Proceedings
13th international Space Syntax Symposium

Akkelies van Nes
Remco de Koning
(editors)

Western Norway
University of
Applied Sciences

Proceedings 13th International Space Syntax Symposium

Akkelies van Nes & Remco E. de Koning (editors)

Department of Civil Engineering
Western Norway University of Applied sciences
Inndalsveien 28, 5070 Bergen, Norway

Proceedings 13th international space syntax symposium, 20-24 June 2022

ISBN 978-82-93677-67-3

Online proceedings found on:
https://www.hvl.no/en/research/conference/13sss/

The international space syntax interim committee

Laura Vaughan, UCL, UK

Meta Berghauser Pont, Chalmers University of Technology, Department of Architecture, Sweden

Akkelies van Nes, Western Norway University of Applied Sciences, Norway

The international space syntax steering committee

Luiz Amorim
Laboratório de Estudos Avançados em Arquitetura, Universidade Federal de Pernambuco, Brazil

Meta Berghauser Pont,
Chalmers University of Technology, Department of Architecture, Sweden

Ruth Conroy Dalton
Architecture and Built Environment, Northumbria University, UK

Jin Duan
Southeast University, China

Margarita Greene
Escuela de Arquitectura Pontificia Universidad Católica de Chile, Chile

Teresa Heitor
Instututo Superior Técnico, Universidade de Lisboa, Portugal

Frederico de Holanda
Faculdade de Arquitetura e Urbanismo Universidade de Brasília, Brazil

Kayvan Karimi
Space Syntax Laboratory, The Bartlett, UCL, UK

Young Ook Kim
School of Architecture, Sejong University, Korea

Daniel Koch
School of Architecture and the Built Environment, KTH, Sweden

Ayse Sema Kubat
Faculty of Architecture, Istanbul Technical University, Turkey

Lars Marcus
Chalmers University of Technology, Department of Architecture, Sweden

Akkelies van Nes
Western Norway University of Applied Sciences, Norway

Alan Penn
Bartlett Faculty of the Built Environment, UCL, UK

John Peponis
School of Architecture, Georgia Institute of Technology, USA

Sophia Psarra
Space Syntax Laboratory, The Bartlett, UCL, UK

Laura Vaughan
Space Syntax Laboratory, The Bartlett, UCL, UK

The international space syntax reviewing committee

Wafa Al-Ghatam
Kinda Al-Sayed
Luiz Amorim
Paulo Anciaes
Yassine Bada
Sonit Bafna
Meta Berghauser Pont
Evgeniya Bobkova
Tom Bolton
Andrea Braga
Beatriz Campos
Isin Can
Luísa Cannas
Nadia Charalambous
Valerio Cutini
Francois Dufaux
Beatrix Emo
Chen Feng
Lucas Figueiredo
Ahmed Tarek Zaky Fouad
Francesca Froy
Chiara Garau
Ilaria Geddes
Jorge Gil
Margarita Greene
Sam Griffiths
Sean Hanna
Birgit Hausleitner
Teresa Heitor
Frederico de Holanda
Kayvan Karimi
Daniel Koch
Reinhard Koenig
Remco E. de Koning
Kimon Krenz
Ayse Semat Kubat
Ann Legeby
Jae Hong Lee
Michelle X.H. Ling
Sharifah S.S. Mahdzar
Mark David Major
Bardia Mashhoodi
Valério Medeiros
Abdelbasseer A Mohamed
Darren Nel
Akkelies van Nes
Vinicius Netto
Pirouz Nourian Ghadi Kolaee
Garyfalia (Falli) Palaiologou
Panagiotis Patlakas
Hoon Tae Park
John Peponis
Decio Rigatti
Miguel Serra
Yao Shen
Ermal Shpuza
Todor Stonajovski
Lasse Suonperä Liebst
Wendy Tan
Ilgi Toprak
Edja Trigueiro
Kali Tzortzi
Cláudio Ugalde
Laura Vaughan
Alice Vialard
David Viana
Haofeng Wang
Claudia Yamu
Yu Ye
Reem Zako
Fábio Zambieri

Index

Architecture: Architecture spatial theory

Architecture: Space Syntax and architectural design

Buildings: Complex buildings

Buildings: Cultural and educational buildings

Buildings: Shopping and retail

Cognition: Environmental and behavioural psychology

Cognition: Spatial Cognition and way finding

Cognition: Virtual Reality

Design & Planning: Data-informed Design and Planning

Design & Planning: Generative Design and Planning

Design & Planning: Urban Strategic and Transport planning

Economy & Urban space: Informal economies

Economy & Urban space: Land use studies

Economy & Urban space: Real estate studies

Future Cities: New data and Smart Cities

Future Cities: Slow traffic and online economies

Future Cities: Urban Sustainability

History & Urban Morphology: Archaeological studies

History & Urban Morphology: Historic centre and village conservations

History & Urban Morphology: Suburbs and new towns

Methodologies: Software development

Methodologies: Spatial Network analysis

Space & Society: Space and Crime

Space & Society: Spatial and social justice

Teaching: Design studio

Teaching: Theory course

392

A combination of 3D model and panoramic photography for a 3D isovist tool

CRISTINA CÀNDITO, ILENIO CELORIA, ALESSANDRO MELONI

DEPARTMENT ARCHITECTURE AND DESIGN, UNIVERSITY OF GENOA, ITALY

ABSTRACT

The identification of the elements within space that can be perceived by an observer is achieved by the isovist tool which can be developed in a planimetric vision. What is lacking is the possibility of identifying the elements in three-dimensional form. Recent studies were aimed at extending isovist to space in different ways. In our study, the potential of the 360-degree panoramic photography technique was exploited to obtain a three-dimensional visualisation. We carried out research on an interior architectural space which was surveyed and reconstructed virtually. It was decided to explore the Edoardo Chiossone Museum of Oriental Art (Genoa, Italy) designed (1948-1971) by Mario Labò because of its volumetric simplicity contradicted by an articulated cyclical path which is difficult to identify. The combination of panoramic photography and virtual parametric model led to preparation of a tool (*PanoProj*) useful for simulating a 3D isovist, which considers objective data (the visible portion of the space from a single viewpoint) and which offers the possibility of making perceptual considerations through dynamic simulation in a virtual model environment. Two different views were compared in sequence along the path, and different tools were also used such as a vertical 2D isovist and a graph. It was found that the spatial riddle of the Chiossone Museum could be explained in a more effective way using an integration of analysis, trying to identify those qualities that give visitors the pleasure of discovering a complex space that gradually reveals itself while being explored.

KEYWORDS

3D Isovist, Panoramic Photography, Parametric Modelling, Graph, Vertical Isovist

1 INTRODUCTION

This paper describes a part of some research about the ways in which architecture spatial qualities are perceived in aesthetic and wayfinding perspectives. Simulation was conducted with different kinds of users, as the research also aims to tackle the tough challenge of the accessibility of spatial information for people with visual disability. In this work, the space qualities of a museum architecture of the 20th century are investigated with a new technique that matches virtual modelling and panoramic photography to obtain a three-dimensional, realistic, and dynamic visualisation of the isovist.

Spatial perception through visual sensation may be studied by different tools, and among them isovist appears to be one of the most efficient. Gibson (1947) was the first to talk about the polygonal representation of the visible space that changes with the position of the observer. Isovist is intended as an instrument that helps understand spatial perception as it is the "set of all points visible from a given vantage point in space and with respect to an environment" (Benedikt 1979)[1]. Isovist could be analysed through its area and shape, describing some spatial features such as convexity or openness. All the research that has developed measures from isovist maps or connected it with analysis tools and predictions in social behaviours cannot be cited. Those most related to our interest will be selected and the intention is to contribute by formulating a proposal for a three-dimensional, dynamic, and realistic version of isovist.

In fact, despite its three-dimensional definition, isovist normally appears as a polygon in planimetric projections, capable of being generated and evaluated with parametric modelling tools (Nagy 2017). Some studies have been aimed at extending isovist to space in different ways. For our purposes, we are mostly interested in three-dimensional research in a virtual model. Penn et al. (1997) introduced the *Isovist camera*, an analytic tool in the Pangea 3D-modelling environment that can construct isovists during its movement and calculate their area perimeter ratio.

A significant passage was given in the field of urban landscape analysis, often inspired by authors such as Lynch (1960), Cullen (1961) and Hillier (1984) who stressed the importance of the study of visual analysis, also in a sequential form using maps, drawings, and photos. An evolution in the three-dimensional direction was the *viewshed* concept, intended as the terrain visible from a major viewpoint (Lynch 1976) which was used mostly in landscape analysis. Its evolution could be individuated in the *viewsphere* tool that finds its natural development in the Geographic Information System (GIS) environment (Yang et al. 2007).

The specific features of our case study make the involvement of the vertical isovist particularly interesting, also in its perceptive distinction with the horizontal isovist (Krukar et al. 2020). The study of the connections among different level of buildings is also important (Varoudis, Psarra 2014).

[1] Krukar et al. (2020) cited two early studies by A. Hardy (1967) and C.R. Tandy (1967), both published in A.C. Murray, Methods of Landscape Analysis, London 1967. For an extended state of art on isovist, see Ostwald and Dawes (2018).

Important research generalised the use of the visibility graph (Turner et al. 2001) that integrated different isovists and allowed analysis of the characterisation of architectural space (Benedikt, McElhinney 2019), also in promising reciprocity between observer and observed (Lonergan, Hedley 2015).

