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INVESTIGATIONS ON THE DESIGN PROCESS OF ELADIO DIESTE: 3D PARAMETRIC MODELLING OF MODERN LATIN AMERICAN ARCHITECTURAL HERITAGE

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ABSTRACT:

The Uruguayan Engineer Eladio Dieste underwent a quest for thinness in the field of structural design which rendered his reinforced masonry thin-shell structures at a conspicuous position in Modern Latin American Architectural Heritage, so much so as to have Dieste’s work in Latin America and Europe included in an indicative list for UNESCO’s cultural heritage sites as of 2010. Nonetheless, the design process that led Dieste to such innovative structural typologies is yet to be fully academically explored. Thus, the objective of this paper is to examine the state-of-art regarding the intricate design process of Eladio Dieste’s gaussian vaults and shed some light on the existing gaps within this process by means of the 3D parametric modelling and digital fabrication of selected case studies. The adoption methodological procedures such as 3D parametrical modelling and digital fabrication allows for the establishment of important relationships between the design process and the resulting geometry of Eladio Dieste’s designs, as well as furthering registry of Dieste’s legacy for conservation purposes.

1. INTRODUCTION

1.1 Contextualization of the investigation

It is always challenging to condense in few words the importance of the Latin American architectural legacy. However, when reviewing the modern architectures that have been developing in that continent between 1950 and 1965, some reflections can be extracted that facilitate the understanding of this phenomenon. The constant flow of professionals from one country to another, professionals trained in different schools, by teachers coming from different places, constitutes a complex network of relationships that produced what can be configured and defined as Modern Latin American Architecture. As according to Llobera (2006), the initial proposals of architectural modernity, generated in Europe, were skilfully collected in the Latin American continent, both by European and local architects, with a willingness to adapt it to local constrains. Lara (2008) complements this notion establishing that geographical borders were not an impediment to the flow of architectural ideas that, for its quality as well as its quantity, constitutes perhaps the whole of greater value of modernity. Middle-class people would read about it in popular newspapers and journals, then go about designing their own homes in the modernist style, using distinctive layouts and façades.

Documentation and conservation approaches have evolved since the first modern buildings were awarded heritage protection in the late 1970s. McDonald et al. (2007) corroborate in that sense, bringing about that the recognition of a broad range of heritage values and types of heritage places, changes in heritage management, reduced government support, and the importance of public participation have all influenced what is protected and how it is conserved. The continuing debate on these issues, such as what Stratton (1997) pointed out as the realization that early modern buildings are soon due for their second round of repair, and the fact that their post-war siblings are facing their first, stressed the importance of documentation and research studies on these excerpts of cultural heritage such as this investigation on Eladio Dieste’s built work.

Eladio Dieste was as a Uruguayan engineer that, in his own words, discovered himself creating architecture while designing and building warehouses and churches (Carbonell 1987). These design problems were tackled through an ever-developing conscience of form, which as according to Anderson (2004), led Dieste in a quest for thinness that would yield irrefutable innovations in the design process of thin shell structures. Accordingly, Anderson (2004) elevates the gaussian vaults (Figure 1, left) as the banner for Dieste’s greatest structural feats, for it constitutes a previously unseen structural typology resulting from his design and constructive experimentations in a then virtually unexplored construction technique, reinforced masonry.

Nonetheless the value of Dieste’s contributions, the consultation of established academic indexers such as Web of Science (Clarivate Analytics 2018) and Avery Index (Pro Quest 2018) has revealed that there are very little academic explorations regarding Eladio Dieste, especially when it comes to his structural achievements and design strategies. This paradoxical ostracism becomes intensified when taking into consideration that as of 2010 (UNESCO, 2019), a substantial amount of works designed and built by Dieste in Uruguay, Argentina, Brazil and Argentina has been included in an indicative list to become cultural heritage.

Therefore, the main objective of this research is to examine the state-of-the-art regarding the design process of the gaussian vault structural typology and thus, to identify and explore existing gaps on its design process by means of the 3D parametric modelling and digital fabrication of selected case studies.

Figure 1: (left) Porto Alegre Market (1970-72), Porto Alegre - Brazil. (right) Church of Cristo Obrero (1958-60), Atlántida - Uruguay.

1.2 Research Concept

The object of study within this research are the gaussian vaults of Eladio Dieste, designed and built by the Uruguayan engineer in the second half of the twentieth century in the territories of Uruguay, Argentina, Brazil and Spain. Accordingly, the main objective of this study is to investigate what is known regarding design process of the gaussian vaults of Eladio Dieste in order to identify and explore gaps on such design process by means of the 3D parametric modelling and digital fabrication of selected case studies.

