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Network analysis and visualization for the history of concrete shells – the case study: Istvan Menyhárd

Orsolya GÁSPÁR*, Alexandra É. KIS[a]

*Department of Architecture, The Pennsylvania State University,
330 Stuckeman Bldg, University Park, PA 16801 USA
ovg5079@psu.edu

[a] Department of Mechanics, Materials and Structures, Budapest University of Technology and Economics

Abstract

The present study explores the potential of network analysis in construction history by mapping the professional life of Istvan Menyhárd, a pioneer of Hungarian shell architecture. He relied on the most up-to-date theoretical developments when erecting his first structures before WWII (among others, hypars). His expertise and devotion had a wide impact on later generations of engineers. Suitably for the present study, his life and works are well documented, and the missing links were reconstructible through oral history. The study contributes to the global history of twentieth-century concrete shells by showcasing the work and influence of a lesser-known engineer. It offers insight into how closely connected was the network of the early (pre-WWII) shell builders, despite geographical distances. It also underlines the divergence of focus and methods and the relative isolation of the Second World after WWII. From a methodological point of view, the potentials and limitations of the network/based approach are highlighted. Key areas are identified where the current tools (i.e., Gephi) do not provide adequate solutions, outlining areas of further research: the database structure and visualization of the emerging network should be tailored to the specific needs of construction history. Preliminary results addressing those shortcomings are discussed.

Keywords: construction history, concrete shells, network visualization, social network, Second World, data analysis, Istvan Menyhárd, Gephi

1. Introduction

The history of concrete shells is a complex web of precedents and influential masters. While it is often intuitive to notice similarities between two structures, proving any link between them is a challenge. Network analysis offers a framework that can be used to highlight similarities (e.g., by clustering based on geometrical characteristics) in a more systematic manner, and to identify direct or indirect links between designers (i.e., social network analysis). Moreover, visualization of the emerging networks allows recognition of patterns even in large datasets. These approaches have been successfully applied in historical studies [1] art history [2], and anthropology [3], but it is yet to be exploited in construction history.

Networks describe the relation between entities in various systems. Their visual representations, graphs, consist of nodes (or vertices, i.e., entities) and edges (relations). Both the structure and the evolution of networks have been intensely researched, mainly because of the wide applicability of abstract principles observed [4].

The analysis of social networks was a pioneering field in network analysis [5], well established by the mid-twentieth century. With the advent of the XXI. century, the exponential growth of available data accelerated research, and consequently, new tools (including Gephi [6], which we used for this study) for analysis and visualization of networks as graphs were developed and are widely used today.

Graphs generated by Gephi (and similar software) can offer valuable insight on key properties of a network visually, eliminating the need that the end-user comprehends the underlying mathematical concepts (Figure 1). Moreover, network analysis software allows the study of the evolution of the graph, as each vertice and edge of the graph can have a timestamp. We leveraged this feature extensively (Figure 3) when mapping the evolution of the extent of Menyhárd's influence, and by extension the developments in Hungarian shell architecture over time to test the claims of earlier studies [7].

There is a growing interest in applying network analysis when studying architectural history: prevalently these studies focus on personal relations [8,9], as such they belong to the broad field of historical network studies. This study is also greatly influenced by both the motivations and the methods of historical network analysis, but it also considers another type of relation, inherent to architectural design: the influence of direct or indirect (through publications) contact with buildings and theoretical advances.

Istvan Menyhárd (1902-1969) was among the first to ever build a concrete shell in Hungary (his first shells were constructed in the 1930's). He left his mark on the Hungarian shell architecture through his own designs, but even more through his wide-ranging influence on his peers and later generations of engineers and architects. He is a member of the pioneering shell builder generation, which started their career before WWII. His formative years were greatly impacted by direct and indirect (through publications) knowledge transfer with the international community involved in thin shell theory and construction: as an example, his pre-war hypar shells can be cited, which he designed relying on the theory outlined by Ferdinand Aimond a few years earlier [10]. After WWII, the relative isolation of Hungary, which belonged to the Soviet Sphere of interest then, accelerated knowledge transfer [7,11] between Hungarian professionals to compensate for the lack of access for many to Western publications. This consequently increased Menyhárd's significance nationally.