A recent study (Ünlü et al. 2019) was aimed at using sequential three-dimensional isovists as polyhedral portions of space that have their centre at the observer's viewpoints changing along a path: information given by their shapes and other spatial features was integrated with psychological outcomes.

In a realistic direction, some studies added the contribution of visual data coming from a digital model and a cylindric form of panoramic photography (Fisher-Gewirtzman 2016). Another research project used 3D point clouds to investigate the impact of location for information displays using the integrated analysis of 2D and 3D isovists (Dalton et al. 2015) and some researchers have proposed the potential use of a Lidar tool (Lu et al. 2019).

It was decided to use the Edoardo Chiossone Museum of Oriental Art (Genoa, Italy) designed (1948-1971) by the Italian architect Mario Labò (1884-1961) as a case study. A building distinguished by a troubled history that characterised its construction, and which constitutes a point of reference in the field of Italian museum architecture, although it is still little studied. The museum is characterised by fairly simple regular volumes that define the exhibition hall: the main room, where the empty space emerges in the building (Lanteri Minet 2017; Spesso, Porcile 2019). The apparent simplicity is contradicted by the spatial organization and users understand its cyclic distribution only slowly, while they are moving and exploring it.

In our study we intend to exploit the potential of the 360 degrees panoramic photography technique to obtain a three-dimensional realistic visualization. We built a digital model after an accurate survey of the indoor and we use the cubic representation of panoramic photography, which can provide six different planar projections: six one-point perspectives sharing the same point of view, and which differ in the direction of the gaze. We projected a sequence of panoramic photos using *Grasshopper* algorithm, so we can perceive, through the virtual model, the position of observers and what they can see.

With this method, we obtained three-dimensional and realistic visions of the space. Our aim was to simulate a visualization of space by a user through parametric modelling tools, by moving the point of view to transform this static instrument into a dynamic one. We also compared our results with 2D isovist that in our case study was more significant in a vertical orientation and we extrapolated an abstract scheme of distribution of different level.

Although we intended to simulate a fluid and dynamic movement in an architecture interior, we only showed a part of the sequence. We also chose to extrapolate only a part of the cube at a time, in order not to complicate the modelling computation of projections: we believe that this limit could be compared with the visual cone, compatible with the natural limit of the angular extension of a adequately defined human view (90 degrees) which can be extended creating projection of other cubic faces.

In this paper we didn't show the whole set of panoramic photos taken from vantage points at different level and their communication in an accessible perspective and we didn't discuss about other phases of our research that includes visitors' interviews made with people with and without visual disability to indagate how and when they understood the spatial structure along the path. The use of our tool can be extended to the study of spatial features through the computation potential of the digital parametric model (areas, volumes, their ratio, or others), but we believe that the qualitative observation could be the most important for our purposes.

2 THEORY: VIRTUAL MODEL AND PANORAMIC PHOTOGRAPHY

Experience of the exploration of a space may be simulated in a 3D virtual model or with panoramic photography, but how can one identify the position of observers together with the elements of space they perceive? The isovist tool works well in the second dimension, but its application becomes very difficult in the third dimension, and this is probably the reason why there are many solutions offered by researchers. In order to obtain a useful tool, we need to ask ourselves the real purpose of the simulation we want to realise.

We conceived a combination of two different tools we normally use in surveying and representing architecture: a 3D virtual model and panoramic photography. The first is useful for its capability of being a field of simulation, especially in its parametric integration, and the second provides an image of the architecture capable of approaching realistic perception.

3 METHODS. A PROJECTION OF A PANORAMIC PHOTO IN A VIRTUAL MODEL

There are different instruments to represent architecture, also in a realistic way. In this research, we wanted to realise a visualisation capable of identifying observers and the portion of space they can see inside a building. It is not a matter of texturising the model, but of creating a dynamic transformation of the vision during a simulated navigation, so a virtual tour, realised with panorama photo techniques projected on 3D model surfaces, was considered.

We chose the Chiossone Museum as a case study and different tools were integrated to explain its complicated distribution, also involving 2D vertical isovist and graph studies that are able to synthetise the essence of the whole architecture.

3.1 The peculiar case of the Chiossone Museum

The Edoardo Chiossone Oriental Art Museum (Genoa, Italy) is a building designed by the architect Mario Labò (1884-1961) starting in 1948 and completed in 1971. It was the first newly built museum project after the Second World War in Italy: a feature that, together with its compositional qualities, makes the museum particularly important on the Italian architectural scene.

In the debate on the theme of musealisation in the post-war reconstruction phase, the city of Genoa, with the well-known projects of Franco Albini (1905-1977) (Bucci, Rossari 2005) and Mario Labò himself, became one of the reference cities for this type of architecture. The building is part of the nineteenth-century park of Villetta Di Negro, an elevated green area in the heart of the city from which two main volumes emerge that define the building: the access compartment and the exhibition hall.

From the architectural viewpoint, the museum space is determined by five staggered levels arranged close to the longer sides and which internally overlook a full-height central void (fig. 1); in addition to the five levels *(2-6)* we find two galleries on the ground floor, distinguished by a reduced height difference (about 0.45 m), attributable to the gallery museum at the beginning and end of the route *(1* and *7).* The floors are connected by stairs positioned along the short sides of the building, which are mainly visible from gallery *1* on the ground floor (fig. 1 c).

Figure 1: Chiossone Museum of Oriental Art (Genoa, Italy): exhibition hall. (a) Plan; (b) Section; (c) Photo.

An erroneous mental prefiguration of space is generated in the visitor as a succession coinciding with the progression of the levels. The actual arrangement, on the other hand, takes place in a cyclical manner, comparable to a double helix able to lead the user through an ascent path *(1, 2, 3, 4)* different from that of the descent *(5, 6, 7).*

The museum maintains a visual connection with the external environment, and more precisely with the historical city centre, thanks to the view offered by the large windows along the south-west façade.

Although it is a rather simple construction in the volumes, therefore, the complexity of the journey reveals a sophisticated system that makes the space unique, and that can only be recognised through movement and direct exploration. These aspects have led us to analyse and carry out in-depth studies, addressing in particular the perceptual and behavioural context determined by movement, but at the same time finding points of connection with some issues related to orientation cited by Ruth Conroy Dalton (Conroy Dalton et al. 2015, p.18-19), such as the importance from the vision to the outside or the potential of the view in elevated points to promote understanding, which are not shown here.

3.2 Panoramic photography

In our study we exploited the potential of the 360 degrees panoramic photography technique to obtain a three-dimensional visualization. Panoramic -or nodal- photography offers a three-dimensional and dynamic view: it allows virtual tours to be created and it can be considered as a tool for studying architectural space (Luhmann 2004). Much of our ability to understand a work of architecture depends on our perception of the qualities of the space represented. To simulate them, we turn to different representations that often, however, do not give us back its experiential qualities. Photography, to a certain extent, allows us to improve the visualization of space, but remains confined within the chosen framing and excludes everything that is beyond it (Jabi 2001).

The photographic gesture is configured as an action that requires the choice of a position (viewpoint) and a viewing angle (camera angle) that affects the framing and the perspective of the image. In 360 degrees panoramic photography the point of view still maintains its importance, while the choice of framing is lost and can be made *a posteriori*, depending on the portion of space that becomes the protagonist of the image. This is one of the most interesting features of this type of photography. Thanks to its versatility, panoramic photography, since there is no offscreen, also becomes a valuable tool for investigating space as a whole.

Thanks to the use of specific software using metadata, we can obtain different kinds of representation: the equirectangular projection -an approximate development of a sphere-, the rectilinear projection -assimilated to a one-point perspective-, the planet projection -which is a stereographic representation-, etc. These derive, in part, from traditional cartographic representations, and can be transformed freely from one form to the other.

Panoramic photography often uses equirectangular projection as one of several ways to develop the surface of a sphere in a plane. This projection is essential to capture, in a single two-dimensional image, everything that is around the observer.

The different projections, combined with the possibilities of navigation, can become valid tools for the study of visual perceptions within an architectural space. From a theoretical point of view, 360 degrees photography is considered as an immersive tool, a communication technology characterized by vividness and interactivity. Vividness denotes the representative richness of the medium, that is, the number of different senses that the medium can involve (sensory *breadth)* and the resolution within each of these perceptual channels (sensory *depth).* Interactivity, on the other hand, denotes the number and quality of actions that users can take to change the form and content of a mediated environment in real time (Steuer 1992). Panoramic photography, therefore, allows the viewer to mentally build a spatial model in which to place himself to observe the intrinsic characteristics of architecture.

The use of devices for virtual and augmented reality favors the construction of this mental model by eliminating the reference points with the surrounding reality. "It is therefore by removing from the eye all the terms of comparison that one comes to deceive him to the point of making him hesitate between nature and art" (Bordini 1984, p. 91), as was the case in the past with the dioramas used for educational and illustrative purposes.[2]

The equirectangular projection, which covers an angle of 360 degrees in the horizontal direction and 180 degrees for the vertical one, can be made with cameras that here we call panoramic, generally equipped with fisheye lenses. The panoramic cameras, recently produced, have flanked those equipped with a single lens in which the image is generated by multiple shots taken from a single point of view (nodal point) around which the camera rotates. Shooting with multiple shots using traditional cameras requires the use of a panoramic head, manual or motorized, which permits the maintenance of the nodal point during rotation. While panoramic cameras can perform the function of merging images within the device, shots made with traditional cameras require specific software to stitch individual images into the final panoramic image. This technique is less immediate than that of panoramic cameras but allows one to obtain images in High Definition.

