the building material and other parts of the building. The basic criterion for determining one architectural unit is the simultaneity of the formation of components.

Key words: architecture, research, stratigraphy, 2D drawing, model

Streszczenie

Wykorzystanie opracowań wektorowych 2D jako etap badań architektonicznych w dobie cyfrowych modeli przestrzennych

W artykule starano się udowodnić, że w badaniach architektonicznych jeszcze przez pewien czas będziemy wykorzystywać dwuwymiarowe rysunki linearne. Podstawą rozważań były materiały z badań prowadzonych w latach 2017–2022. Większość z nich to opracowania wykonane pod kierunkiem autorki przez zespół złożony z doktorantów i studentów Wydziału Architektury Politechniki Wrocławskiej.

W podsumowaniu stwierdzono, że w badaniach naukowych podstawą przekazu powinna być komunikatywność i zrozumiałe publikowanie pośrednich etapów badań. W tym przypadku bardzo dobrą formą zaprezentowania analiz pośrednich jest dwuwymiarowa rejestracja stratygrafii. Aby to ułatwić, wprowadzono pojęcie „architektoniczna jednostka stratygraficzna". W skład takiej jednostki wchodzą wszystkie elementy architektoniczne – zarówno budulec, jak i inne części budowli. Podstawowym kryterium określania jednej jednostki architektonicznej jest równoczesność powstawania składowych.

Słowa kluczowe: architektura, badania, stratygrafia, rysunek 2D, model