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Ramona Feriozzi
Ph.D in "Science of Representation and Surveying". In addition to regarding operational and theoretical aspects in the field of design and architectural surveying, her research interests centre in particular on the study of parameterization for the automatic generation of virtual spaces destined for exposition.

Graziano Mario Valenti
Associate Professor at the University of Rome "La Sapienza". His research activities is focused on the application of new digital technologies to the disciplines of the survey, representation and visual communication. Speaker and reviewer for international conferences He is the author of several papers and books about survey and 3d modelling.

Parametric Procedures to Create Multi-dimensional Virtual Museums

Procedure parametriche per la conformazione di musei virtuali pluridimensionali

The word museum has a wider use in virtual museums. Since these museums are generated within a virtual space, their characteristics are completely different from real museums. For this reason, in light of the possibilities offered by such a space, the virtual museum is imagined as a multi-dimensional place that, while existing in a dimension that is imperceptible to people, is represented in a continuously changing three-dimensional space. The digital technologies used to control the spaces in a parametric environment offer notable possibilities in generating dynamic, reconfigurable "buildings". If the reorganization is controlled by the user, it is possible to create a different museum for each visitor.

La parola museo ha assunto un'accezione più ampia nei musei virtuali. Poiché essi si generano in uno spazio, appunto, virtuale, hanno caratteristiche completamente diverse da quelli reali. Per questo motivo alla luce delle possibilità offerte da un tale spazio, il museo virtuale è stato immaginato come un luogo multidimensionale che, pur esistendo in una dimensione non percepibile dall'uomo, si traduce in uno spazio tridimensionale in continua mutazione. Le tecnologie digitali per il controllo degli spazi in ambiente parametrico offrono difatti notevoli possibilità nella generazione di "architetture" dinamiche e riconfigurabili. Se tale riorganizzazione è controllata dall'utente, è possibile ottenere un museo al servizio del visitatore.

parole chiave: museo generativo, modellazione parametrica, spazio virtuale, data visualization, data spatialization

key words: *generative museum, parametric modeling, virtual space, data visualization, data spatialization*

INTRODUCTION

The reflections giving rise to this study arise from the relationships between cultural goods and digital technologies and, in particular, the virtual simulation of museum space. Today, it seems difficult to make substantial innovations in this area of investigation.
In general, virtual museum experiences are inspired by uses analogous to real uses, ultimately proposing all of the same problems. For example, the display method is similar to traditional museums, with the works organized according to separate microcosms, the paths only internal to the museum even while they are virtual, and the relationships imprisoned in the restricted area of the genre and the discipline of the work examined. Above all, the means of use and exploration mostly reiterate those of the spaces, forms, and modes of the real world. In reality, the successes of investigations to answer these questions in the physical world cannot be identically applied to the virtual world. In fact, the two camps are ontologically different to the point that, what emerges as valid for one is instead limited for the other, precisely because its nature is such that it allows an infinite number of more effective solutions.
According to Francesco Antinucci, museums have three tasks: conservation, study, and display [1]. In a virtual museum, which, by its nature, cannot contain material works but only their representations, the first two tasks are lacking while the third, i.e., exposition, is central. Since the scope of exposition is to transmit culture, a virtual museum can be defined as a machine for communication.
The informational process is separated from, but deeply influenced by, the means through which it is activated, since the immediacy of communication depends on it. Still today, communication occurs primarily through two-dimensional materials such as the pages of a book. In going from the book to the characteristic webpage, there is no significant change on the perceptual plane equivalent to the technological innovation allowing this move. Thus, on both the page and the screen, the written word and images are still the strong points of communication.
Only hypertext constitutes a primary example of the third dimension, which, like a wormhole [2], folds the plane of written information, allowing the user to "jump" from one part of the page to another. Three-dimensionality is instead used today especially to reproduce real expository spaces; since they are reproductions limited by an expository space coinciding with the building, they present the same limitations. Their static nature also inevitably conditions the display.

REPRESENTING INFORMATION IN THE VIRTUAL SPACE

As a general objective, the research aims to investigate "representation" as a device to communicate structured visual information that, arranged in relation to the experience/request of the visitor, defines the configuration of the virtual space. Along these lines, the research explored digital technologies in particular,

Fig. 1. Scheme showing the generation sequence starting from data.