In general, many of the software that permit the stitching of photographs for the creation of equirectangular panoramic images also allow the export of the same with different types of projection. For our purposes, as we will see, we found useful to transform equirectangular images into cubic projections that are made up of six rectilinear images as a whole perfectly identical in projectivity with respect to equirectangular projection (fig. 2). In equirectangular projection, the deformation around the poles makes it difficult to read the elements placed near them. With cubic projection it is instead possible to obtain an image closer to the natural vision of space, useful for carrying out perceptual checks and observing spatial correspondences.

Panoramic photography is particularly suitable for the analysis of architecture because it allows one to observe space in a fluid, continuous and engaging way. This technology permits the creation of virtual tours, consisting of a sequence of panoramic images spaced apart. Although panoramic viewers create a realistic immersive experience, they do not permit the viewer's movement to be smoothly visualized. For example, *Google Street View* creates a discreet system of passages from one panorama to another. A study by Sandnes and Huang (2016) developed a method that suggest a continuous and fluid movement creating smooth transitions between different panoramic photographs.

[2] Even before the invention of photography, in fact, the nineteenth-century painted panorama or diorama, was considered a visual journey that could allow thousands of people to know without being forced to travel (Bordini 2017, p. 142).

For the present research, we use a panoramic camera, *Ricoh Theta Z1,* equipped with two ultra wide-angle lenses located both in the front and in the back of the camera. The lenses, characterized by a focal length of 2.6 mm and an angle of view greater than 180°, generated two partially overlapping circular photographs from which the equirectangular projection was obtained (fig. 3). All the shots were made with the optical axis of the perfectly horizontal lens by placing the centre of the lens 160 cm from the walking surface: the errors due to small rotations or inclinations of the lenses were corrected using the *Hugin* software[3], also necessary to carry out the transform operations into a cubic image (fig. 4).

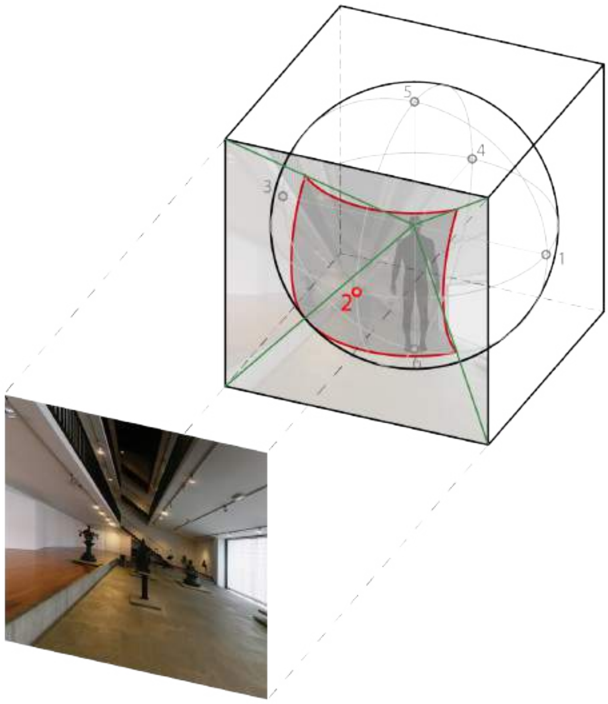

Figure 2: Axonometric scheme related to spherical and cubic representations.

[3] Hugin (http://hugin.sourceforge.net/) is a cross-platform open-source panorama photo stitching merging program.

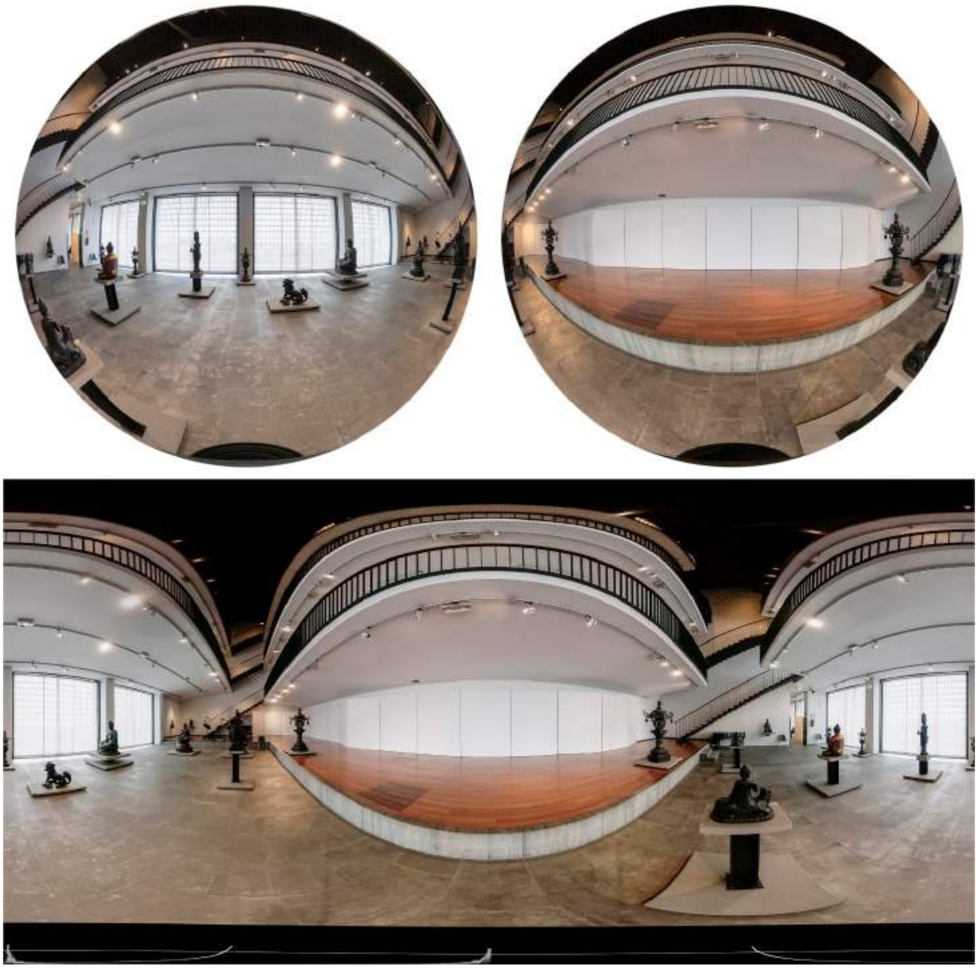

Figure 3: Photographs taken from point B. (a) Images taken with Ricoh Theta Z1 camera; (b) Equirectangular projection obtained by stitching.

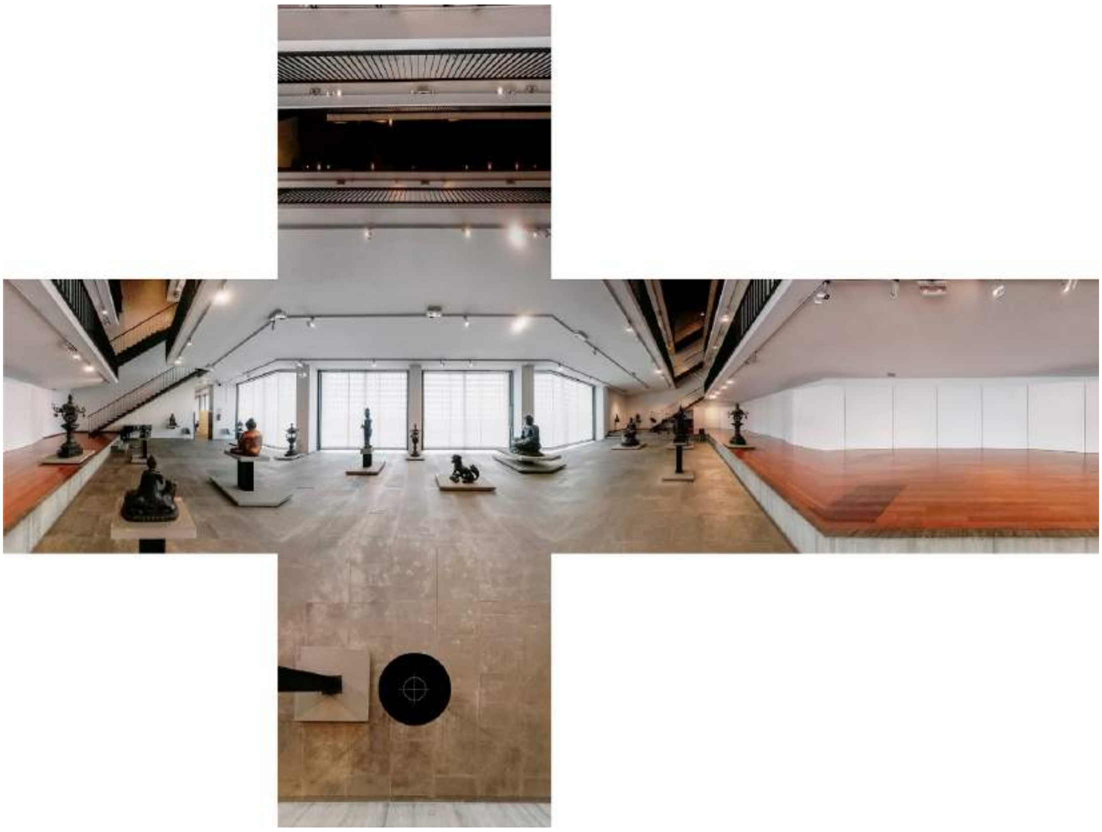

Figure 4: Cubic projection of photographs taken from point B.

