Parametric variations of the “delineationi seconde delle fortezze, e dell’ortografia loro”, from the Trattato di Fortificatione by Guarini

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Ornella ZERLENGA, Vincenzo CIRILLO (Eds.)

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Table of contents

Defensive Architecture of the Mediterranean / Vol. XX / Zerlenga, Cirillo (Eds.)

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Parametric variations of the "delineationi seconde delle fortezze, e dell'ortografia loro", from the *Trattato di Fortificatione* by Guarini

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Abstract

The research was carried out in the framework of the project PRIN 2022 called INFORTREAT, which aimed to create 3D information models that could make accessible constructive knowledge related to military architecture to scholars, professionals, and the community. This paper develops previous work dealing with the graphical reconstruction and 3D modelling of the elements that shape the fortification profile in the Trattato di Fortificatione by Guarini. The author establishes measurements (maximum, average, and minimum) for the thickness and height of the main elements. This way of transmitting knowledge about the art of fortifying meets the manualist's need to provide the reader with a synoptic view of the different possibilities in fortress design and construction. Parametric and BIM modelling are used to verify the maximum, average, and minimum dimensions, creating a digital platform to verify different fortresses' configurations.

Keywords: parametric modelling, fortresses, Trattato di Fortificatione, Guarini.

1. Introduction

This proposal has been realized in the framework of the project INFORTREAT, funded by the European Union – Next Generation EU. The overall goal of the project is to make accessible the constructive knowledge related to military architecture (as described by early modern treatises) through 3D digital information models that can be consulted and queried by scholars, professionals, and the community. The current contribution focuses on Book III of the Trattato di Fortificatione, written by Guarino Guarini in 1676. Book III discusses the so-called second delineations of fortresses and their orthography, i.e., the sizing of the main elements of the fortresses and some geometric constructions related to the external works that support their defensive features and drawings in plan and section.

Like other contemporary treatisers (e.g., Marolois 1615, Sardi 1639, Milliet Dechales 1677), Guarini establishes a series of measurements (maximum, average, and minimum) for the main elements' thickness and height. This way of transmitting knowledge about the art of fortifying meets the manualist's need to provide the reader with a synoptic view of the different possibilities in fortress design and construction.

Previous research by the authors (Spallone, Vitali 2024) interweaved the textual content of Book III with the graphic analysis of the treatise plates, aiming at verifying their dimensional and projective consistency and reconstructing the three-dimensionality of the elements. This preliminary research highlighted the consistent use of the maximum values in the text and the plates. In this contribution, parametric and BIM modelling will be used to verify the maximum, average, and minimum dimensions, creating a digital platform to verify different fortresses' configurations.

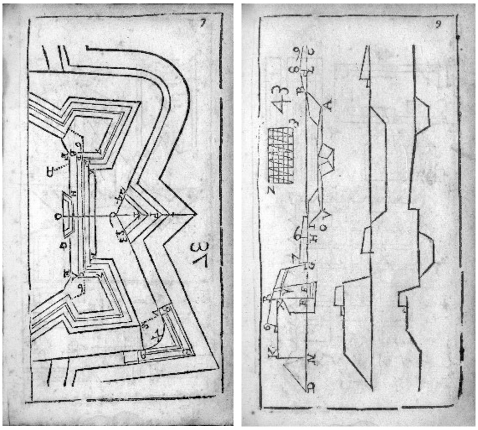

Fig. 1- Second delineations in Plate 7 and orthography of the fortresses in Plate 9 of Guarini's treatise (Source: G. Guarini, 1674).

2. Guarini's treatise in the panorama of theories on military architecture

Guarini, the abbot of the Theatine order, wrote the Trattato di Fortificatione during his time in Turin, from 1666 to 1683, when he died. Numerous other theoretical works, some of which he had undertaken in the earlier Parisian period, were printed in Turin during this period: Euclides adauctus (1671), Modo di misurare le fabriche (1674), Compendio della sfera celeste (1675), Leges temporum et planetarum (1678), and Dissegni d'architettura civile et ecclesiastica (1686), which was to form the basis for the drafting of the Architettura civile, published posthumously in 1737.

The rich theoretical activity is accompanied by the well-known architectural production that includes outstanding buildings like the Carignano Palace, the San Lorenzo Church, and the Holy Shroud Chapel. A third commitment, a didactic nature, sees him educating Ludovico Giulio of Carignano, a distant relative of the Duke of Savoy and Prince of Piedmont, Carlo Emanuele II, to which the treatise examined here is dedicated.