In order to do so, this paper is structured in the following sections: Section "1-Introduction", where in subsection "1.1 Contextualization of the investigation", is laid out the framework in which the object of study is inserted, and where in subsection "1.2 Research Concept", the research's structure and its fundamental concepts are laid out; section "2- Developed Research", where in subsection "2.1. Related Works" there is a concise outline of the state-of-the-art regarding analogous academic exploration, in subsection "2.2 Developed Methodology" there is a synthesized demonstration of the application of the methodological procedures utilized in this research, and in subsection "2.3. Discussion", it is aimed to list the knowledge extracted from the application of the proposed methodological procedures; whereas section "3. Conclusions" seeks to establish a panorama for future explorations regarding the theme.

However, before furthering the explanation of the organizational structure of this research, it is important to establish the definition of the concepts that are central to this endeavour. These concepts are the structural typology of the 'gaussian vaults' as well as his particular sense of 'cosmic economy'.

In the compilations of Torrecillas (1996) Eladio Dieste himself defines the design guidelines which comprise the concept of gaussian vaults:

1 – Brick, mortar and steel form a structurally viable compound.
2 – The election of the catenary as a design guideline in order to handle the compression produced by the structure's self-weight and other stresses.
3 – The compression forces originated from the structure's self-weight are not related to the cross-section.
4 – The strictly necessary dose of steel reinforcement assures that a considerable portion of the structure's surface can sustain the expected admissible tensions, and thus operate as an elastic unit when it comes to concentrated loads.
5- Tests in both small vaults and long-span structures lead by Eladio Dieste himself have shown that the moving of the formwork to the successive structural module does not demand the complete drying of the mortar on the bricks.

In the other hand, the decision to elect reinforced brick as his preferred construction media and elevate geometry as the essence of the gaussian vaults' design guidelines come from the continuous maturation of Eladio Dieste's own take on the concept of economy called 'cosmic economy'. In Carbonell (1987), Dieste defines his sense of 'cosmic economy' as a quest for equilibrium in the universe as a whole, which managed to penetrate in the manner Dieste designed and built. These designs were thought out to be the most resistant, simple and economical to build, and this goal was to be achieved by the resistance through form. Torrecillas (1996) synthesizes this concept of 'cosmic economy' as that in Dieste's designs, only the essential has place, and this objective is to be attained by means of the design's resistance through form.

The adopted methodology (Figure 2) for this research started by the consultation of academic data-bases available in both FAU-Mackenzie and Università degli Studi di Ferrara such as Avery Index (Pro Quest 2018) and Web of Science (Clarivate Analytics 2018) regarding the design process of Eladio Dieste's gaussian vaults. Once this initial step was concluded, there were made *in-situ* visitations of Eladio Dieste's gaussian vaults in order to instil a fuller grasp of the spaces and forms produced by these structures. The bibliographical review extended itself to the verification of the state-of-the-art regarding the design of double-curvature nowadays. These visitations were also beneficial in the sense that they provided original drawings from Dieste & Montanez S. A., only obtained with the aid of the professors from the FADU – UdelaR (Facultad de Arquitectura y Diseño Urbano de la Universidad de la República Uruguay).

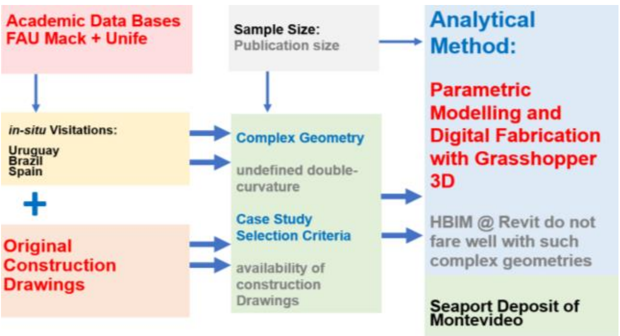

Figure 2: Methodology Workflow

The selection of case studies for this research took into account the quantity and nature of available drawings per design. Due to the physical limitations of this paper as well as the necessity to detail the extensive methodological procedures, the analysis was limited to a single case study: The Seaport Deposit of Montevideo, designed and built by Eladio Dieste in 1979 (Montevideo – Uruguay). The choice was due to the design having the biggest transverse span in Dieste's built gaussian vaults, 44,74 meters, as well as the biggest availability of construction drawings amongst the body of primary sources.

The main reason for the adoption of 3D Parametric Modelling itself was due to inability of traditional modelling tools such as AutoCAD© to fully represent complex geometry such as the double-curvature present in Eladio Dieste's gaussian vaults such

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as the Porto Alegre Market (Figure 1- left). The importance of form in the results aimed by Dieste makes it mandatory to grasp the geometrical conformation of the case study and, consequently, Dieste's design process for thin-shell structures.