2. Motivation and methodology

As discussed in the introduction, Menyhárd had a prolific influence on the developments of Hungarian shell construction. Moreover, his life is relatively well documented, both primary and secondary resources are easily attainable. Mapping his life into a network of influence is hence both relevant and possible. The documentation on the breadth of his influence has so far been anecdotical [12]: the present study offers a reasonably objective and highly visual representation of it. In specific, in this study we explore:

- The influence of Menyhárd's theoretical and, consequently, geometrical preferences on the development of Hungarian shell structures.

Furthermore, the collected data can support or contradict previous claims [7,11] regarding the general features of the Hungarian shell architecture

- Such as chronology of the construction of shell structures, their fields of application, and the most common construction techniques.

Finally, treating the process of mapping Menyhárd's influence as a case study

- We outline the generalizable consequences, relevant challenges for applying network analysis and visualization techniques in the field construction history.

2.1. Methodology

The primary source for mapping Menyhárd's social network was his biography authored by Iván Erényi [12]. Data was supplemented and contrasted with contemporary publications [13,14] and scholarly studies of the era [15]. Original blueprints of selected shells were also consulted. Through an earlier research lead by the first author, an extensive database of Hungarian concrete shell structures was established [16], which was leveraged to gather data on the national context of Menyhárd's work. The data extracted from these sources was entered into our database. For visualization purposes, the nodes