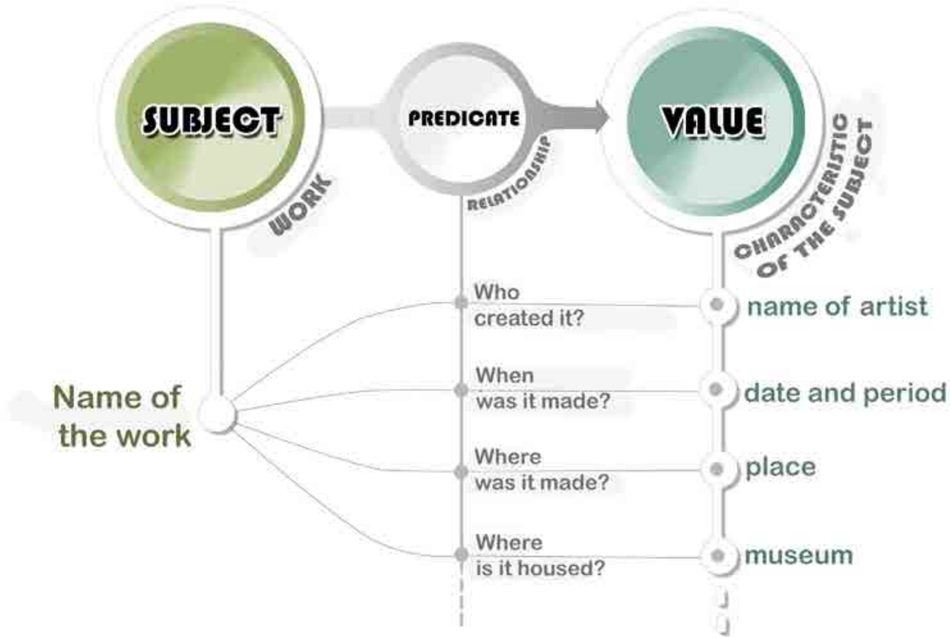

Fig. 2. Scheme showing the relations between subject and values.

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which are useful for controlling spaces in a parametric environment. These offer the possibility to control the generation of dynamic, reconfigurable "architectures" in the virtual space. The parametric space is transformed according to various rules depending on the parameters. The rules are set but the parameters are variable, and those in the virtual museum correspond to the criteria of placement in the informational space. The multitude of variable information involved in this generation defines a multi-dimensional field that exceeds the boundaries of the three-dimensional physical space. It is therefore possible to substitute the traditional sequence of exposition in the physical museum with numerous narrations that coexist in the same virtual space.
Beyond a length (x), width (y), and height (z), the multi-dimensional virtual space allows further parameters to be defined, for example, those aimed at making different levels of interpretation available. It therefore refers to a three-dimensional space that can be reconfigured according to the means of aggregating the works chosen by the user.
Visitors are the protagonists and the museum is modelled around their choices. By varying the initial data, that is, the criteria of aggregating the information, a parametric procedure produces a different, optimized expository space each time.
To obtain this result, the research concentrated on three areas of investigation:
- the works and their placement in the space;
- the type of space generated after arranging the works;
- the geometric procedure that generates the space identified in the previous point.
The virtual space is also free of particular endogenous directionalities such as the vertical dimension, which is expressed by gravity, since it is not one of its intrinsic characteristics. As a consequence, the information can be positioned in any direction without restrictions.
The informational points situated in the space can be interrelated according to a logic of proximity that brings similar works closer together and moves different works further apart. In a virtual museum, multiple expository logical systems can coexist since there are many possible parameters of interpretation.
In this experiment, the user can organize the museum

	pol.1	pol.2	pol.3	pol.4	pol.5	pol.6	pol.7	pol.8	pol.9	pol.10	pol.11	pol.12	pol.13	pol.14	pol.15	pol.16	pol.17	pol.18	pol.19
Associated image																			
Radius	1	1	1	1	1	2	2	2	2	2	4	4	5	5	6	6	7	7	7
No. Sides	3	4	6	7	8	3	4	6	7	8	4	5	3	5	3	7	5	8	8
Colour	green	red	blue	white	blue	yellow	light blue	green	yellow	white	giallo	light blue	yellow	green	red	light blue	blue	magenta	red

Fig. 3: Cataloguing polygons to position.