Such traditional software and drafting tools also make it difficult for designers and researchers to fully comprehend and analyse the geometry of contemporary architects' production such as Zaha Hadid and Frank Gehry. Veiga and Florio (2015) and Picon (2004) corroborate with conjoint usage of 3D Parametric Modelling and Digital Fabrication techniques in this sense of thought mentioning that the hand manipulation of the digitally fabricated pieces potentializes the comprehension of the geometry of the design, as well as the family of variations within the algorithms produced with 3D Parametric Modelling. Sass and Oxman (2006) complement this notion asserting that the hand manipulation of these physical models also allows for an enhanced comprehension of their tectonic aspects and different spatial relationships. The adoption of strategies which enhance the grasp of the resulting geometry of the design is important for in the compilations of Gutierrez (1998), Dieste himself criticized modern architecture's planar geometric solutions as being held hostage by the paradigm of floorplan-section-elevation in architectural representation.

If in one hand recent research such as Balzani et al. (2019), Monaco et al. (2019), and Iadanza et al. (2019) establish the association of 3D integrated survey and HBIM as the state-of-the-art regarding the documentation of geometry of cultural heritage, Zardo et al. (2017) establish that the manipulation of doubly-curved geometry in the BIM platform is an obstacle to be overcome by Dynamo©, the visual scripting platform available within Autodesk Revit©. Zardo et al. (2017) also puts Grasshopper© (Mcneel 2018) in a preferable position to manipulate such geometries due to the widespread availability of plugins developed by its own community of users, and a greater body of research and forum publications when compared to Dynamo©. Therefore, the choice of software for the 3D parametric modelling and digital fabrication of the case studies was Grasshopper© in association with Rhinoceros 3d 6.0© (McNeel 2018).

In order to fully grasp the adequation of the methodological procedures above, it is important to understand the concept of 'algorithm', 'parameter', and their implications in the design process within 3D Parametric Modelling. Tedeschi (2011) refers to algorithms as a logic and finite sequence of steps which aim to solve a problem. 3D Parametric Modelling makes use of algorithms because they are harboured into a form-generating design strategy. Kolarevic (2003) states that these algorithms are composed by a dynamic computational formula that can create various shapes and forms, while Florio (2005) synthesizes this concept defining algorithms as plastic representations of mathematical expressions. Carpo (2011) goes on to further clarify that these elements are not an object, but an algorithm that can produce a finite variation of analogous objects, design elements, or whole designs themselves. This variation of by-products results from alterations in the inputs, or parameters, of the algorithms.

2. DEVELOPED RESEARCH

2.1 Related Works

The consultation of the academic data-bases Avery Index (Pro Quest 2018) and Web of Science (Clarivate Analytics 2018) has revealed scarce mentions of Eladio Dieste, especially when it comes to Dieste's design process and its implications on the resulting geometry of the designs. This ostracism is paradoxical when compared to the innovations in the field of structural design proposed by Dieste. Pedreschi (2000), Anderson (2004), Ochsendorf (2004) and Melachos et al. (2019) have examined the nature of such innovations, which can be synthesized by the establishing of a previously unknown thin-shell typology, the gaussian vaults, in a virtually unexplored construction technique, masonry.

The afore mentioned ostracism is a collateral effect of the overall neglection of Modern Latin American Architectural Heritage in the academic explorations of the twentieth century. However, the dawn of the 21st century has seen an exponential increment which is bound to reverse this status in the decades to come. To cite only a prominent example, Kenneth Frampton (2015) only added additional chapters regarding Latin American Modern Architecture in his latter editions of 'Modern Architecture: A Critical History'.

The consultation of the academic data-bases suggested that thin-shells structures in general have seen a recent increase in numbers. Bechthold (2008) states that the two main stages of the design process of thin-shells are divided into 'form-finding' and 'behavior analysis', which also comprises the optimization of the form amidst the original concept and its constructive viability. Baricci (2016) defines 'form-finding' as the process of finding and making emerge new forms that are statically viable, with Veiga and Florio (2015) complementing this definition stating that 'form-finding' reaches a statically viable form once it derives a shape that satisfies equilibrium conditions. In the other hand, Bechthold (2008) defines the 'behaviour analysis' step as a prediction of the surface's behaviour under load.

Bechthold (2008) suggest that 3D Parametric Modelling is poised to promote a paradigm shift in the design process of thin-shell structures because it allows for a design process where 'form-finding' and 'behavior analysis' could happen simultaneously. If in one hand, Bechthold (2008) warns that 3D Parametric Modelling has only been used experimentally in this sense and that Finite Element Analysis (FEM) is still the dominant procedure regarding 'behavior analysis', publications from Holzer, Hough and Burry (2008), Preisinger (2013), have continued to tackle 3D parametric modelling as a procedure for the design process of thin-shell structures in the digital age and sought to integrate and compare it to traditional FEM.