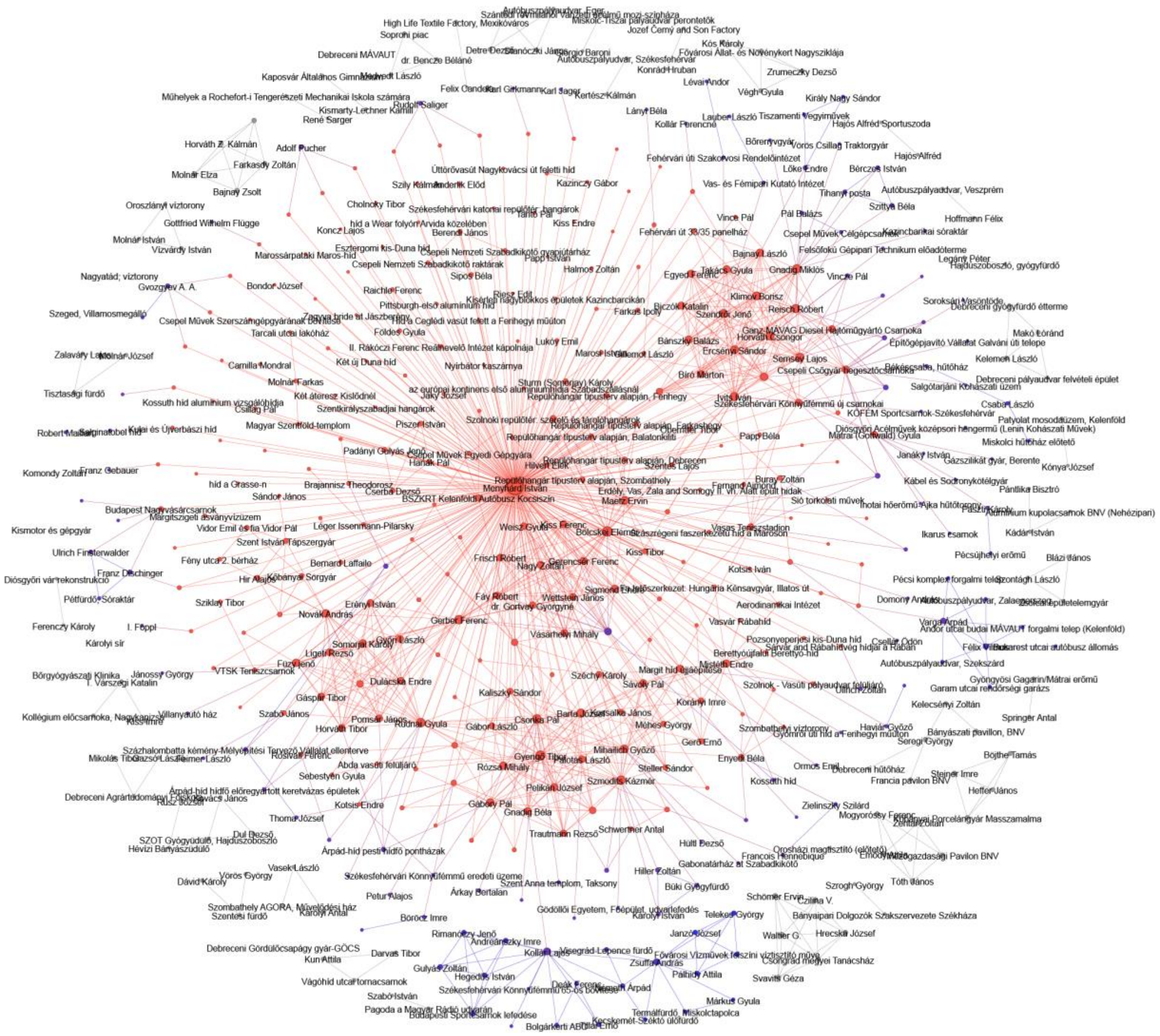

Figure 1: Network of influence in Hungarian shell construction (including shells and designers), centered around István Menyhárd (corresponding node in the centre). It includes all documented Hungarian shell structures. The colorscale from red to blue indicate the person's or building's distance from Menyhárd (the red is close, the blue is distant)

and edges needed to be defined. As there is no established methodology in what constitutes and edge and what defines a node in the realm of construction history, we developed our own system. We interpreted nodes very broadly: in addition to people, any product, including built and unbuilt projects, but also papers and books are turned into nodes. Edges are restrained to describe relations: these can be directed or undirected. Our decision was driven by an understanding that structural and architectural design can be equally influenced by personal relations, personal or secondary experience with a building and theoretical studies-even though, as elaborated in the Discussion (Section 4) these are not fully exploited yet. In establishing the graph this way, we intended to treat each type of influence "equal". Subsection 4.3.2 further elaborates on the challenges of classifying certain entities as edges or nodes, but we want to highlight in advance that events and workplaces were particularly controversial in this sense.

The database containing the nodes and edges, along with their assigned attributes is stored in an Excel spreadsheet. We processed and visualized the data with the Gephi network analysis software. The data was imported to Gephi using a .gexf file generated by a custom-made Python code from the (original).csv file.

The main benefit of the chosen software was that it allowed easy sorting of the data through attributes: the attributes specified for nodes and edges can be filtered, and the filters can be nested in Gephi. One can easily distinguish nodes according to their attributes by setting different colors for each type. The size of the nodes (can) reflects their degree (how many edges are connected to them – the greater the node, the more 'central' its role is in the connectivity of the graph). This helps to visually identify hubs or assess the influence of selected individuals. Remarkably, previously claimed 'hubs' [15] are clearly identifiable in the graph emerging from this study.

Furthermore, as hinted in the Introduction, Gephi can handle a dynamic graph: if the nodes (and edges) are dated, the network's evolution can be traced. We leveraged this property when capturing the trends in shell construction activity over time (Subsection 3.1). The software also offers a wide range of metrics to quantify various network properties (e.g., the average distance of two nodes (how many nodes one must traverse to get from one to the other), the largest distance between any two nodes etc) and have a range of inbuilt algorithms to arrange the nodes in the plane according to their relation to each other (clustering). The former offers valuable insight into how connected the network or its segments are, and the latter allows quick visual feedback on important centers of innovation.

2.1.1. Edges and nodes, attributes

The edges in the graph are defined by their two endpoints. Two types of edges were defined: the undirected edges denote acquaintances between two persons while directed edges are usually associated with the creation of something, i.e., publication or structure. Each node and edge have attributes according to Table 1 (it only shows attribute classes, certain attributes, such as type, had subcategories). It is important to highlight that edges hence are only created between two people, or one person and another type of node (i.e., no edges were defined linking two buildings, two papers, etc., see also Subsection 4.3).

Table 1: Node and edge attribute classes

	ID	Source node	Target node	Label	Type	Date	Source of information
Node	x			x	x	x	x
Edge	x	x	x	x		x	x

The first four attribute classes are essential to specify the elements of the graph. The nodes were divided into subcategories by their type to filter the data. Each component of the graph has a date associated with it, to allow track changes in the network over time (to create a dynamic graph). Node types are structured according to their properties as shown in Figure 2.