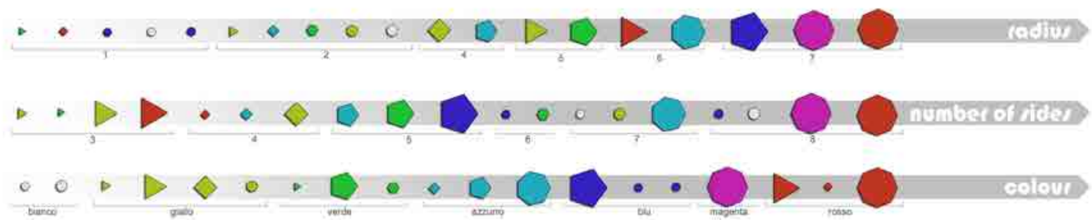

Fig. 4: Example polygons ordered first by radius size, followed by number of sides, and finally by colour.

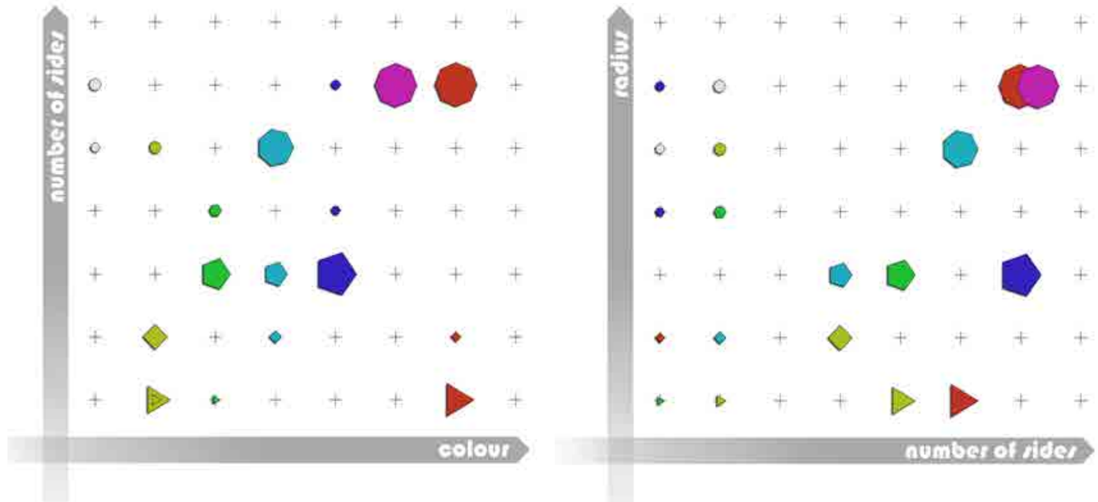

Fig. 5: Placement of the example polygons in the plane according to colour and number of sides (left) and according to radius and number of sides (right).