More recent analysis such as Firl and Bletzinger (2012) and Mesnil et al. (2018) suggest that architectural form-finding methods still have to overcome the difficulty to allow for both different load cases and non-linear analyses. Mesnil et al. (2018) establish that the construction of shell structures must overcome big economic constraints pertaining to fabrication, especially so with doubly curved shells due to issues related to facets planarity and the repetition of elements.

In 'Pandeo de láminas de doble-curvatura', Dieste (1978) explains his calculation methods for reinforced masonry shells and his towers. This could be considered the sole bibliographical reference which contemplates the design process for gaussian vaults and free-standing vaults. The already mentioned compilations of Carbonell (1987) and Torrecillas (1996) focus on Dieste's design guidelines, but also possess excerpts of writing from Dieste (1978) himself.

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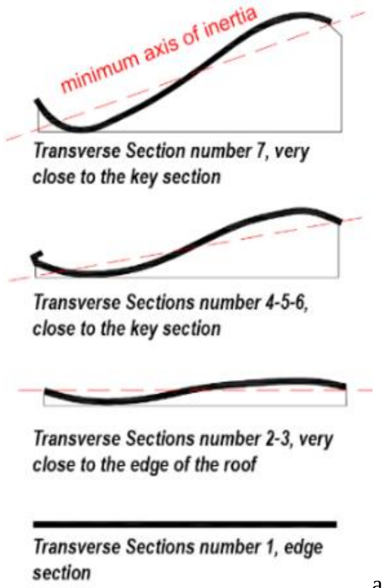
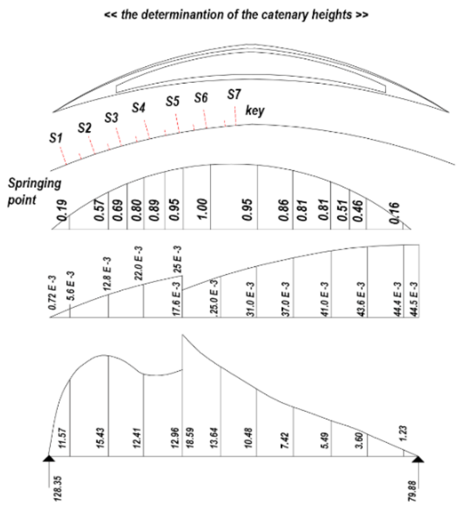
Melachos et al. (2019) analyzed ‘Pandeo de láminas de doble-curvatura’ (1978) and establish that this process is constituted of successive attempts to reduce the buckling of the curvature of the surface to a negligible magnitude. In the first stage of his design process the Uruguayan engineer sought to minimize the transverse section’s axis of inertia (Figure 3-a). In the second stage, he went on to translate the resulting test axes on which he obtained the minimal values for momentum of inertia onto the surface’s longitudinal section. This resulting section had its section heights adjusted with the aid of the diagrams of bending moments and force (Figure 3 -b).



a.

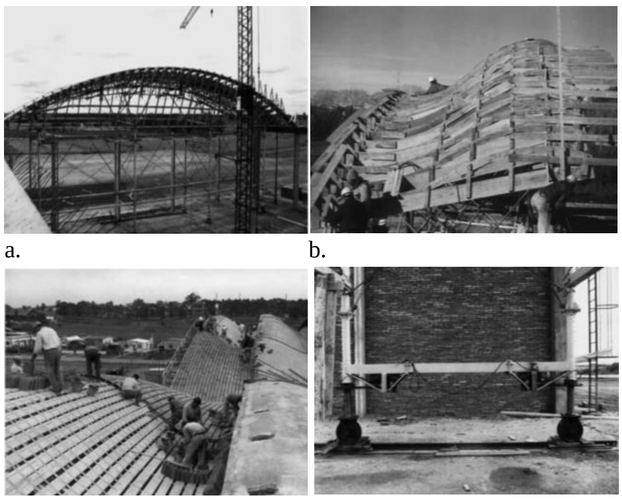


b.

Figure 3: the two major steps from Eladio Dieste’s calculation methods are (a.) the adaptation the transverse section to its minimum axis of inertia, and (b.) the adjustment of the longitudinal section heights with diagrams of bending moments and force.

The writings of Anderson (2004) and Carvalho (2006) are important for they establish a walk-through of the known steps of the construction process of the gaussian vaults. Carvalho (2006) is the sole author amongst the consulted bibliography besides Dieste himself, in both Torrecillas (1996) and Carbonell (1987), which mentions that the geometry of the longitudinal sections extracted from the calculation process is translated to the construction site as a series of sequential ribs, which form the roof surface of a single structural module (Figure 4). Pedreschi and Larrambebere (2004) suggest that Dieste’s architecture results from the Uruguayan’s defiance of conventional architectural design process.