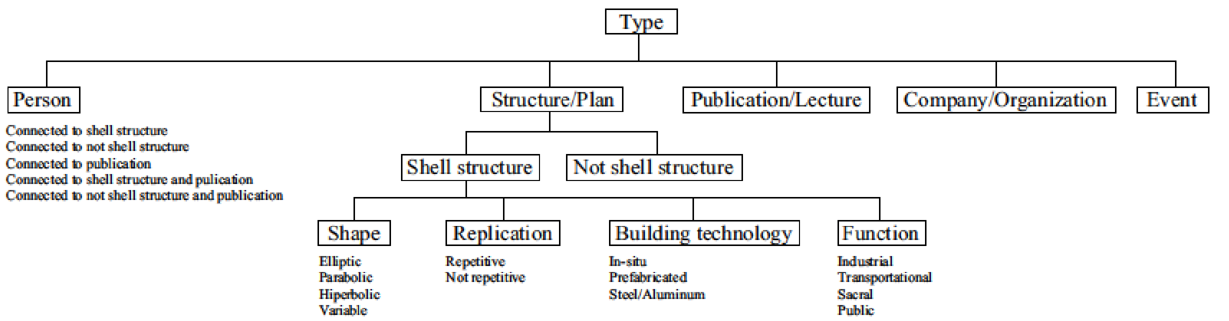

Figure 2: Node types, and their subcategories

3. Mapping the life of Istvan Menyhárd

The graph arrangements presented in this chapter all follow the same scheme. All graphs only contain shell structures that were built in Hungary (the list is as comprehensive as the available documentation allows), but they contain both foreign publications and engineers and architects. In the innermost circle one can see the shell structures that were built before World War II and cannot be attributed to Menyhárd. Moving outwards the next circle shows the pre-WWII shells for which Menyhárd is listed as the designer. Next are the post-WWII structures built with the involvement of Menyhárd, and finally the post-WWII structures that are not directly linked to Menyhárd (though many were conceived under his influence, see Subsection 3.1) in the outermost circle. Because of the rule of creating edges (Subsection 2.1), on any visualization that excludes people, no edges are present.

3.1 Chronology of Hungarian shell structures

The early period in the Hungarian shell architecture spans from the 1930s until World War II. During this time Menyard built several, pioneering structures: he designed the hypar roofing of several warehouses, including those at Csepel in 1938. Those were among the first hypar shells ever built in the world. The Autobus Garage at Kelenfold, constructed in 1942, was then the largest spanning shell structure of its kind (a translational elliptical surface with 80 m span).

The following period is the heyday of shell structures in Hungary, from late 1950's to mid 1960's [7]. In the first ten years after WWII hardly any shells were built due to material- and construction technological shortage. After WWII Menyhárd's first in-situ reinforced concrete shell structure was the KOFEM Factory at Szekesfehervar (1957), which became a model for the shell roofs used in a series of later industrial buildings [17].

Figure 3. Autobus Station, Zalaegerszeg (left), Árpád Varga, 1965, Warehouse, Csepel (right) 1938-39, István Menyhárd

During the late period of shell construction (from the mid 1960's) many infrastructure-related buildings (train- and bus stations and ports, e.g., Autobus station at Szekesfehervar and Zalaegerszeg, Figure 3, left) were built in Hungary, designed primarily by UVATERV, the state-owned design office for infrastructure. Remarkably, most of these buildings were roofed by hypars. We learned of Menyhárd's

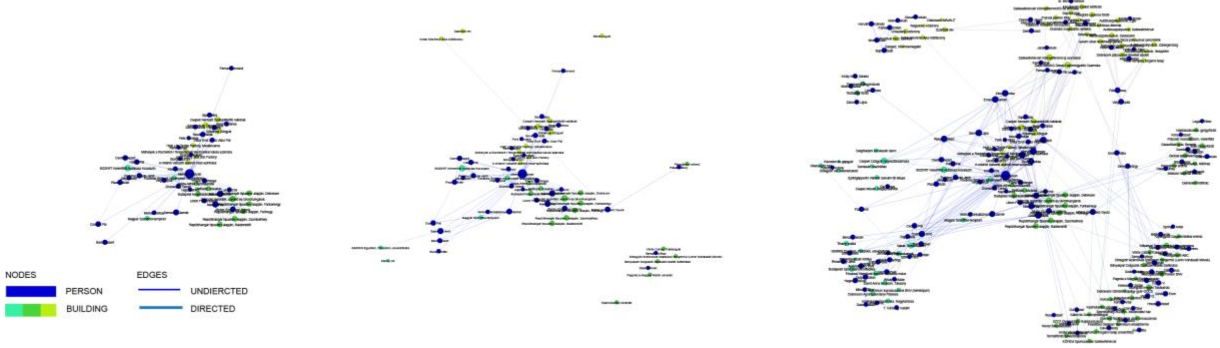

Figure 4. Evolution of Menyhárd's network of influence. The snapshots are taken, from left to right in 1944, 1954 and 1965, It shows the lack of construction activity in the decade after WWII.