by choosing just three characteristics (parameters) out of numerous possibilities. These possibilities may correspond to the different descriptive qualities of a work, so the creation of this type of museum assumes the existence of a database of catalogued works.
The museum's works/information may be catalogued according to the logic of the semantic web [3], where the information is defined by assertions composed of subjects, predicates, and objects. The subject declares the name of the individual work of art while the object is a characteristic of the work, whose relationship with the subject is expressed by the predicate.
The example figure cites some types of relationships between subject and value. In theory, this list can be expanded infinitely. The position of the works in space will be chosen according to three of these relationships chosen by the final users according to their own interests.
To better understand the spatial relationships between points/information, the problem was simplified into a plane, considering only two parameters instead of three.
The choice of the sample works did not fall upon the works of art since their cataloguing would have constituted a further problem that lies outside the scope of this research. The choice was instead made to use simple geometric forms, which, as such, have perfectly measurable characteristics. In particular, a sample of regular polygons was used. These were catalogued according to three criteria: the number of sides, the radius of their circumscribed circle, and the colour. Figure 3 shows the values associated with the polygons (pol. 1, pol. 2., etc.) for each of the three predicates (radius, number of sides, and colour), and the image associated with it. The image constitutes the virtual representation of the original work. This example case relates to two-dimensional coloured shapes, but in a more complex context the image can be substituted with a three-dimensional model or any information that can be digitized.
In a real museum, the exposition is generally linear according to a single parameter. Thus, the objects in this example can be positioned according to one of the three characteristic criteria of the figures. In this way, each element will lie in relation only to the ones before and after; any other connection is excluded.
Using two parameters, the complexity of the relationships increases exponentially. For example, in displaying the polygons by colour and number of sides, each element is not only related to the elements above and below, with which they share a colour, but also to those to the left and right, with which they share the same number of sides.
The organization can thus be read in every direction. For example, the polygons on the lower left have the fewest sides and the lightest colours (white and yellow), while those on the upper right have more sides and redder colours.
Something curious occurs in the second column of the first line: since there are two yellow triangles, their position in the grid (in relation to these parameters) is the same, and the two elements therefore overlap each other. This condition, in the view of a virtual museum composed of multiple spaces, does not constitute a problem: if a single work were displayed in each room, the two yellow triangles would be next to each other in the same environment since the values of each in reference to the organizational predicates are identical and it would therefore be correct to view the two works together.
But this type of ordering is not the only one possible. As mentioned above, the parameters can be modified to generate a different museum for the same works. In the case of the polygons in the example, the two yellow triangles lie very far apart if the elements are positioned according to radius and number of sides. In this new configuration, the lower left contains polygons with few sides and small radii; the upper right instead contains those with more sides and larger radii. This time, it is two octagons with the same radius that overlap. Although the two forms have different colours, they are equivalent according to the two organizational parameters.
In this grid, the order of use is free but informed since the user knows the organizational parameters implemented along the lines and columns. More complexity is obtained by adding a third dimension (and therefore a third criterion).
Once the points/information are positioned, it is necessary to study the means of dividing the space. This is really a problem of tessellation. Among the infinite number of possible tessellations, Voronoi diagrams were used for the goals of the experiment because they allow a division to be made starting with points like those obtained after the points/information are positioned.
Since this is a three-dimensional space and not a plane, the Voronoi diagrams produce polyhedrons rather than polygons. Each face of these polyhedrons is a portion of the plane that is perpendicular to the segment uniting two points and passes through the midpoint of the segment. The three-dimensional Voronoi regions are called "cells" if they enclose a finite portion of space. This occurs when the number of points is large enough to generate planes that, by intersecting, form a polyhedron. In the virtual museum, each polyhedron corresponds to a display room containing a single work and bordering other cells that contain other works resulting from the search.
Users can virtually navigate between cells and visualize the objects displayed in 2D or 3D, directly obtaining the related information through links and other multimedia elements.
An algorithm is used to control the form. Starting from the points positioned in space, it generates partitions related to each point according to the rules of Voronoi tessellation. The resulting spatial regions are extremely irregular polyhedrons. If on the one hand the complex-

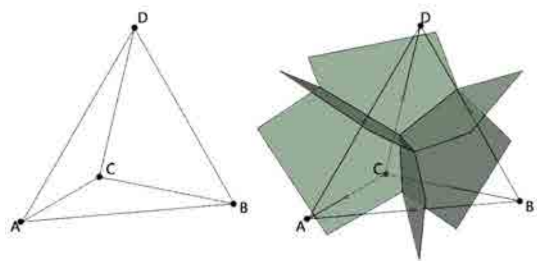

Fig. 6. Voronoi diagram related to four points in space. The six planes that divide the space are normal to the segments that connect the points and pass through their midpoints.

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ity of the geometries produced increases the connections within the virtual space, on the other hand, the spaces that are too narrow or too wide make it difficult if not impossible to navigate the museum and enjoy the works. In addition, since each face of the solid generated by the Voronoi procedure pertains to two rooms at the same time, it is the only connection between the two spaces and should therefore be extensive enough to permit navigation.
These considerations were fundamental in implementing the algorithm to generate the Voronoi geometries. The objective is to create spaces that are both complex but balanced, and which respect the minimum requirements of usability.
Since humans are three-dimensional beings, they cannot perceive the fourth spatial dimension, but only observe its projection in the third dimension. This projection varies as the point of view changes, and since there are an infinite number of points of view, there are also infinite 3D projections of a 4D object.
To understand this concept, consider the example of a three-dimensional cube. It has an infinite number of two-dimensional representations according to the direction of projection. In the same way, a hypercube, a four-dimensional cube, has infinite representations in 3D space. In general, a 4D object could generate an infinite number of 3D spaces in continuous variation. Analogously, a four-dimensional virtual museum comprises all of the possible three-dimensional configurations. The virtual space can therefore be changeable and allow the spaces to be continuously rearranged.
In a virtual four-dimensional museum, the works would be arranged contemporaneously according to all the possible criteria; it is up to the user to choose which alternative to visualize and materialize three-dimensionally.
One can therefore imagine a virtual display no longer as a sequence of determined, static spaces, but as a continuous creative process. A virtual museum is the three-dimensional representation "of the infinite richness of existing arrangements and relationships in the four dimensions" [4].