The shots were made along the exhibition path by placing the camera in successive characteristic points, intended as decision points where people make a choice of navigation and direction, such as road intersections and turning points (Jiang, Claramunt 2002). The morphology of the envelope of our case study is essentially presented as a parallelepiped within which it is possible to follow a continuous path, articulated on the described staggered planes, which starts from the entrance and returns to the same point without retracing the same path. For each level, three characteristic points were identified from which the panoramic photographs were taken: one central and two laterals. In this way, information was obtained that can return a perception of the entire space but also to verify the visibility index of the architectural elements in relation to the distance from the observer.

3.3 3D parametric model and preliminary studies

The study of the Chiossone Museum is determined by preliminary phases of surveying, using analogue and digital systems, among them photogrammetry; these steps are fundamental activities for the three-dimensional reconstruction of the architectural space realised through Rhinoceros[4]. The information was selected in order to obtain a synthetic three-dimensional model, correct from the viewpoint of linear measurements and the surface directions.

In this model, the desire was to import the information collected with the survey campaign through the panoramic photography conducted in the characteristic points of space. The

[4] Version 6. Robert McNeel & Associates (https://www.rhino3d.com/).

combination conceived between virtual model and panoramic photography was achieved through two complementary phases: the first phase which consists of the choice of cubic projection and its dynamic materialisation in a virtual environment and the second phase that allowed the effective generation of a projection of the images perceived from an observation point. This combination was named *PanoProj* and it was then used to make qualitative considerations on two viewpoints in sequence.

3.4 *PanoProj*, Phase 1: a point of view in a wallpapered cube

Integration of the different tools, virtual model and panoramic photography, was achieved thanks to the use of cubic representation, which can provide six different one-point perspectives sharing the same viewpoint and differing in the direction of the gaze. In fact, six main directions each perpendicular to one face were obtained.

Some previous works used different projections of panoramic photography, such as the cylindrical projection applied by Fischer-Gewirtzman (2016) to describe the most perceptually relevant spatial factors in the vision of an external environment, or the spherical representation that proved to be an effective tool for surveying (Calvano 2018).

Cubic projection was identified as the most suitable method of representation to experiment with immersive techniques that hybridise photographic shooting with graphic integrations (Olivero et al. 2019). Since it is composed of one-point perspectives, it is a representation that is close to a natural vision: for this reason, it had previously been experimented with in an intuitive identification of 3D isovist in an ancient building (Càndito et al. 2020). In this research, the use of cubic projection is suggested by the need to overcome the limits imposed by other projections of panoramic photography compared to the instrument we used. Our aim was to acquire a projection useful to visualise the portions of the model perceived by an observer and a result can be obtained through the *Grasshopper Image Sampler* component, which uses flat images corresponding, in our case, to each face of the cubic projection.

We built a cube of 3.20 m per side with a face coinciding with the floor in order to have in the centre the viewpoint (1.60 m) and the dynamic identification of the shooting points was set, always using *Grasshopper* (fig. 5a).

The first phase of definition of the algorithm concerns the modelling of the cube (fig. 5b) and the superimposition of the images on its surfaces (fig. 5c). The viewpoint, as mentioned, corresponds to the centre of the cube the edges of which are highlighted to make them more visible through the *Pipe* component (1-2). The vertices of the cube (3) are important because they identify the surfaces to which to attribute the image extrapolated from the cubic projection (4).
For the visualisation of the photographic images, as we said, the *Image Sampler* was then used. This component can be connected with the *Mesh Colours* command involving the transformation

of the surfaces of the cube into mesh and permitting attribution of the RGB values of each pixel with its *u* and *v* coordinates of the geometry as they result in the photographic images. This phase is useful to superimpose the photos on 3D model thus verifying the correspondence between the two.

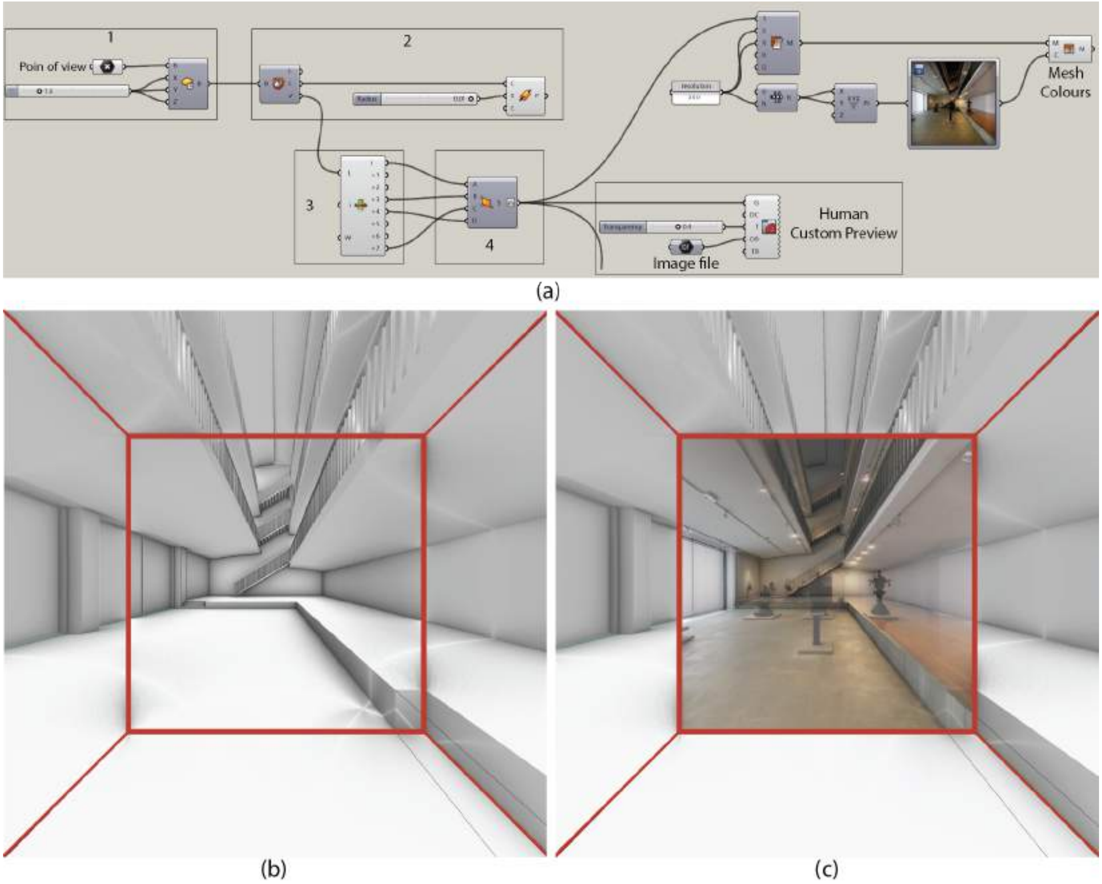

Figure 5: Cube generation and photo image overlay. (a) Definition of the algorithm; (b) Photographic view of the edges of the cube; (c) Overlay of the image with the 3D model.

The *Custom Preview Materials* component, belonging to *Human* plugin, could further facilitate this comparison, as it would allow the contemporary view of the image and the model, managing the transparency values. Although it is more immediate, since it is a dynamic viewer, the latter possibility is not necessary for the use of meshes in addition to existing surfaces.
A camera was placed at the shooting point, with a target perpendicular to the surface of the cube. To simulate what really happened, the camera features were used which, as was seen in the previous paragraph, correspond to a focal length of 2.60 mm. This process, as mentioned, allowed us to obtain a shooting point from which it was possible to observe only the edges of the cube or the overlap of the image with the model.

It was decided to analyse the shooting point at the entrance of the exhibition hall on the ground floor (point *A*) and the one in the centre of the same (point *B*) (fig. 6). To further narrow the field of investigation, we turned to the analysis of a single portion of the cube surfaces, which can be represented by a single face. For the logic of the direction of the exhibition path, the one to the north-west was chosen.