profound influence on the lead structural engineer, Arpad Varga (who took Menyhárd's post-graduate shell seminar right after WWII) firsthand, during an earlier interview with him. He also explained that he had no awareness of foreign developments (including Felix Candela's contribution). Consequently, the hypars designed by UVATERV are direct descendants of Menyhárd's pre-war hypars (Figure 3 and 5).

3.2 Geometrical characteristics of Hungarian shell structures

In this study the examined shell structures were divided into four groups according to their shape (i.e., the Gaussian curvature of the surface). It is remarkable that hypar shells were built in great numbers after WWII, not least due the design activity in UVATERV (see 3.1). Each group was further divided into two subgroups based on whether their construction typology was repetitive or not. The resulting clustering is shown in Figure 5. There is a clear dominance of repetitive structures, which is hardly a surprise, as reusable formwork could significantly improve the economy of shell construction. Menyhárd's most influential contribution was the innovative, reusable and movable formwork his team developed for the roofing of the KÖFÉM factory.

3.3 Most relevant shell construction technologies

Menyhárd was an ardent proponent of cast-in situ shell construction [12,17]. This was in strong opposition of the state-mandated ideals of the early post-war ear in Hungary, which promoted prefabrication. However, as the Figure 6, right suggests, eventually most shells were built as cast-in situ concrete structures. Menyhárd pushed through the first cast-in-place shell after WWII (the KOFEM Factory), but in fact, by that time economic realities also forced a change in what was considered favored