Guarini mentions Goldmann, Pagan, Dögen, and Freitag in terms of constructing Dutch-style ramparts. Still, his unstated references include Pietro Sardi, whom Guarini recalls in Architettura civile (Trattato II, Capo secondo, Osservazione prima), regarding the definition of the geometric foot, the unit of measurement he adopted in the Trattato di Fortificatione.

Furthermore, James McQuillan (2014: 624-625) points out that Guarini knew the Jesuit Claude-François Milliet Dechales, the writer of Cursus seu mundus mathematicus (1674), who included in his treatise a section about military architecture, published separately as L'art de fortifier in 1677. McQuillan observes the exact structure of this last book and Guarini's and affirms that "there is little doubt that both authors were working in parallel to some extent and that Guarini did not have the flair in the field of military architecture to exhibit his usual expertise." Explicit references between the work of the two also emerge from the authors' comparison of the drawings on which the present work is based with those drawn up by Dechales (Fig. 1).

Both treatise writers, as religious, had a theoretical approach that differed from that of the military engineers personally involved in war activities, who could validate the quality of their proposals with experience. However, Guarini's involvement in the design of the Porta di Po in Turin and the hypothesized authorship of an anonymous design of some external works (Fara, 2001) entitled Citadel of Turin with the new opinion ("Cittadella di Torino con il parere novo" kept at the Bibliothèque Nationale de France), that could confirm Guarini's involvement as a consultant of Savoy family for Turin military architecture.

3. Geometry, architecture, ballistics, and construction

In the development of Guarini's text, the intertwining of geometry, architecture and ballistics develops in a dialogue that connects these three aspects to the prescriptions for fortress construction: depending on the construction techniques and materials to be adopted, the dimensional and geometric characteristics of the individual elements change according to the defence techniques, the resistance of the structures to attacks and the different means by which these attacks are carried out.

Following this reasoning, the use of soil or stone masonry alone produces, for example, variations in the thickness and cross-section of ramparts and parapets, just as the need to move and position artillery, militia and cannons imposes minimum spaces for the flat portions of the rampart, fausse-braye, and covered way.

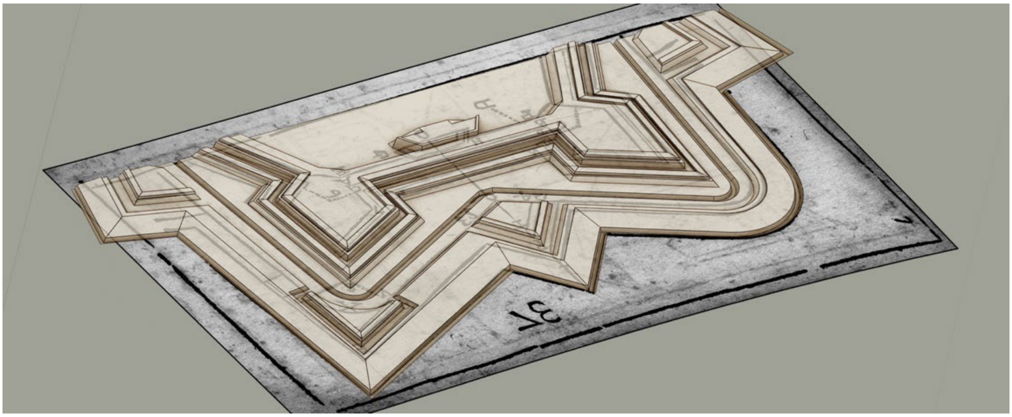

Fig. 4- Superimposing the reconstructive 3D model of the fortress on Guarini's iconography (G. Guarini, 1674, Plate 7. Graphic elaboration by M. Vitali, 2024).

The relationships between architecture, geometry, and defence that we have briefly outlined produce noticeable variations in the body of the fortress. These variations, which, together with the minimum, average and maximum dimensional requirements, respond to a broad and flexible framework of construction needs and impediments, lend themselves well to parametric and algorithmic modelling, which, as we shall see, allows for their rapid and constant control, in a combinatorial mechanism of possibilities that can be evaluated from time to time about construction costs and military effectiveness (Fig. 4).

4. Between orthographic projections and metric variations

The reconstruction of the elements in the centre section of the curtain up to the external works involved, as we have seen, the identification of the maximum dimensions (thicknesses and heights) defined by Guarini in four tables as a guide to the interpretation and redrawing of Guarini's plan and profile plates. The process was divided into the three phases of:

- Reconstruction of Guarini's iconography starting from the first delineation – i.e., the construction of the geometric scheme, interior polygon, and bastions of the fortress – (Spallone, 2015, Spallone, 2017), which highlighted the author's choice to draw only two lines for the variable thickness elements with a scarp section;
- Reconstruction of orthography, with the identification of scarps and accessory elements;
- Completion of the icnography with the lines deduced from the orthography.