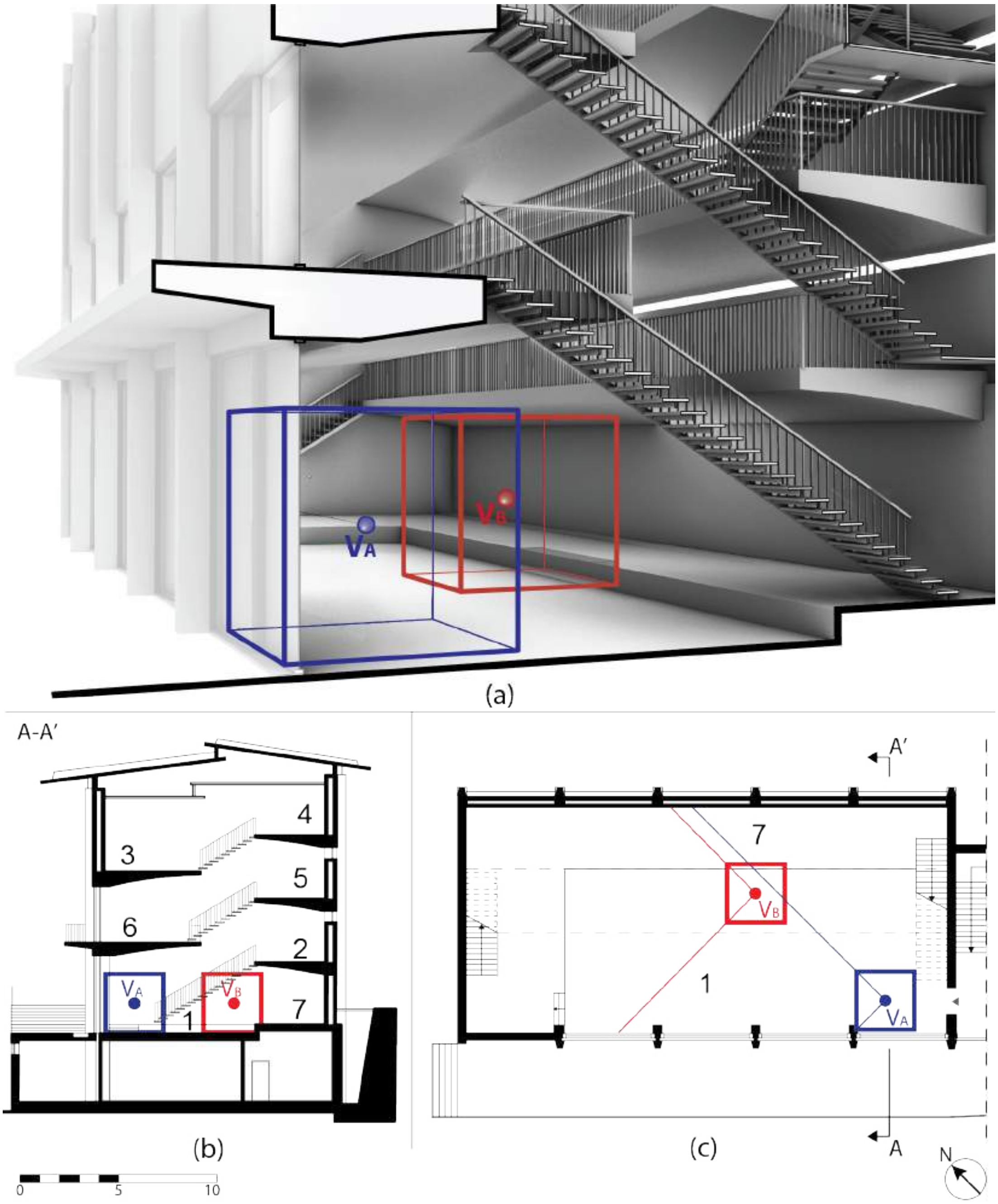

Figure 6: The arrangement of the cubes within the architectural space and the projection of the north-west surface (in blue). (a) Perspective cross-section; (b) Section; (c) Plan.

3.5 *PanoProj*, Phase 2: the projection on the model surfaces

Having defined the correspondence between photographic image and virtual model, we investigated the themes of projections from a finite centre and that are practically reflected in the rules of projective geometry and perspective. Conical projections -with a finite centre- are generally little applied within three-dimensional modelling software: even with *Rhinoceros* and *Grasshopper* only cylindrical projections -with an infinite centre- can be obtained automatically. However, there are different studies and applications aimed at filling this gap and achieving an effective process by exploiting the commands already present within the software. There are studies that refer to the use of a script code (Majewski 2019) or that regulate the elements involved in the projective process using mathematical functions (Gross 2019).

These precedents allowed us to understand which solution might be the most effective to achieve our purpose. One aspect analysed concerned the understanding of the characteristics and potential of the *Image Sampler* component, especially regarding its characteristic of attributing a numerical value calculated according to the pixels of an image to each point of a grid. The possibility of overlaying the surface of the image with its chromatic characteristics maintaining the values determined by the RGB channel was previously explained, but in the present algorithm it was decided to use the black and white version of the image, because it allowed us to attribute a numerical value to the points according to the degree of brightness channel in a range from 0 (black) to 1 (white). The list of values thus obtained was used to constitute circumferences characterised by their position (their centres coinciding with the points of the image) and their brightness (their rays).

Analysing the application of Owen Olthof (2021) on the management of the *Image Sampler* and that of Ethan Gross (2019) related to the definition of the projective process, the useful aspects to define our algorithm were identified (fig. 7a).

The reference elements from which to start are basically two: the surface of the cube (side 3.20 m) and the image to be projected (320 x 320 pixel). The chosen face of the cube was reparametrised and divided according to the number of the image pixels (u= 320; v= 320), to ensure that both values correspond to the coordinates of the photograph (fig. 7c, 7d in red).

The use of circumference was an expressive choice that was considered particularly relevant, but there are different possibilities regarding the representation of the data provided by the *Image Sampler.* Arturo Tedeschi (2010, p.110-111), for example, used a grid composed of spheres that change their size according to the brightness of the image; other cases, instead, followed the same logic using horizontal or vertical segments of variable length (Gökmen 2019).
To acquire the chosen view, composed of circumferences, it was necessary to carry out a new mapping of the domain related to the *Image Sampler* data, which is a procedure that involved the use of the *Remap Domain* component and that is defined according to the following inputs (Olthof 2021):

- *Value***:** image sampler values (0 to 1) to remap.
- *Bounds*: that identifies the range of values present for each list of points.
- *Construct Domain*: defines the maximum and minimum value of the remapped domain.

The remap process was necessary because the direct connection of the *Image Sampler* with the radius would lead to obtaining circumference radii with values between 0 and 1, that are sometimes incompatible with the dimensions that separate the centres, since contemplating circles that intersect with each other and would not allow the understanding of the image.

The last step of the algorithm concerns the process of circumferences projection on the three-dimensional model (fig. 7b). The procedure started with the subdivision of the circumferences (*Divide Curves)* through 10 separating points, that are fundamental because they will actually be projected on the surface of the model (Gross 2019).

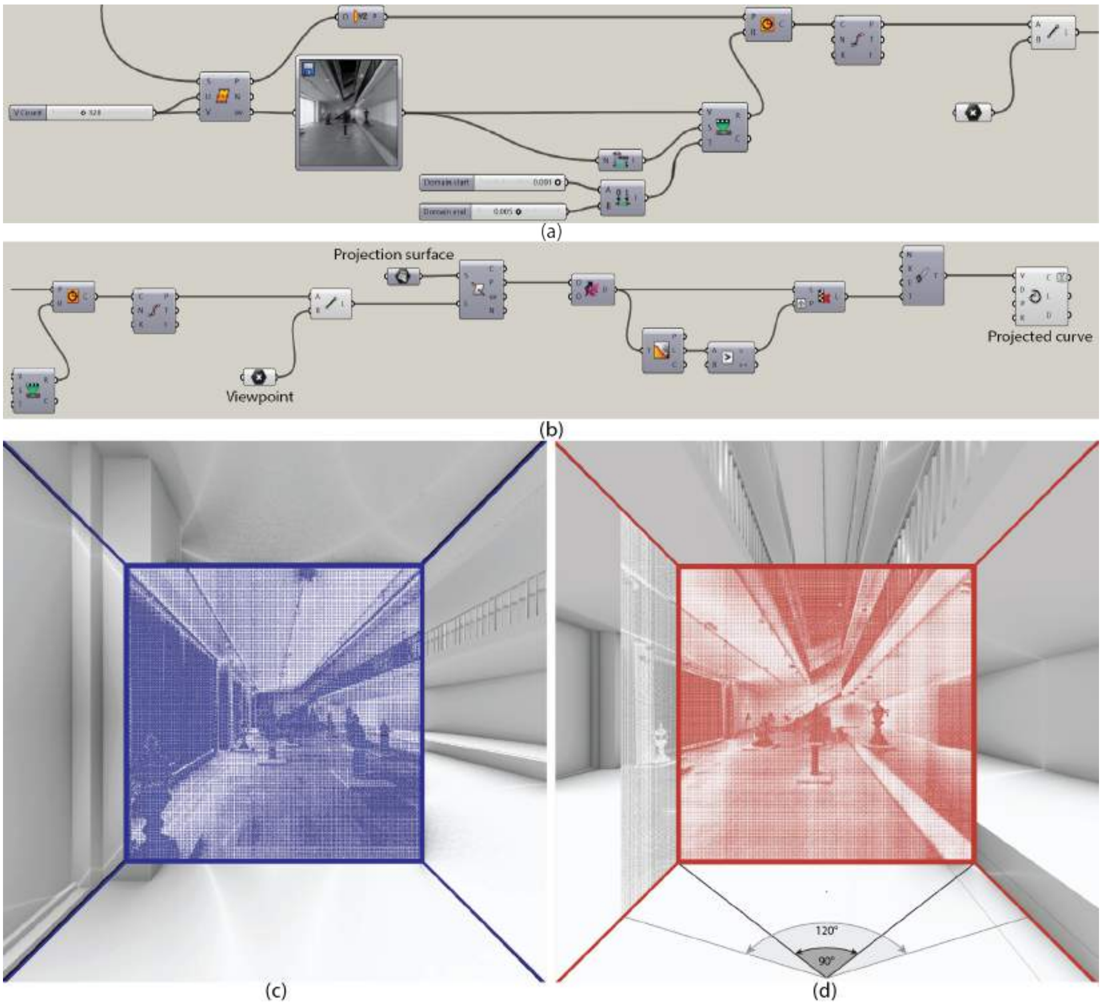

Figure 7: Schematisation of the image using circumferences and its projection. (a) Algorithm that converts image brightness data into variable-radius circumferences. (b) Algorithm describing the projection on the surfaces model. (c) Frontal view from observation point A; (d) Frontal view from observation point B, with the possibility of enlarging the angle of view.