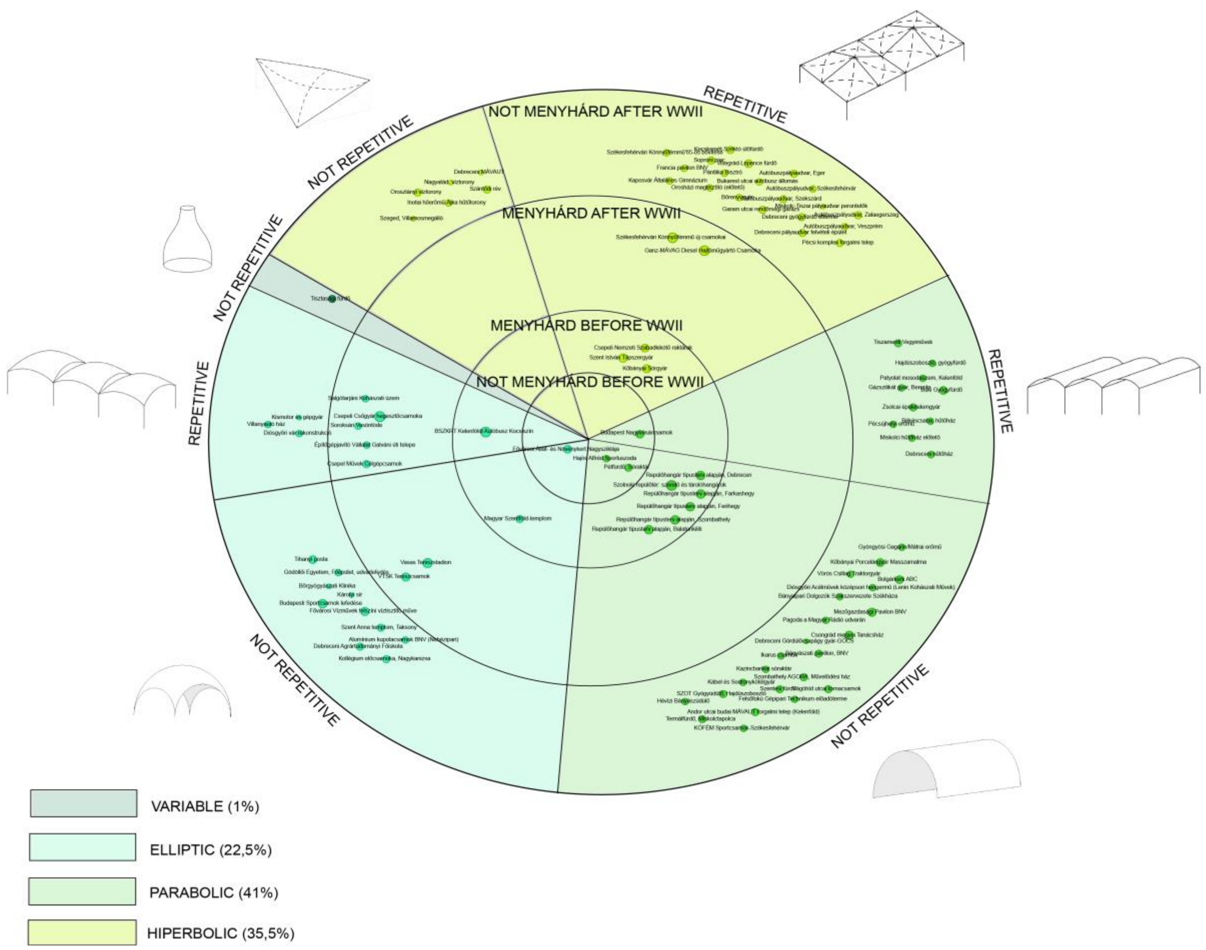

Figure 5: Hungarian shell structures grouped by their shapes

construction technologies (due to their high complexity and tailor-made design, shells proved to be less suitable for prefabrication).

3.4 Fields of application of shell structures

The proportion of public buildings is relatively high (Figure 6, left), which slightly contrasts the claim of Gáspár and Sajtos [11], that Hungarian shell structures are dominantly industrial and transportation constructions. There is a remarkable correlation between public buildings, and non-repetitive shell structures: obviously, public buildings usually require a central space, while industrial buildings, or buildings for transportation typically aligned longitudinally.

4. Discussion - Potentials and shortcomings of current tools

During this study, we primarily focused on supporting (or disproving) informed assumptions regarding the general properties of Hungarian shell architecture (e.g. [7,11]): The typical field of application of shells, the typology of the shells' geometries, the construction activity distribution over time, and international influences. Our main motivation was to show the capabilities of a data-driven approach in comparative construction history.

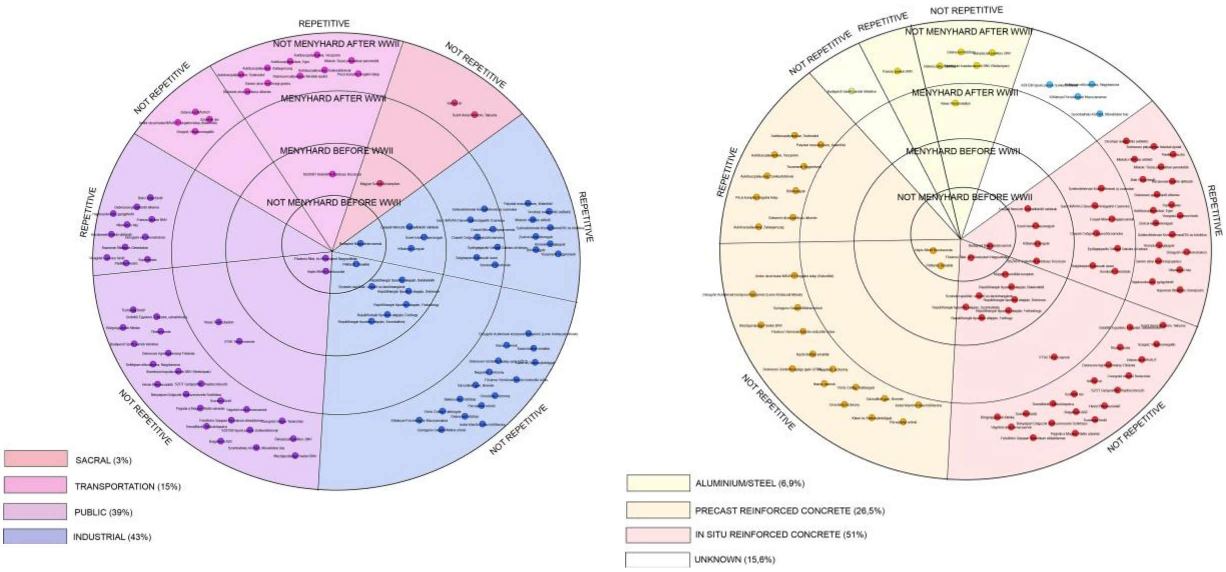

Figure 6: Hungarian shell structures grouped by their funcion (left) and their construction technology (right)