Guarini's method: "knowing perfectly how to draw the plans, and make the icnography, depends on the orthography, and this on the other" (Guarini, 1737) proves its effectiveness in the above passages.
Three tables relating to the thicknesses (maximum, average, and minimum) of the elements, respectively, inside the interior polygon and parallel to it, outside the interior polygon and parallel to it, outside the interior polygon and not parallel to it (accessory works such as half-moons and ravelins) and a table relating to the heights (maximum, average and minimum) of the same elements, allow construction in geometric feet.

The geometric foot (about 0.299697 m), as Guarini states on page 44 of the text, coincides with the King's foot used in France and corresponds to seven ounces of liprando foot (Bevilacqua & Spallone, 2024).

These tables, put together in the research mentioned above (Tab. 5), were used in the reconstruction of orthographic projections of the fortified system and, in the following paragraph, will be used to parametrize the fortress models.

The table system constructed by Theatine reveals a manualistic approach for rapid practical application, common to that of numerous contemporary authors (e.g., Marolois 1615, Sardi 1639, Milliet Dechales 1677).

In deepening the comparison undertaken concerning Dechales's work, a table provides as many as six values, from minimum to maximum, for the thicknesses of the elements. At the same time, the heights are given in the table and in the text.

	elemento	icnografia /ortografia(disegnate)	larghezza			altezza		
			max	med	min	max	med	min
Seconde delineationi interiori	Muro CD	Scarpa del muro*	3	2	1			
		Muro CD*	9	8	7	18	16	14
	Parapetto AB	Parapetto nel piano AB	24	22	18			
		In cima però sarà	21	18	15			
		La sua scarpa interiore	1	1	1			
		L'esteriore	2	2	2			
		Parapetto interiore altezza				6	6	6
		Parapetto esteriore altezza				4	4	4
	Scabello	Scabello	3	2	2	**2		
	Terrapieno EF	Terrapieno tutto EF	84	72	60			
		Sua scarpa interiore	18	16	14			
		Terrapieno alla cima EF	66	56	46	18-22***	16-20***	14-18***
	Cavagliere GH	Cavagliere GH dietro	300					
		Cavagliere GH davanti	200					
Seconde delineationi esteriori che seguono la forma delle prime linee	Falsa braga IL	Via della falsa braga IL	21	17	15			
	Parapetto falsa braga MN	Parapetto della falsa braga al piede MN	24	18	14	8	6	4
		Nella cima	21	15	11			
	Il margine del fosso	Il margine del fosso	6	6	6			
	Fossa	L'ampiezza della fossa	132	108	84	12	11	10
		Ma nel fondo	108	84	64			
		Scarpa della fossa	12	11	10			
		Fossetto nel mezzo	24	20	16			
	Via coperta	Via coperta	21	17	15			
	Trinciera esteriore	Ampiezza della trinciera esteriore	79	70	69			
	Scabello	Scabello	3	3	2	**2		
Seconde delineationi esteriori che non seguono la forma delle prime linee	Rivellino 1° metodo geometrico Mezza luna metodo geometrico	Terrapieno inferiore	40	36	30			
		Scarpa esteriore	3	2	2			
		Scarpa interiore	6	5	4			
		Terrapieno superiore	34	30	26			
		Parapetto al piede	20	18	15			
		Scarpa esteriore	2	2	2			
		Scarpa interiore	1	1	1			
		Parapetto alla cima	17	15	13			
		Scabello	3	2	2			
		Via del terrapieno	20	17	15			
		Fossa	40	35	30			
		Scarpa delle rive	10	8	6			
		Via coperta	28	15	15			
		Spalto o trinciera	20	15	15			

Tab. 5- Synoptic table of elements' dimensions and their presence in the drawing in Guarini's icnography (in blue) or orthography (in red). * the orthographic drawing represents the wall (*muro*) and the scarp (scarpa) together; ** hypothesized height, *** heights without and with the wall. The nomenclature of the elements is taken from the treatise (elaboration by R. Spallone, 2024).

5. Tabular data parameterization

The translation of dimensional prescriptions contained within the treatise's tables into a three-dimensional parametric model was accomplished by utilising Rhinoceros 8 and its visual algorithmic editor, Grasshopper.