The division according to this numerical data allows us to get sufficient points for the reconstruction of the projected circumferences, especially in reference to the planes not parallel to the surface of the cube which, as known, lose the regularity of the circle to take the form of ellipses. To make the projection, it is necessary to generate the visual rays that originate from the viewpoint (shooting point of the camera and centre of the cube) and pass through the 10 points belonging to each circumference. The rays intersect the surfaces of the model (*Surface Line)* generating the projected points. A condition that must occur to obtain the tracking of the curve projected is that it occurs in a complete way, that is, that all 10 points that define it are projected inside the surface and we verified this through the *Shift Path* and *Tree Statistics* components. The final step consists of tracing the curves (*Interpolate Curves*) projected thus remodulated and selected.

It was decided to repeat this process for each individual surface of the model capable of receiving the projection, so that the surfaces that are actually important could be selected and thus allow separate analysis. The systematisation of all the surfaces involved permitted us to achieve the desired effect: a projection of the previously discretised image that realises the simultaneous visualisation on the model of the observers and what is visible by them (fig. 8c).

3.6 Two different views in *PanoProj*

The generation of the *PanoProj* tool is aimed at observing sequences of panoramic views in a virtual environment, in order to carry out first of all qualitative analyses that emerge from the comparison.

It is initially useful to emphasise the importance assumed by the visual field and the amplitude of its angle, which is not limited to only 90°, but considers the physiological characteristics of vision, including peripheral vision: an amplification that can reach approximately 120° horizontal amplitude (Savino, Danesh-Meyer 2012, p. 12). With this angle, inside the cube, part of the lateral surfaces adjacent to the observed frontal image (fig. 7c, 7d) are also included, thus exploiting the flexibility of the designed instrument.
The dynamism of space exploration also contemplates the possibility of the rotation of the viewpoint, that can be obtained by moving the head and the gaze: movements that characterise the exploration phases.

The comparison between two sequential visions can be carried out initially according to a planimetric approach (fig. 9a), which allows us to observe how, with the same amplitude of the visual field, the transformation of the spatial elements involved: a difference that is reflected in the three-dimensional reading.

The process carried out on the three-dimensional model recalls the logic of the 2D isovist in which, however, only a portion is considered that is limited by the visual angle and by the portion of a circumference that represents the depth of the visible field, having as radius the maximum distance from the occluding surface (Conroy 2001, p. 62). The dimensional difference between the two maximum radii heralds a wider and more detailed view at viewpoint *B*. A three-dimensional interpretation would lead to the involvement of a sphere that recalls the logic of 3D isovist previously analysed.

The comparison between the projections of the images on the model (fig. 8c), also supported by photographs (fig. 8a, 8b), revealed differences that affect the reading of the space and the consequent behaviour within it. Shooting point *A*, adjacent to the entrance of the room, does not provide the global understanding of the space but allows one to trace a direction of movement towards the front staircase, which also stands out thanks to its inclination and chromaticity in strong contrast with the white wall. From this viewpoint, however, it is not possible to identify or understand the different levels: the visible elements are reduced to galleries *2* (on the right) and *6* (on the left) not sufficient to understand the totality of the space. Large surfaces of the space are also involved, but they are less relevant and useful for the purpose of understanding the architecture: in fact, the flooring and the windows emerge.

The plan disposition, devoid of the exhibition apparatus, shows a direct contact with the few steps arranged frontally, inducing the viewer to move towards them, even if the statues reduce their visibility. It is precisely because of their presence that it encourages one towards the interior of the room and more precisely in the direction of the next viewpoint (*B*).

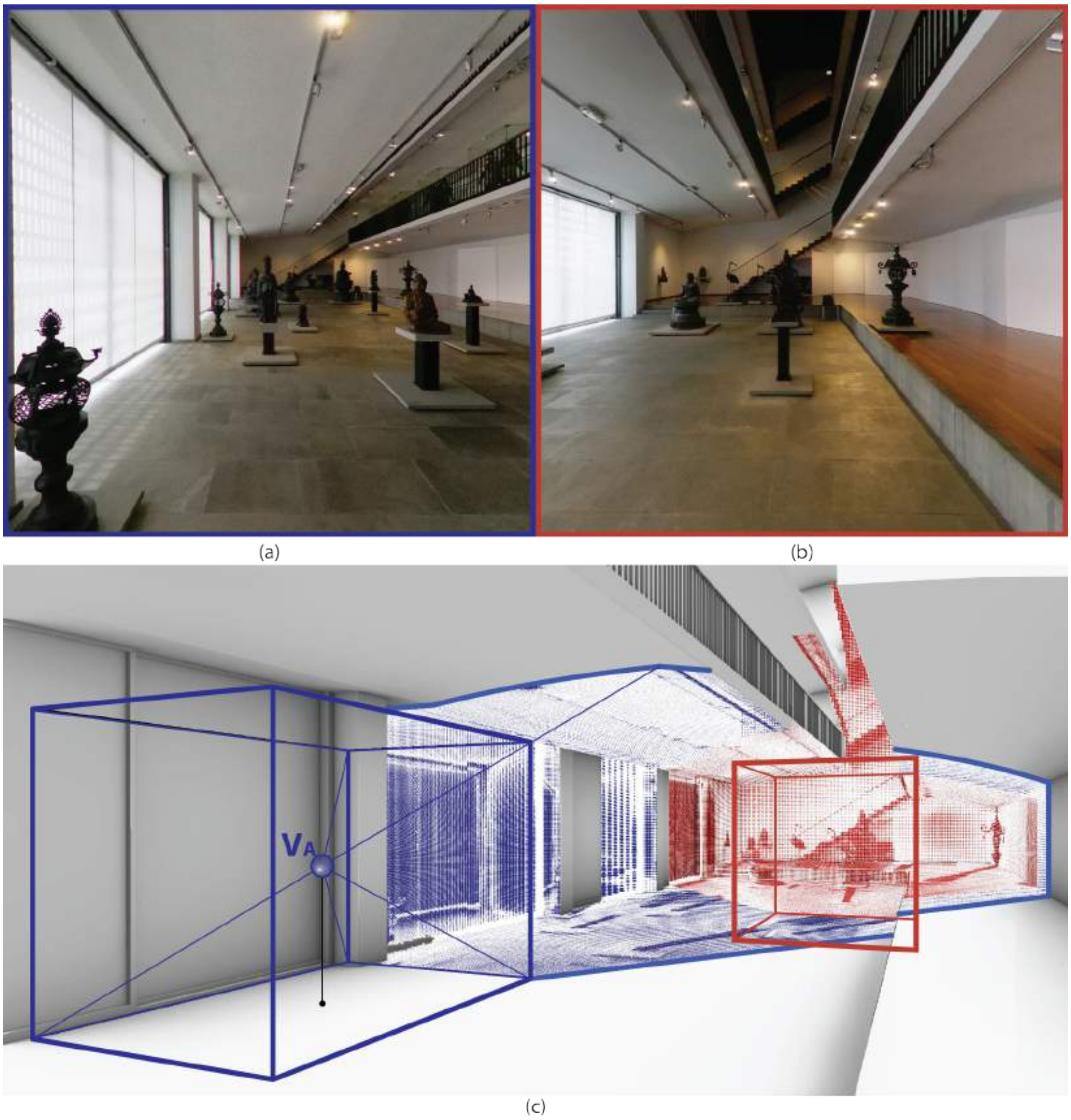

Figure 8: Comparison between the two observation points (see the plan in the next figure). (a) Photo from viewpoint A. (b) Photo from viewpoint B; (c) Perspective cross-section with the overlap of surfaces involved in projection.

The areas involved in the projection from point *B* (fig. 8c) reveal several elements that contribute to a broader understanding of space. The window surfaces are reduced, and it is possible to observe what happens at the west corner of the building, from which the staircase leading to level 2 starts. The surface of the north-west wall of the building, the main subject of the view, is clearly visible, and reveals a wider and more complex vertical development than that offered previously, which displays the system of alternating galleries and their connection via stairs. From this point, one gets a clarifying view of the ground floor and the museum, even if it is not entirely sufficient to understand the totality of the building and its complexity.

A further reflection can involve the theme of the distorted image and the importance of the viewpoint for the reading of space, an explicit aspect if we compare the frontal visions (fig. 7c, 7d) with the accidental ones (fig. 8c): the first case corresponds to the correct viewpoint that determines a reconstruction of the recognisable image and completely coinciding with the original photo, while in the second case, the viewpoint changes returning a distorted image not entirely adequate to recognise the surfaces involved.

In general, the process carried out through the projection generated a mapping of the surfaces that allowed us to perform qualitative analysis of the space, concerning the comparison of the crucial nodes where the viewer is called to make choices. In the case considered, the intention was to investigate the spatial elements most involved and that affect the interpretation and understanding of architecture, emphasising the importance of the consequentiality of the shooting points and the dynamism of the entire system.