4.1 New insights, proven and disproven hypotheses

Many of our assumptions were confirmed: first and foremost, Menyhárd's significant impact. A declared characteristic of the Hungarian School, its tendency toward geometries described by a closed-form solution is also affirmed [11]. Similarly, the existence of a pre-war blossoming period in shell construction activity, followed by an almost 10-year hiatus before shell construction was resumed also became apparent thanks to the dynamic graph representation. Still, when experimenting with a new tool, one hopes to gain new insights, either contradicting previous results or pointing towards potential new research endeavors.

4.2 Unexpected results and the limits of a high-level comparative analysis

In earlier studies of the first author on the context of Hungarian Shell architecture, its close relation to the German School was emphasized. While this is a plausible concept (similar educational system, direct influence through the construction activity of the Dywidag company in Hungary in the 1930s [7]), our most recent results highlight the significant impact of French shell theory. It is important to emphasize that this analysis focused on Istvan Menyhárd's life, work and influence, it can only capture his personal preferences. Nevertheless, given his wide impact locally, this sheds a new light on the development of the Hungarian School of shell design: the formative influence of (early) French shell theory must be acknowledged. In the same study ([7]) industrial buildings were identified as the primary field of application for shell structures. The data, once visualized and sorted, challenges this interpretation. The number of public and industrial buildings in the databank are comparable, depending on whether one classifies 'transportation' (stations) as public or industrial, either one can gain a slight advantage.

While the underlying study focused on the social network of Istvan Menyhárd, the graph is somewhat representative of the Hungarian School's as it contains all, currently documented shell structures, along with their designers. It is therefore remarkable how certain groupings of designers (heavily interconnected within but with sparse connections beyond their peers) can be identified in the graph. This somewhat conflicts with our expectations: Menyhárd and other (within the context) famous figures worked at multiple offices and in multiple roles during their careers, but at the current state the graph suggests this was rather the exception as the norm. Most design teams worked together for substantial periods. This, on the other hand explains or supports claims of the literature [15] that these 'groupings' often developed distinct formal characteristics, imprinted on their designs. We believe this deserves further study, with more balanced literature analysis (not focusing on Menyhárd).

The perceived similarity of the two shell structures (Figure 8), supported by strong social links between their designers prompted us to briefly investigate the method's ability to predict links between buildings. The Church of the Holy Land, in Budapest was designed (but eventually never built) by Farkas Molnár and István Menyhárd in the early 1940s. The Church of St. Anna in Taksony was designed (and built) by Aladár Árkay and Pál Csonka in 1956. For both, the centralized volume is covered by a shell roof

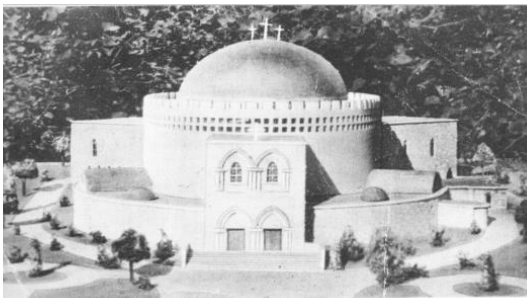

Figure 8. Church of the Holy Land, Budapest (left) (1944), Church of St. Anna (Taksony), right (1957)

based on an ellipsoid. To our knowledge, ellipsoids were only used (or meant to be used) for these two structures in Hungary. The similarity of the two dome geometries is remarkable at first glance. The graph (Figure 1) highlights the close relationship between the two structural engineers, Menyhárd and Pál Csonka (which is supported by written records, as well). However, our follow-up investigations underline that even the combination of visual resemblance and confirmed social links can only be regarded as a base for future historical studies. We studied contemporary resources and the primary design documentation: it became evident that the dome geometries, apart from them being based on an ellipsoid surface, are quite different and no record indicated any closer connection between the two designs.