The methodological approach, consonant with recent investigations into the digitalisation of military treatise heritage (Rechichi et al., 2024), entailed structuring an algorithm organised into thematic clusters, each dedicated to a specific fortification element. This modular algorithm organisation mirrors the logical structure employed by Guarini in his treatise, wherein each fortification element is systematically described and dimensioned. Furthermore, the decomposition into clusters enables discrete management of various modelling phases, from defining initial delineations to generating more intricate elements (Fig. 6).

Dimensional control was implemented through a selection system based on multiline data panels, enabling simultaneous modification of all correlated parameters via a single selector, thus ensuring model coherence across varying dimensional choices. This approach proved productive in managing the multiple-dimensional variables in the treatise's tables, facilitating expeditious verification of diverse possible configurations.

The generation of geometries was addressed through single-rail sweeps, with particular attention devoted to defining section curves. These were constructed as closed polylines based on points controlled by parametric vectors, whose direction and magnitude vary according to the selected dimensional values (maximum, average, or minimum). The primary challenge in this phase was ensuring geometric continuity between adjacent sections, which is fundamental for avoiding both interpenetration and discontinuities in the model. This objective was achieved through a system of concatenating section control points, wherein each section curve shares tangency points with its adjacent counterpart, thus ensuring a coherent transition of generated poly-surfaces.

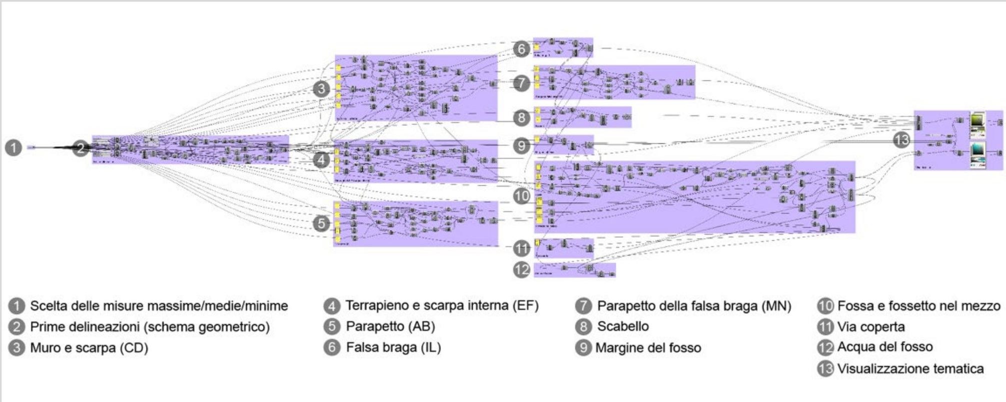

Fig. 6- Visual algorithm of the fortress elements (graphic elaboration by E. Pupi, 2024).

The resultant parametric model enables the exploration of dimensional variations prescribed in the treatise's tables and the modification of fundamental geometric parameters such as the number of sides in the base polygon – set in this instance to six sides – and the proportions of corner bastions.

The relationship with Guarini's original drawing proved fundamental in the initial phase of defining primary delineations (Fig. 7), from which the basic geometric proportions of the fortification system were extracted.

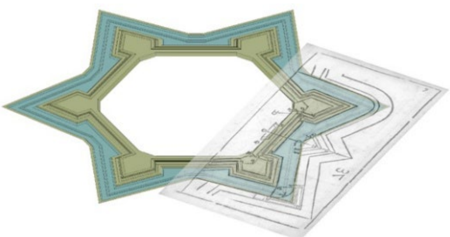

Fig. 7- Parametric model of Guarini's fortress based on maximum dimensions (graphic elaboration by E. Pupi, 2024).

However, the subsequent parametric modelling phase was primarily predicated upon tabular values provided in the treatise, constituting the principal analytical reference for the dimensional definition of all elements.

This methodological choice enabled the maintenance of philological rigour in the three-dimensional translation of Guarini's prescriptions whilst ensuring the flexibility to explore the diverse configurations envisaged in the treatise.

6. From parametric model to BIM

The transition from parametric modelling to Building Information Modelling (BIM) marks a significant advancement in architectural heritage's critical reading and digitalization (Calvano et al., 2022; Cursi et al., 2022). This research focused on creating a generative model of an ideal fortification based on Guarino Guarini's treatise, as seen in the previous paragraph, using Grasshopper to parameterize the design and produce model variations. The next phase involved integrating these models into a BIM environment, specifically within Revit, facilitated by the Rhino. Inside application enables direct import of geometries generated in Rhinoceros and Grasshopper into Revit, thereby ensuring continuity between the parametric model and the BIM platform.