3.7 2D vertical isovist and graph studies

The *PanoProj* tool is useful to create a virtual tour capable of revealing what is observed from another viewpoint as well as the user position. Although different panoramas were shot along the whole path, it was observed that it might be convenient in this phase to integrate them with other kinds of analysis to explain the spatial meaning of the architecture examined as a whole. Vertical 2D isovists, which are useful to discover different aspect of space (Krukar et al. 2020), were used. We found interesting to compare two different vertical 2D isovists taken at the first level of the museum. Indeed, using the same viewpoints applied in the previous analysis, very different views of the space can be observed.

In the isovist generated by point A, at the start of the path, observers could only know that they had entered a space articulated in different levels to which they could access through staircases (fig. 9b). At this stage, they could only see the ceiling of level 6 and of the levels protruding from the north-east side of the volume (2 and 5), as the others are partially or totally hidden.

Moving onto viewpoint B, on the contrary, they would have the whole view of the different levels and a significant perception of the staircases positioned on the shorter sides to north-west and south-east (fig. 9c). Moreover, the view is also suggestive because of the differences of the lower part of the floor-slab geometries and materials.

As for the staircases, it could easily be observed that they were entirely visible only on the north-west side, because on the opposite one the last staircase is only partially perceptible, since it is developed in the depth of levels 4 and 5 which it connects.

At this stage, visitors would be able to understand the spatial articulation because the vertical connections tell them there is no direct link between levels that are in sequence for their altitude. Despite this information, it was observed that users normally understand that there are no such connections only along the exploration of the different levels of the exhibition.

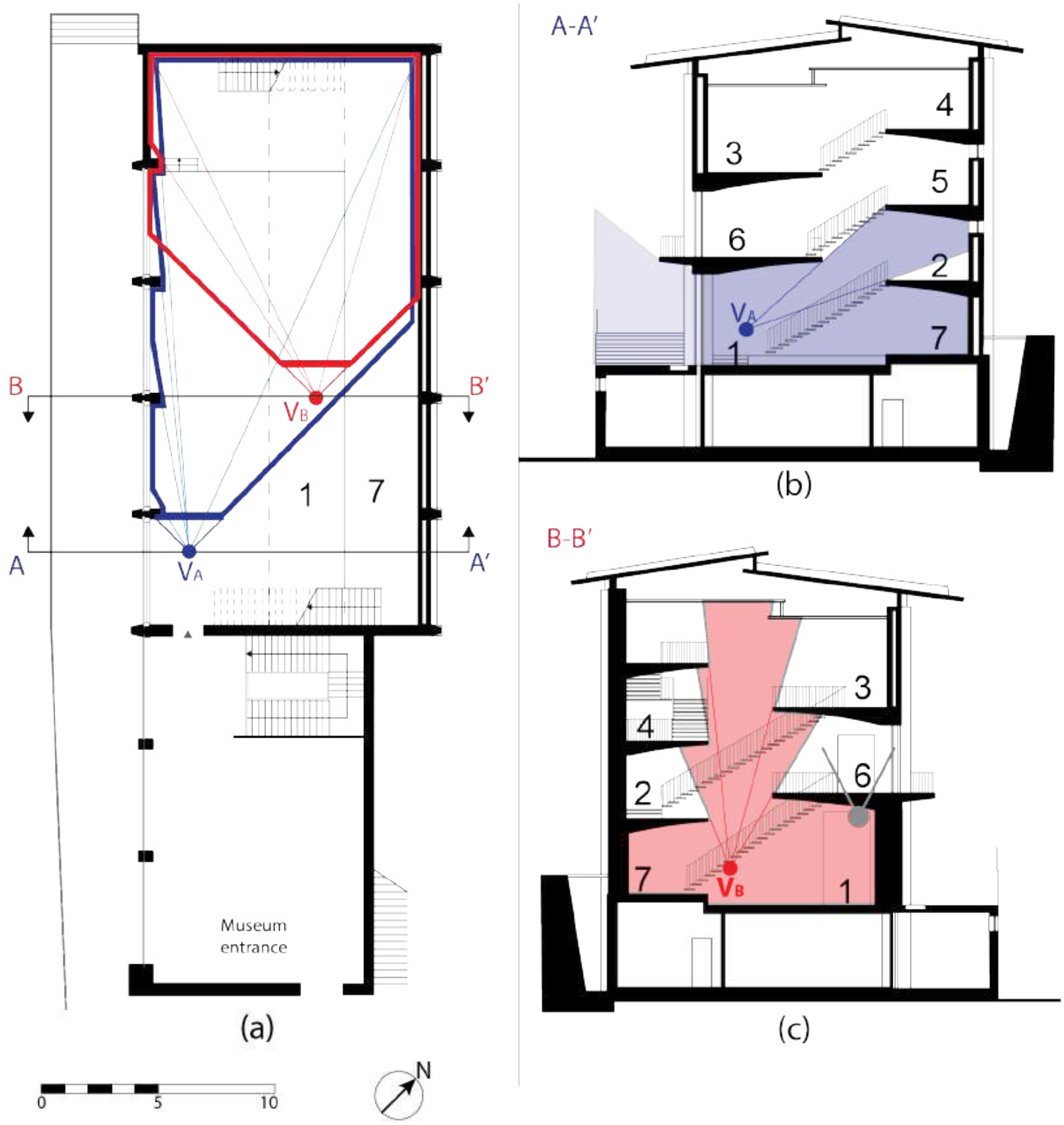

Figure 9: Vertical 2D Isovists from points A and B. (a) Plan that highlights the different spatial elements involved in the two observation points facing the north-west wall; (b) Section in point A towards south-east side; (c) Section in point B towards north-west side.

We synthesized the distribution in a graph scheme (fig. 10a) and this was integrated with a 3D structure which can help to explain the not intuitive cyclic distribution of levels: a red path that rises from level 1 to 2 to 3 and 4 (fig. 10b, in red) can be distinguished and a descending one from 4, to 5, to 6 and 7 (in blue), since 7 and 1 - connected by a green line - are almost at the same altitude. The cylindric shape was used as a reference to St. Patrick's Well, built by Antonio da Sangallo il Giovane (Orvieto, Italy, 1527-1537) which shows a similar space riddle composed of two parallel helical paths.

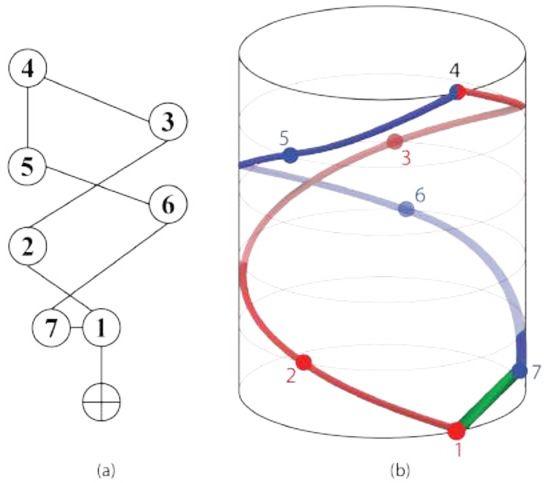

Figure 10: The distribution of the whole Chiossone Museum; (a) Graph; (b) Schematic 3D illustration.

4 RESULTS

In this study, we conceived the *PanoProj* tool as a combination of a 3D virtual model and multiple panorama photos taken inside of an architectural space. The integration of these two different kinds of representation has been achieved thanks to the use of the cubic projection of the panoramic photography which provides six different one-point perspectives having in common the same viewpoint and differentiated by the orientation of the gaze, which together offers, in fact, a global vision of the space.

This configuration allowed us to verify how panoramic photography could be a useful way to obtain a 3D isovist, and which offers the possibility of making perceptual considerations through dynamic simulation in the virtual parametric modelling environment.

The viewpoint and its combined cube of the panoramic projection move accordingly with a parametric logic capable of being adapted to the investigation needed (*PanoProj*, phase 1). The discrete projection of the photo image (*PanoProj*, phase 2) approximates the actual appearances, and the 3D model helps to feed a realistic picture of the space through its boundary surfaces.

We chose as a case study, the Chiossone Museum of Oriental Art (Genoa, Italy, built between 1948 and 1971), because of its apparent simplicity that is contradicted by the spatial distribution: with its cantilevered and staggered levels and its cyclic path, visitors gradually understand its organisation while they are moving and exploring it.

Comparing two subsequent views taken in characteristic points of level 1, their main features and the transformation of the visual perception during the navigation of the space could be observed. *PanoProj* was applied in a flexible way, and we are well aware that it could give some information that must be integrated with other studies. For this reason, we combined the observation conducted with *PanoProj* with other analyses conducted with a graph and 2D vertical isovist.

In this way, an abstract scheme of distribution of different levels was used to explain the complex cyclic path realised in the Chiossone Museum, that could also be obtained using many different viewpoints.

5 CONCLUSIONS

In this paper, it has been shown how useful it can be to study the features and transformations of users' views during the exploration of space, maintaining, at least in part, the dynamism and realism of natural perception. With this in mind, a tool was conceived capable of materialising observers' views inserting the images of the cubic projection within the three-dimensional model: *PanoProj*.

PanoProj can be useful to study space features, but we are well aware that there is no tool or representation method able to give a satisfactory investigation about spatial perception alone, so, the observation should be integrated with other analyses.

Although the angle of vision given by one face of the cube (90 degrees vertical and horizontal) was adopted, it cannot be affirmed that it is always sufficient, but it can easily be extended in *PanoProj* involving, at least in part, other contiguous faces of the cube.