4.3 Database and Visualization

4.3.1 Where is the data?

Network visualization can be very insightful, especially if working with a large amount of data. It requires a systematized database. As is often the case in the field of historical studies, such database was not readily available. In the frame of our previous research project we established a simple database, consisting of an Excel sheet listing Hungarian concrete shells and a digital archive containing images of the structures, scans of contemporary publications and original blueprints. While the digital archive proved to be useful, it has been extensively expanded based on further archival studies. Eventually, to compile with the input file requirements of Gephi, we decided to build the database used for this study from scratch.

4.3.2 What is a node and what is an edge?

One of the biggest challenges when determining the structure for the database, is to decide what constitutes a node and what translates to an edge. Eventually, we want to develop a methodology that can tell a visually compelling story of influences. From this point of view, the distinction we made between node and edge makes sense: any entity that can have a graphical interpretation, became a node and edges describe ‘relations’ only. In our current database, designers, buildings, books and papers, but even events and companies are represented as nodes (the last two somewhat challenge our own chosen definition of a node). It is unlike (but not unprecedented [8]) the approach used by some of the cited studies, which rely on one type of node (e.g., in McEnerney’s study [9] the nodes are people, or as in Lulewicz’s [3], archeological sites). It is important to highlight that from a network analysis point of view this can be problematic. Typical metrics used in network analysis are hard to interpret if all nodes and edges are active. First and foremost, the degree of the nodes (i.e., the number of ither nodes they are directly connected to): It does not translate to the number of collaborators, or the number of built structures etc., rather a combination of all of those. A metric for the connectivity of the whole graph, the average path-length is, again, misleading as it mixes distances between people, peoples and objects etc. However, using filters based on predefined categories of nodes (people, publication, building etc). relevant metrics can be derived easily.

Nevertheless, the argument might be made that as opposed to using multiple type of nodes it might also be meaningful to use multiple type of edges (e.g. [8]). We plan to explore this further.

4.3.3 Visualization

One of the driving forces for us in applying network analysis to the history of shells is to exploit its potential to emphasize the conscious and unconscious “formal quoting” present in architecture. It is particularly relevant (and a more realistic aim) for shell structures, as their formal vocabulary was somewhat limited (“new” forms often required the development of specific solutions within the theory of shells). Current approaches to identify similarities in architecture [18] and art [19] focus on establishing relationships between one or more objects using image recognition and deep learning. They do not aim to analyze the reason for similarity. This is the potential of including similarity metrics in network analysis for the construction history of shell structures: visual characteristics are just one layer of information of the building. In anthropology [3] similarity metrics of objects (i.e., ceramics) are well established, and widely used to identify temporal or societal connections between archeological sites. Considering similarity between buildings alongside social networks of their designers can explain the occurrence of similar shell geometries in different places, at different times (with obvious limitations, see Subsection 4.2). However, even including images in Gephi proved to be challenging. We struggled to find an existing framework that would allow us to meaningfully integrate and work with images. Currently, the geometrical features of the shell structures are added manually as an attribute to the ‘type’ category in the database. This allowed us to prompt the groupings on Figure 5. But, this only allows a very high-level classification and fails to highlight stronger similarities within each geometrical group. We consider this to be one of the major shortcomings of the present methodology. Currently all edges established have people as at least one of their nodes (there are no direct links between two buildings), and hence there are no edges in Figure 5. In the next phase of this study, we plan to add more subtle geometrical characteristics to define similarity metrics and automate the link (edge) generation between similar shells.

5. Conclusions

Present paper described the possibilities and constraints of applying network analysis techniques to construction history. Specifically, we visualized the network of influence of István Menyhárd, whose work had a lasting impact on the Hungarian school of thin concrete shell design in the XX. century. From a construction historical viewpoint, the network analytical approach was especially useful in highlighting the influence of the French School on the developments in Hungarian shell design. Their early results served as a theoretical foundation for the design of Hungarian shells in a greater extent than previously assumed. Moreover, the visualization of Menyhárd’s network of influence made the relative isolation of smaller designer groups apparent, which, given the relative low number of engineers involved in shell design in Hungary is somewhat surprising. One of the main findings of our work from a technical point of view paves the way for our future research: While existing network visualization tools well support an analytical interpretation of a dataset, they lack features that would allow an associative discovery of connections. Similarities broadly interpreted have been spurring construction history research. Hence, our aim is to integrate the possibility of discovering and tracking similarities visually (i.e., through images of the buildings/structures) in a network.

Acknowledgements

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