Figure 4 illustrates Larrambebere’s synthesis in Anderson (2004) of how these longitudinal ribs were then complemented with transverse ribs in order to establish a grid for the future surface. With the framework for the surface done, the construction workers could start the bricklaying process, the introduction of minimally necessary dosage of steel reinforcement and, when deemed necessary due to weather conditions, an upper layer of mortar was laid upon the roof in order to protect it. Once the mortar between the bricks lost the humidity necessary to withstand the positioning of the masonry and steel reinforcement, the formwork was glided through a system that allowed its vertical and horizontal movement. In Carbonell (1987) Dieste describes having invented these and other construction site mechanisms. This process repeats itself until the last module of the surface is completed.



a. b. c. d.

Figure 4: Synthesis of the construction primer of the Gaussian Vaults: a-b) building the longitudinal and transverse formwork from the calculated geometry, c) the bricklaying and introducing of steel reinforcement, d) gliding the formwork horizontally to the next structural module.

©Larrambebere (2004) and Anderson (2004).

2.2 Developed Methodology

Notwithstanding, the state-of-art regarding the design process of these gaussian vault roofs does not explain exactly how the translation of calculated geometry to the construction site as formwork ribs took place. The answer to this question lies in the ‘geometry of the vault’ drawing sheets (Figure 5).

The ‘geometry of the vault’ sheets of the research’s case study, the Seaport Deposit, have corresponding tables with data from the coordinates of the intersections of the transverse and horizontal formworks (Figure 5), suggesting that this was how Dieste transferred the geometry from his calculation methods to the construction site.

This table of geometric coordinates (Figure 5) was used to generate the algorithm in the software Grasshopper© associated with Rhinoceros 3d 6.0© (Figure 6), which represents the interpolation of all coordinates of key transverse section “0”. All these point coordinates were translated into X-Y-Z data and resulted in the transversal sections, such as key transverse section “0” in the Rhinoceros display. The same procedure was executed in all transverse sections (0-28) and all longitudinal sections (A-R), and all resulting interpolated curves were turned into a surface with the command “loft” (Figure 6).

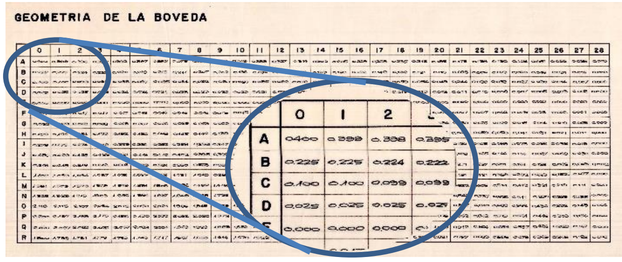


Figure 5: The ‘vault of the geometry’ tables have the point coordinates of each intersection between the transverse and longitudinal ribs of the gaussian vault’s roof formwork.

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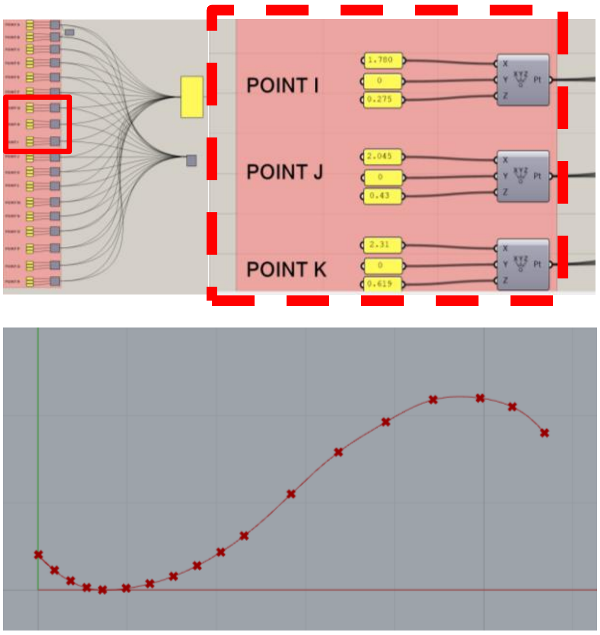
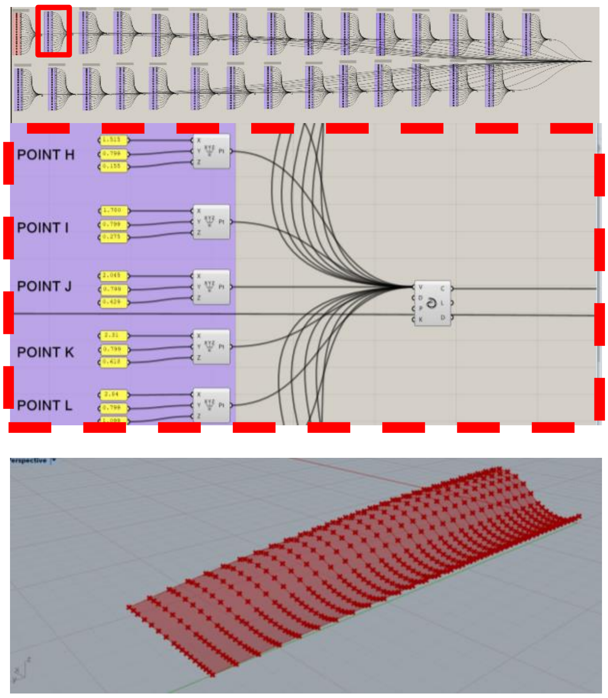