Although we were focused on the use of this tool only for qualitative analysis, *PanoProj* can be extended to the study of spatial features through the computation potential of the digital parametric model. Indeed, in this research it was sufficient to define the space with its characterised boundary surfaces, but we even individuated polyhedra during their transformation, which can be measured through their multiple geometric properties.

ACKNOWLEDGEMENTS

Although the paper was conceived in team by the authors, Ilenio Celoria wrote paragraphs 3.2. Panoramic photography, Alessandro Meloni wrote paragraphs 3.1. The peculiar case of Chiossone Museum, and 3.5 PanoProj, Phase 2: the projection on the model surfaces, and Cristina Càndito wrote the rest of the article. Images are conceived and realised by the authors. We would like to thank Aurora Canepari, director of the Chiossone Museum.

The present research was carried out in part with the help of P.R.A. 2020 funding (Athenaeum Research Project), entitled “Architectural illustration between geometry and perception”; scientific coordinator: C. Càndito.

REFERENCES

Benedikt, M. (1979) ‘To Take Hold of Space: Isovists and Isovist Fields’, *Environment and Planning B: Planning and Design*, 6(1), pp. 47-65. doi: 10.1068/b060047.

Benedikt, M., & McElhinney, S. (2019). Isovists and the Metrics of Architectural Space. *BLACK BOX: Articulating Architecture's Core in the Post-Digital Era.* Conference ACSA 2019. Pittsburgh, March 27-30, 2019

Bordini, S. (1984). *Storia del panorama. La visione totale nella pittura del XIX secolo*, Roma: Officina edizioni.

Bordini, S. (2017). *Il viaggio dello sguardo. Modelli iconografici e simbolici nella pittura dei Panorami, Il mondo rappresentato. Metafora del viaggio e viaggi reali*, Roma: Editoriale Artemide.

Bucci M., Rossari A. (2005). *I musei e gli allestimenti di Franco Albini. Documenti di architettura*, Milano: Electa.

Calvano, M. (2018) ‘Spherical panoramas for architectural surveying. From image to 3D model’, *Building Information Modeling, Data & Semantics*, 3, pp. 6-15.

Càndito, C., Castro, A., Meloni, A. (2020) ‘Representation, Perception and Wayfinding. University Architecture of the Past and Present’, *CONNECTING. Drawing for weaving relationships. Proceedings of the 42° International Meeting of UID,* pp. 1820-1841, Milano: Franco Angeli.

Conroy Dalton, R., Holscher, C. Spiers, H. (2015 B) ‘Navigating Complex Buildings: Cognition, Neuroscience and Architectural Design’. *Studying Visual and Spatial Reasoning for Design Creativity*, pp. 3-22. doi: 10.1007/978-94-017-9297-4_1

Conroy, R. (2001). *‘Spatial Navigation in Immersive Virtual Environments’*. PhD thesis, The faculty of the built environment, London University College.

Cullen, G. (1961). *Townscape,* London: Architectural Press

Dalton, N., Conroy Dalton, R., Marshall, P., Peverett, I., Clinch, S. (2015) ‘Three dimensional Isovists for the Study of Public Displays’, *10th Space Syntax Symposium,* London: Space Syntax Laboratory, The Bartlett School of Architecture, University College London.

Fisher-Gewirtzman, D. (2016) ‘Integrating weighted views to quantitative 3D visibility analysis as a predictive tool for perception of space’, *Environment and Planning B: Planning and Design*, 45(2), pp. 345-366. doi:10.1177/0265813516676486.

Gibson, J.J. (1947) ‘Motion picture testing and research’, *A.A.F. Aviation Psychology Program. Research Reports (7),* Washington D.C.: U.S. Government, Printing Office.

Gökmen, S. (2019). Grasshopper Tutorial: Image Based Mapping. *Parametric Online.* https://www.youtube.com/watch?v=PGbYo4FTkOQ (retrieved 20 July 2021)

Gross, E. (2019). Project (move and scale) curves in perspective view on a surface. Perspective Projection. *Rhinoceros Forum.* https://discourse.mcneel.com/t/project-move-and-scale-curves-in-perspective-view-on-a-surface/77586/2 (retrieved 8 June 2021)

Hillier, B., Hanson, J. (1984). *The Social Logic of Space*, Cambridge: University Press.

Jabi, W. (2001) 'Visualizing and investigating architectural space using spherical panoramic imaging', *Technology conference 2000: Emerging technologies and design: the intersection of design and technology,* Washington, DC: Association of Collegiate Schools.

Jiang, B., Claramunt, C. (2002) 'Integration of space syntax into GIS: New perspectives for urban morphology', *Transactions in GIS*, 6(3), pp. 295-309. doi: 10.1111/1467-9671.00112

Krukar, J., Manivannan, C., Bhatt, M., Schultz C. (2020) 'Embodied 3D isovists: A method to model the visual perception of space', *Environment and Planning B: Urban Analytics and City Science*, 48(8), pp. 2307-2325. doi: 10.1177/2399808320974533.

Lanteri Minet T., (2017). *Mario Labò. La produzione architettonica e il ruolo di promotore culturale nella prima metà del XX sec*. PhD thesis, The faculty of Architecture, Bologna University of Study.

Lonergan, C., Hedley, N. (2015) 'Unpacking isovists: A framework for 3D spatial visibility analysis', *Cartography and Geographic Information Science*, 43(2), pp. 87-102. doi: 10.1080/15230406.2015.1065761.

Lu, Y., Gou, Z., Ye, Y., Sheng, Q. (2019) 'Three-dimensional visibility graph analysis and its application', *Environment and Planning B: Urban Analytics and City Science*, 46(5), pp. 948-962. doi: 10.1177/2399808317739893.

Luhmann, T. (2004) 'A historical review on panorama photogrammetry', *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 35(5), pp. 1-8. doi: 10.1.1.101.2588.

Lynch, K. (1960). *The Image of the City*, Cambridge: MIT Press.

Lynch, K. (1976). *Managing the Sense of Regions*, Cambridge: MIT Press.

Majewski, R. (2019). Project (move and scale) curves in perspective view on a surface. Projection. *Rhinoceros Forum.* https://discourse.mcneel.com/t/project-move-and-scale-curves-in-perspective-view-on-a-surface/77586/2 (retrieved 8 June 2021)

Nagy, D. (2017). 'View analysis with isovist', *Generative Medium (blog).* Catalog of lecture notes, technical tutorials, and other content from an advanced computational design course at Columbia University's Graduate School of Architecture, Planning, and Preservation (GSAPP).

Olivero, L. F., Rossi, A., Barba, S. (2019) 'A Codification of the Cubic Projection to Generate Immersive Models', *Diségno*, 1, pp. 53-63. doi: 10.26375/disegno.4.2019.07.

Olthof, O. (2021). Image Sampler – Grasshopper Tutorial. *Owen 02.* https://www.youtube.com/watch?v=iAm8XnROuTY&t=274s (retrieved 15 July 2021)

Ostwald, M. J., Dawes, M. J. (2018) *The Mathematics of the Modernist Villa. Architectural Analysis Using Space Syntax and Isovists*, Cham: Springer International Publishing. doi: 10.1007/978-3-319-71647-3.

Penn, A., Conroy, R., Dalton, N., Dekker, L., Mottram, C., Turner, A. (1997). Intelligent architecture new tools for the three-dimensional analysis of space and built form, *1st International Space Syntax Symposium,* London: University College London.

Sandnes, F. E., Huang, Y-P. (2016) 'Translating the viewing position in single equirectangular panoramic images', *IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, pp. 389-394. doi: 0.1109/SMC.2016.7844272.

Savino, P. J., Danesh-Meyer, H. V. (2012). *Color Atlas and Synopsis of Clinical Ophthalmology. Wills Eye Institute. Neuro-Ophthalmology.* Philadelphia: Lippincott Williams & Wilkins.

Spesso, M., Porcile G. L. (2019). *Da Zevi a Labò, Albini e Marcenaro: Musei a Genova 1948-1962: intersezioni tra razionalismo e organicismo*. Genova: Genova University Press.

Steuer, J. (1992). ‘Defining virtual reality: Dimensions determining telepresence’, *Journal of Communication*, (42), 73-93. doi: 10.1111/j.1460-2466.1992.tb00812.x.

Tedeschi, A. (2010). *Architettura Parametrica. Introduzione a Grasshopper.* Potenza: Le Penseur.

Turner, A., Doxa, M., O'Sullivan, D., Penn, A. (2001) ‘From isovists to visibility graphs: a methodology for the analysis of architectural space’, *Environment and Planning B: Planning and Design,* 28(1), pp. 103-121. doi: 10.1068/b2684.

Ünlü, A., Edgü, E., Şalgamcioglu, M. E., Çanakçioglu G., Yilmaz E.A. (2019) ‘Isometric measurands on perceived spaciousness: exploring volumetric isovist’, *12th Space Syntax Symposium*, 132, pp. 1-20.

Varoudis, T., Psarra, S. (2014) ‘Beyond two dimensions: architecture through three-dimensional visibility graph analysis’, *The Journal of Space Syntax*, 5(1), pp. 91-108.

Yang, P.P.-J., Putra, S.Y., Li, W. (2007) ‘Viewsphere: A GIS-Based 3D Visibility Analysis for Urban Design Evaluation’, *Environment and Planning B: Planning and Design*, *34*(6), pp. 971-992. doi: 10.1068/b32142.