PECULIAR FREEDOMS OF THE VIRTUAL SPACE

In the virtual space, the rules of traditional architecture no longer apply and the museum spaces are free to be configured in any direction. In this field, it makes no sense to spend time looking for structurally plausible forms. The connections between the points/information guide the generation of geometries without regard for statics.
The three-dimensional Voronoi diagrams chosen for the experiment materialize the networks of conceptual connections among the works. Displacements are allowed not only in the xy-plane, but also along the z-axis, offering a further relational criterion among the museum rooms and therefore among the works of art. It is precisely the lack of gravity that allows the logic of a linear layout to be overcome in favour of a reticular layout.
This network of connections is geometrically represented by Delaunay triangulation, which connects the points/information according to mathematical logic.

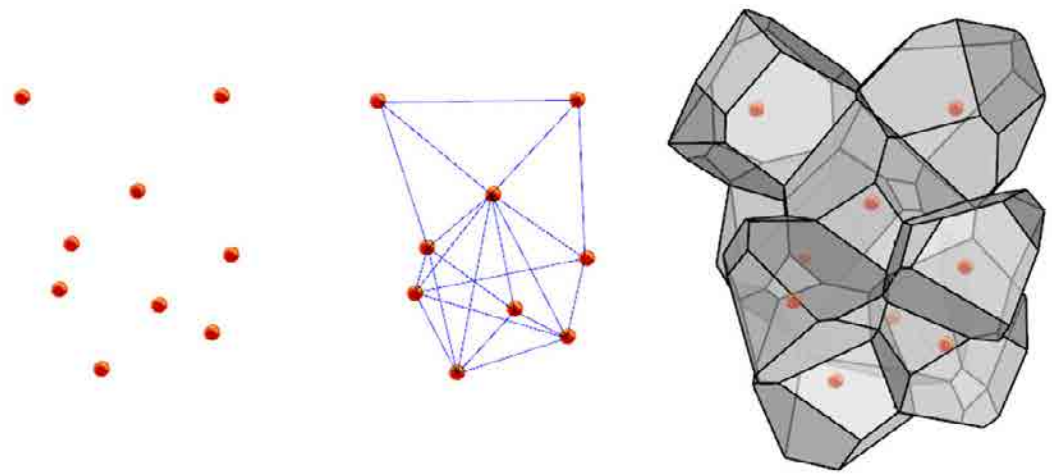

Fig. 7. Delaunay triangulation and Voronoi cells generated by a finite series of points situated in 3D space. The Delaunay network corresponds to all the possible paths within the museum.

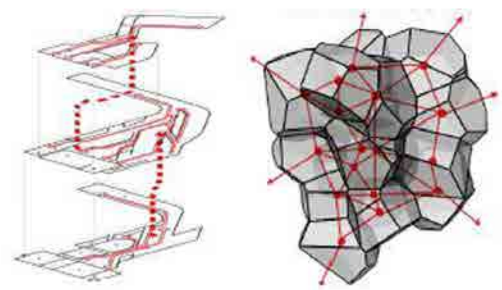

Fig. 8. Paths compared in the classical and virtual museums.

The Voronoi cells generated echo the Delaunay tetrahedrons, which are materially translated into expository rooms (Voronoi cells). The borders of these rooms are planes perpendicular to the segments connecting the points/information (points of the Delaunay tetrahedrons) and form the network of relationships. This means that each initial cell of a work has as many faces as there are works connected contiguously to it. The cell faces therefore have a double sense: they limit the initial space relative to every point and they serve as the interface to communicate with the adjacent cell and therefore with the work contained therein.
A virtual space without gravity allows a range of information to be accessed and visualized simultaneously, and it favours communication on three levels:
- it eases the global connections among the points/information because it allows for movement in any spatial direction;
- it allows the three-dimensional models of the works to be viewed from any point of view and therefore favours knowledge of the object;
- it allows information about the work to be accessed while moving around it through a 3D dynamic interface.
With the addition of the fourth dimension, the flows in the museum are not exhausted with a single configuration. By varying the parameters used to arrange the points/works, the Voronoi cells are reorganized, "moving over each other and changing their shape" until a new structure is reached. The transition reorganizes the polyhedrons, always beginning with the points/information. Modification of the parameters determining the layout of the works leads to a different geometrical structure. After spatially reconfiguring the museum, the visitor, aware of the change, continues the visit in a completely new museum with different relationships that denote the logic of proximity among the works. This change depends on the user's willingness to learn during navigation; strong in the knowledge acquired during the first visit, the user chooses to revisit the expository logic to further amplify this knowledge. It is a dialectic process between the visitor and the museum device.