a.

b.

Figure 6: (left) Algorithm developed in the software Grasshopper© in association with Rhinoceros 3d 6.0© which extracted the point coordinates of the gaussian vault roof surface’s key transverse section, whose curve is displayed at the Rhinoceros interface (right).

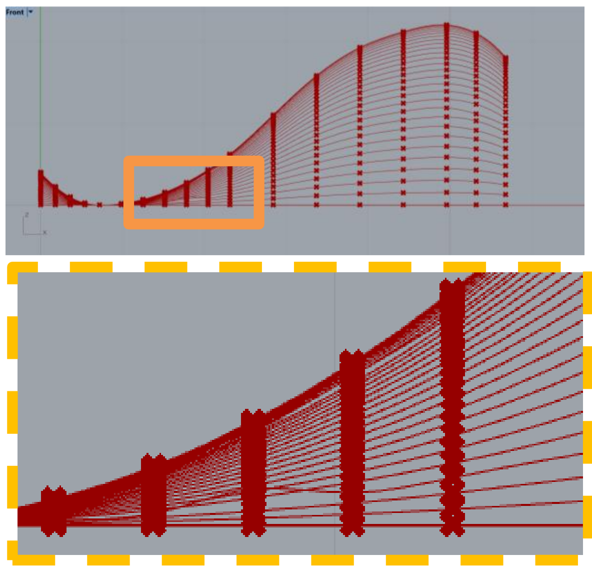
However, the overlaying of all transverse curves in the Rhinoceros 3d 6.0© display reveals that the transcription of the calculated data to the “geometry of the vault” tables was susceptible to errors. Figure 8 reveals the disruption of the section’s geometric pattern in the lower part of the surface (indicated by the orange rectangle in Figure 8). Such errors, alongside with the complexity of such double-curvature geometries proposed by Dieste, suggest the necessity of the construction site to operate as an extension of the design process to assure the correct execution of the proposed geometry. This extended design process corroborates with Dieste’s critics to the limitations imposed by traditional drafting tools in the proposition of new forms in Gutierrez (1998), and also suggests the possibility of continuous correcting and adjusting of form within the construction site.



a.

b.

Figure 7: (a.) Algorithm developed in Grasshopper© in association with Rhinoceros 3d 6.0©, which gathers the complete set of point coordinates from Figure 5, and the corresponding surface generated in the Rhinoceros display (b.).



a.

b.

Figure 8: The Grasshopper© algorithm of the overlaying of transverse sections of the gaussian vaults of the Seaport Deposit of Montevideo, designed and built by Eladio Dieste in 1979, in Montevideo, Uruguay. This algorithm reveals mistakes in the transcription of values from the calculations to the ‘geometry of the vault’ sheets.

The next step was the rapid prototyping and CNC cutting of the surfaces produced in the Grasshopper 3d© algorithm in Figure 7 in order to shed some light in the interaction between the design process and resulting geometry in Eladio Dieste’s gaussian vaults, besides furthering the comprehension of the nature of the double-curvature itself. The rapid prototyping (Figure 9) was executed using FDM (Fused Deposition Modelling) on a Felix 3.1, in a scale of 1:100.

Figure 9: Rapid prototyping process and half-a-module produced using FDM on a Felix 3.1.

These 3d printed surfaces were used to analyze the design and construction process of Eladio Dieste’s gaussian vaults alongside the simulation of the extraction of formwork ribs by means of CNC cutting of transverse and longitudinal ribs. These ribs were interlocked manually to form the geometrical framework of the surface (Figure 10).

These ribs were extracted from the same surface in the algorithm of Figure 6, which was connected to another Grasshopper© plugin called Bowerbird©. The algorithm in Figure 10 used Bowerbird© to handily decompose surfaces in a framework for CNC cutting purposes. The amount of ribs that could be cut can also be controlled by the Bowerbird© component ‘BB Waffle’ (Figure 10 b).