The initial step in transferring the model from Grasshopper to Revit involves importing the geometries as Boundary Representations (BReps), which may be open or closed depending on the requirement, into specific BIM categories, such as Walls and Topographical Solids. These categories reflect the structural and topographical elements of the fortifications as studied in the treatise. However, the model, originally built in geometric feet, must be scaled to metric units before importing, ensuring adherence to the measurement standards commonly employed in

BIM and allowing for accurate dimensional representation in the project context.

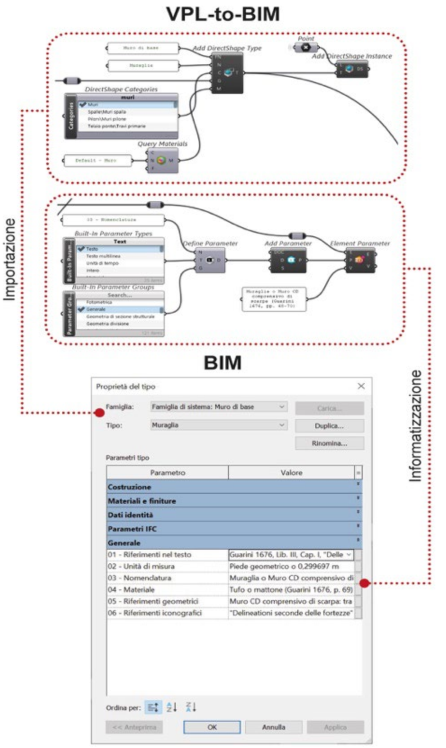

Fig. 8- Extract of the visual algorithm (Grasshopper) and type properties (Revit) of the Wall; import and informatisation nodes of the model and dialogue box of the selected element (graphic elaboration by F. Natta, 2024).

Once imported as DirectShape elements, the individual geometric parts of the fortification are further enriched with information. Using Rhino.Inside, specific design parameters are defined, including textual data derived from analyses of Guarini's treatise. This process allows the informational properties associated with different parts of the geometry to remain intact even when modifications are made to the original model.

Through the generative algorithm developed in Grasshopper, the parametric model can be continuously modified and updated in real time in Revit. This enables a dynamic and adaptable approach to modelling that meets the project's specific requirements (Fig. 8).

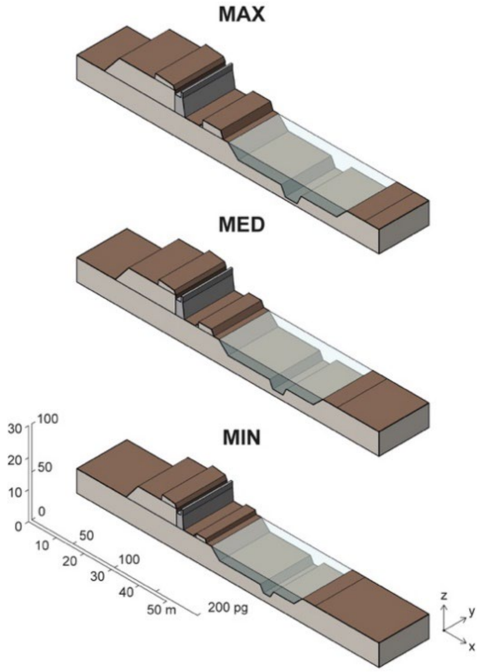

Fig. 9- Axonometric section (Revit) of Guarini's fortress; variation in size of the consistencies through maximum, average and minimum values taken from Guarini's tables (graphic elaboration by F. Natta, 2024).

A key aspect of the study is the potentiality to visually represent various construction solutions based on dimensional variations defined by Guarini, such as the maximum, average, and minimum measures for a hexagonal fortification with a side length of approximately 900 geometric feet (about 270 m). These variations are critical for exploring alternative project configurations, such as wall or bastion adaptations, and facilitate understanding each solution's structural implications (Fig. 9).

In addition to information parametrization based on textual data, the method offers the potential for associating numerical data with the model. This includes calculations of excavation volumes required for constructing the ditch, the earthworks, and the volume of masonry works. Automating these calculations, made possible through BIM integration, enables preliminary estimates of materials and work requirements, supporting detailed planning and efficient resource management.

7. Conclusions

As we have seen, the manualistic and tabular approach of numerous 17th-century treatises on military architecture offers opportunities for three-dimensional verification of dimensional values attributed to plans and profiles of fortified structures.

This work, on the one hand, takes on the value of verifying the scalability of the method of model implementation through parametric modelling and information enrichment through BIM, which is currently being developed by the research group of the broader PRIN project, and on the other hand, opens up possible future developments in relation to the efficient interoperability between the two systems.

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