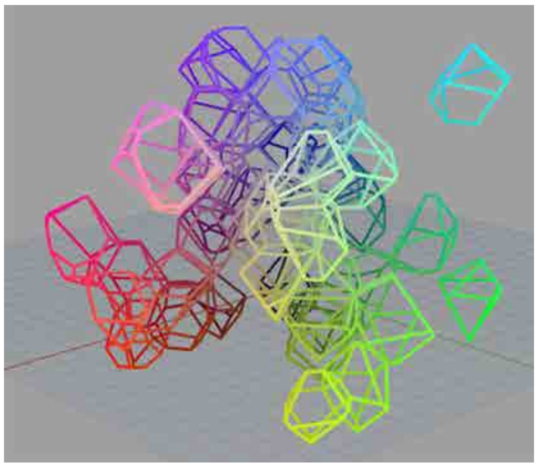

Fig. 9. Pipes coloured according to their position in space. Red was used along the x-axis, green along the y-axis, and blue along the z-axis.

ORIENTATION

Orienting oneself within the space is fundamental in understanding the relationship between the works, but the task becomes difficult in an irregular geometry that lacks a principal direction.
The sense of orientation is not "a passive relationship between a human being and the surrounding space" [5], but rather an active process that leads to the construction of a mental representation of space. For this, the experience of the places and memory are fundamental in the individual's capacity for orientation.
This possibility is, however, denied to visitors of the virtual parametric museum, who find themselves visiting an environment that is new each time. For this reason, amid distributional uncertainty, it is of crucial importance to insert invariants that do not distort the principles of the museum. The choice was therefore made to return to colours. The cells of the museum—while continuously moving and changing shape—are organized with respect to an (x,y,z) axis system that is instead constant. With this characteristic, it is possible to assign a fixed colour to every point in space—independent of the architecture of the museum—and ensure that the structures are attributed with the colour of the point at which they are generated.
The RGB colour model reproduces the spectrum of visible light, assigning a value from 0 to 255 to each of three channels (red, green, blue). Since there are three orthogonal axes that define the space, this model is the most appropriate for these purposes.
Even though they are different, the museum structures will therefore all have the same colouring. Visitors will know, for example, that by moving along the x-axis, the hue of green of the room will be come more or less intense, and the same holds for blue and the y-axis and red and the z-axis.
In addition, other indications of orientation were provided with a light source. For this reason, a single external directional light source was introduced as an absolute reference, which is visible from within due to semi-transparent walls.

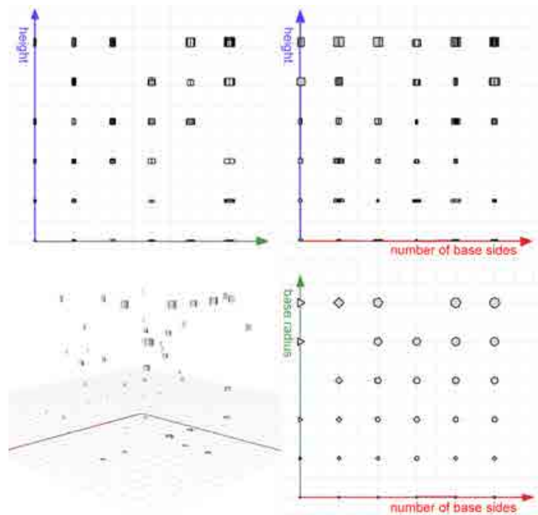

Fig. 10. Orthogonal projections and perspective view of the 50 solids positioned in space according to the chosen parameters.

EXPERIMENTAL APPLICATIONS

From these theoretical premises, the work progressed through practical experiments that led to the definition of geometrical rules to generate the spaces, and ultimately, to the implementation of the algorithm through the chosen nodal system, Grasshopper.
As an example, the choice was made to work with a random system of geometrical solids that have perfectly and objectively measurable characteristics: a heterogeneous group of right regular prisms generated randomly with an algorithm. The minimum and maximum dimensions of the solids were designed to favour a spatial layout that highlighted the common characteristics and the differences between the objects. The works were catalogued in a database and a sheet containing the following was compiled for each prism:
- the subject, the unique name associated with each solid;
- the objects, the categories corresponding to the measurable characteristics (number of base sides, area of the base, height, area of the lateral surface, radius