The option for a model scale of 1:30 was a manner to have the closest amount of ribs in the model as proposed by the ‘vault of geometry’ tables without hindering the model’s hand manipulation and allowing its manufacturing in a material that would be solid enough not to brake during both assembly and manipulation. The usage of Bowerbird© was also important for geometrical explorations of this nature for it allowed for the labeling of the ribs and to rationalize the manual assembly with Grasshopper© component ‘Text Tag 3d’.

The manual assembly of the model (Figure 10) was important for it allowed the research team to reproduce the difficulties that construction workers might have found before comprehending such a complex geometry. Carvalho (2006) suggest that the construction process of such surfaces was done first by laying the longitudinal ribs and then, the transverse ribs. However, the manual assembly of the model could not be done in such order for the long longitudinal ribs bent too much. The solution for the manual assembly process was to fit the transverse ribs between the two outermost longitudinal ribs.

The consulted bibliography did not mention further details regarding the process of assembly of the ribs to form the surface framework. The model assembly (Figure 10) was made easy in this sense for each rib came out of the CNC cutting already marked. This step was thought out in the Bowerbird© algorithm with the use of the Grasshopper© component ‘Text Tag 3d’, while Bowerbird© ‘BB Waffle’ made sure each rib already came with the fitting entrances carved out.

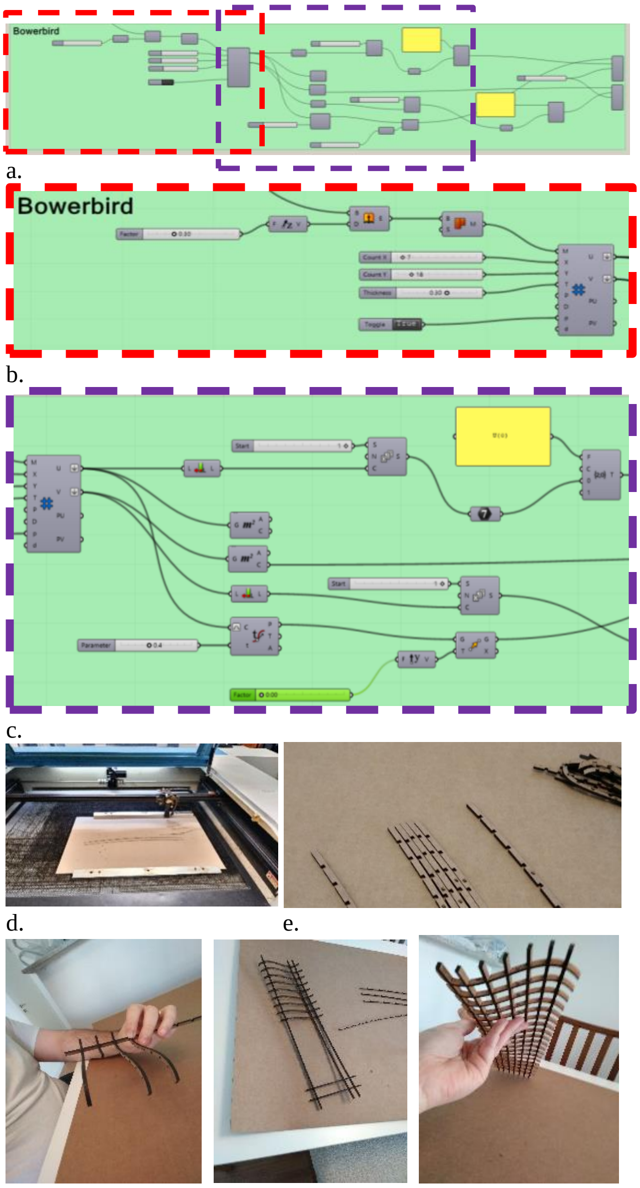


Figure 10: (a) The algorithm developed in Grasshopper© in association with the Bowerbird © plugin and Rhinoceros 3d 6.0© took advantage of the component (b) ‘BB Waffle’, which allowed the (c) CNC cutting of the framework of the roof’s surface of (d) identified ribs and the (e-g) simultaneous positioning of the ribs in the manual assembling process.

2.3 Discussion

The overview of the state-of-the-art regarding the design process of the gaussian vaults of Eladio Dieste and the current paradigms of design process of thin-shell structures allowed for the identification of gaps within the registry of Dieste’s design process for such typologies. The 3D parametric modelling and digital fabrication of samples of Dieste’s thin-shell structures allowed for the examination of Dieste’s design process, especially when compared to the current paradigms of thin-shell design process.