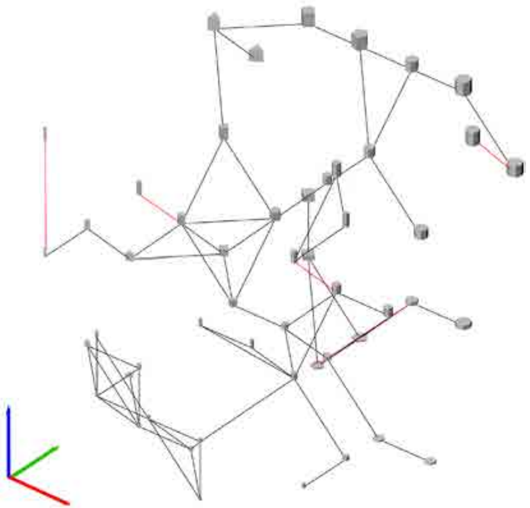

Fig. 11. Delaunay diagram representing the network of connections within the museum.

Fig. 12. Digital representation of an exterior view of the three-dimensional model of the museum, complete with the formal elements and light sources added in the rendering phase.

of the circle circumscribed around the basic polygon, perimeter of the base, and volume);
- the representation of the data (the three-dimensional model).

In addition, each element was associated with key words in the form of tags, which are especially important in the search phase because they return results that are coherent with the user's requests. The characteristics of positioning the solids set with the goals of the search are: the number of sides of the base polygon for the x-axis, the base radius for the y-axis, and the height for the z-axis.

Each of the chosen parameters returns a series of numbers related to each solid, values that represent the position of the solid in space.

From the prisms positioned thus, the algorithm automatically generates the expository spaces according to the geometric rules of the Voronoi diagrams. The first step creates the Voronoi cells around each prism. The algorithm then identifies the isolated regions and connects them with tunnels. Finally, coloured pipes are generated, which are fundamental in orienting the interior of the space. The museum obtained can be navigated in infinite ways since it does not have a set path; rather, each room/cell is connected to the adjacent ones in order to generate a network of connections. In fact, this network is a spatial Delaunay diagram. Visualizing this diagram, the echo of the Voronoi diagram, means visualizing all the possible paths.

The potential of this method is evident. Navigation within the museum can be compared to the flow of thoughts: one moves from one to another by associating ideas. In the museum, one moves from one solid to another—nearby due to its conceptual affinity—guided by the conformation of the spaces.