Figure 11 establishes a synthesis of such findings, suggesting that Eladio Dieste’s design process accomplished what the current paradigm of thin-shell’s design process struggles to do: to aggregate both form-finding and behavior analysis in a concomitant stage of design process. Upon dissecting Eladio Dieste's design process, it is possible to suggest that the continuous repetition of the adaptation the transverse section of the gaussian vault to its minimum axis of inertia, and the adjustment of the longitudinal section heights with diagrams of bending moments and force, constitute in a thin-shell design process which promotes simultaneous form-finding and behavior analysis due to the concomitant adjustment of geometry aiming to withstand the main threat to its equilibrium, buckling.

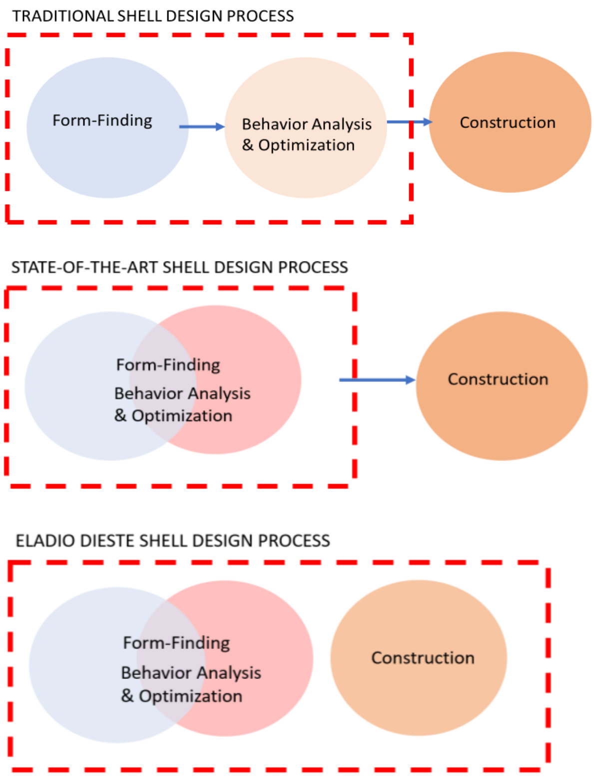


Figure 11: Confrontation of the current paradigms of thin-shell design process with Eladio Dieste's design process for such typologies.

However, Dieste's notion of 'cosmic economy' implied the usage of all resources at the very best, including his construction workers' expertise. This expertise was included in the design process upon their comprehension of the geometrical surface before them during the assembly of the formwork ribs in the construction site. The rapid prototyping and CNC cutting of surface models corroborate with Dieste's notion that complex geometry's grasp is beyond traditional drafting techniques and had to be mastered in the construction site. Thus, for Dieste, his calculation methods assured him the mathematical assuredness for his design solutions, while the construction site assured him the geometric and spatial confirmation of his mathematical form hypotheses.

The compilations of Carbonell (1987), Torrecillas (1996), and Gutierrez (1998) analyze Dieste's design guidelines, while Anderson (2004) and Carvalho (2006) also do so and establish a detailed construction process. Nonetheless, Dieste (1978) himself seem to have been the only one reflecting upon his actual design process.

The 3D parametric modelling which allowed for the digitally fabricated surfaces was only feasible due to the extraction of the point coordinates from the 'geometry of the vault' tables. The manner in which this table was used and communicated in the work site is an incognito. However, it most likely constitutes the means of connection between the results of Dieste's form-finding and behavior analysis procedure, and the comprehension of Dieste's geometries in the construction site by himself and his construction workers.
Nonetheless, the consultation of such 'geometry of the vault' tables, as well as their usage in the overall surface's 3D parametric modelling, revealed that the transcription of the calculated data to the "geometry of the vault" tables was susceptible to errors. In one hand these errors could result in the assembly of incorrect formwork, but they could provide an opportunity for further geometric comprehension and geometric adjustments in the construction site.

3. CONCLUSIONS

The present research has identified existing gaps in the design process of the gaussian vaults designed and built by Eladio Dieste, during the second half of the 20th century in Latin America and Europe.

This research's results suggest that Eladio Dieste's design process for such structural typologies accomplishes what the current paradigm of thin-shell design structures struggles to do so: to integrate form-finding and behavior analysis in a concomitant stage of the design process. In such design process, the construction stage was also included in the design process as validation of the form hypothesis generated by Dieste's calculation methods.

Also, the results suggest that the extraction of the point coordinates from the 'geometry of the vault' tables constitutes the primary means of transference of the geometry from calculation to the architectural drafting and construction stages. However, the manner in which the calculation method of Dieste actually yielded the "geometry of the vault" tables is yet to be explored.

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