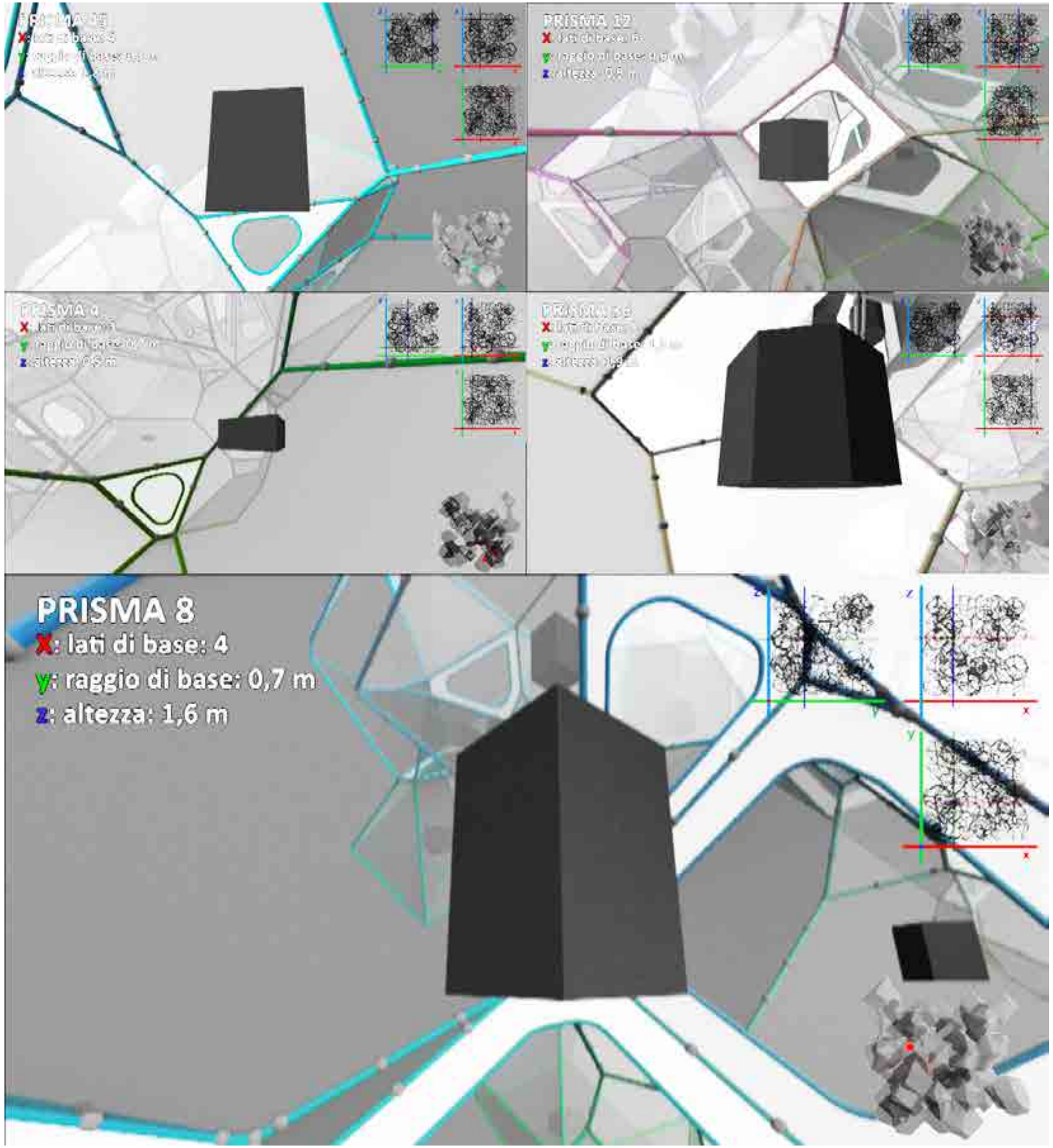

Fig. 13: Frame extrapolated from three-dimensional navigation of the museum. The name of the work and the positioning parameters are shown at the top left of each frame. The navigators are found on the right: two-dimensional navigators at the top and three-dimensional navigators at the bottom.

CONCLUSIONS

Despite the infinite possibilities of modern technological means to simulate a virtual space, the information is still used in most cases in a two-dimensional field such as a page. The research presented here aimed to involve the third dimension (and the fourth as well) to study the related implications.
Today, the navigation of virtual three-dimensional spaces is still difficult because it requires using nonintuitive tools simultaneously: the keyboard for movements and the mouse to direct the framing.
This problem is quickly being solved using devices for virtual reality (VR headset) and tracking systems to interact with the environments. When virtual reality is available for everyone, uses of the third dimension to access information will likely multiply.
From these premises, the research ventured into still-undiscovered territory, so much so that useful applications were found in the world of art and science-fiction literature.
The representation of data in three-dimensional spaces offers an infinitely greater number of connections, similar to the structure of human thought. For this reason, use of the data becomes ever more intuitive and rapid; it is not mediated by written language, but makes use of visual information to intensify the transmission of knowledge.
Generative architecture played a central role in reaching the experimental objectives in that it allowed geometries modelled on information to be constructed that are capable of accompanying—orienting—visitors to museum exhibits.
Tests on the experimental prototype confirmed that the definition of rules and methods of use in the virtual world, which are capable of overcoming the simple metaphorical reproduction of the exploratory habits of real spaces, are terrains rich with the potential to make communication and the uptake of information much more effective.

NOTES

[1] Francesco Antinucci, Comunicare nel museo, Laterza, Bari 2010.

[2] A bridge that allows instantaneous movement between two well-separated points in space. Theorized in 1916, they assume a fourth spatial dimension in which the three-dimensional space can curve. The existence of wormholes, or Einstein-Rosen bridges, has not been proven, but they have anyway entered the common imagination due to science-fiction literature and films.

[3] The semabtic web is the "set of services and structures capable of interpreting the meaning of web content. It is an extension of the web … in which the information has a precise meaning and in which computer and user work together. [It] consists in representing the model of a specific domain of knowledge, codifying the information through ontologies, with the formal description of the concepts organized by classes, relationships, and rules, so that the machine can interpret the information and use it correctly" (Enciclopedia Treccani).

[4] Robert Heinlein, La casa nuova, in Sergio Solmi, Carlo Fruttero, Le meraviglie del possibile. Antologia della fantascienza, Einaudi, Torino 1959.

[5] Francesca Pazzaglia, Marco Poli, Rossana De Beni; Orientamento e rappresentazione dello spazio. pag. 12.

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