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# What are you looking at?

## Technique for analysing visual connectivity between different spaces

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## ABSTRACT

This paper presents a new technique for analysing visual connectivity in discontinuous areas and between different areas. Spatial continuity is considered in VGA (Turner and Penn, 1999) since all nodes in the system represent the possibility of view and movement. Although, in several buildings, the user is able to see spaces that are not always physically accessible. Visual continuity, especially in domestic spaces, can impact on privacy or social segregation such as the visibility of a private area from a social area. A new technique should consider the separation of visual and physical connectivity. For this to happen, not just continuous space must be analysed, but also connectivity between nodes inside different discontinuous areas. Additionally, this new technique must be able to differentiate two kinds of spaces, assuming them separated by physical or conceptual barriers. The first space, should be the possible points of view of a user represented, as usual, with a group of nodes. The second space, should be the regions that could or could not be seen by this user and will be named here as target points. A tool, developed in Python, identify different kinds of nodes, test visual connection, and quantify the connectivity. This tool generates a chromatic representation of the visual connections considering this difference. The results allow the identification of areas seen from specified spaces. This new variety of VGA is called Target Mode. The intention of this paper is not emphasizing the limitations of VGA current implementation, but rather contribute for the technique evolution.

## KEYWORDS

Visual graph analysis, Visual connectivity, Spatial continuity, Points of view, Target points

## 1 INTRODUCTION

This paper presents a new technique for analysing visual connectivity in discontinuous areas and between different areas. The development of this proposal followed larger research about domestic space from modernist architecture in Brazil (Santana, 2017; Santana, 2019) to contemporary houses in Latin America (in development). Techniques for analysing topologic spatial distances and movement possibility can answer several questions regarding spatial configurations of the domestic spaces, including function, user separation and encounter.
The architectural experience in the domestic space is complete for the inhabitant, free to move inside, but not for visitors of domestic workers, to whom are imposed some limits. The user location may deny visibility even inside a continuous space. Visual protection is directly related to the permission given to the visitor to go deep into the depth of the spatial structure. Since the visual apprehension is dynamic through movement, the space is uncovered each step of the way. This permission, part of the social codes, maintain privacy in certain situations without doors. Certain spaces, deeper in the structure can be accessed by visitors with more intimacy with the inhabitant. (Santana, 2019).

Hanson (1998) constantly associates permeability to visibility on architectural experience, assuming they can be compared as a relation between spaces. The first one needs adjacency to exists and is completely experienced by movement. The second one is immediate, 'unmediated by rules', therefore apprehend the space without movement and in a passive manner. In several cases, visibility connection, as opposed to permeability connection, occur between non-adjacent places or on a sequence of spaces at the same time. This means that spaces can be adjacent but visibility may not exist, by contrast, spaces can be multiple and sequential, and visibility exist due to axiality.

The inclusion of the concept of time in art resulted in change in the architectonic space usage. Time as a new dimension was introduced in the architectural experience through movement, in a dynamic spatial perception (Anderson, 1984). This resulted in certain changes to create visually rich spaces and new possibilities of movement to allow full perception of the building. This attempt to make space more fluid to movement was included in several ways in the building, such as different ways to access the building and the reduction of physical barriers. For Peterson (2018), the modern space, has in its essence an 'universal continuous space'. The modernist free plan would not allow interruptions of this space that acts as the background to the architectonic object. This continuous space would be formless, infinite, universal and singular. For Montaner (2014), this inclusion of time in the experience, would need the dematerialization of space to be complete, but it was limited due to requirements of privacy, control and security. Transparency, helped by technology advancements, was introduced as a barrier to movement – sometimes temporary – but not a barrier to sight.

Both Frampton (2008) and Curtis (2008), describe the Brazilian Modern Architecture through buildings designed by well know architects, identifying free forms on the built volume, spatial interpenetration and relations with the natural landscape. Clearly, this set of features are not enough to explain the complexity of Brazilian architecture. Bruand (1981), in other hand, goes deeper into explaining certain spatial characteristics in houses designed by Brazilian modernist architects that involves the site occupation, relation between interior and exterior, domestic functions organization and spatial continuity. Transparency and opacity acting as a duality for connecting social areas to exuberant gardens and hiding private and service areas.

This increased reduction of physical boundaries can be observed in Brazilian modernist houses (Santana, 2019), but also on contemporary houses in Latin America. This happened specially in the social sector: with the elimination of separated formal and informal spaces; with the reduction of walls and doors from this sector to others; and with the increase of openings between interior spaces and from them to the exterior. The geometric manipulation of the remaining walls and openings kept the other sectors protected from view.

Analysing visibility connection between domestic spaces can be done through the creation of isovists. This concept was introduced in architectural space by Benedikt (1979). The isovist can represent the visible area from a specified location in space. Since it's an abstraction over an architectural plan (or section) can be generated considering opaque and transparent elements. The occluded areas can be then related to privacy requirements or visual interpenetration among several regions. Isovists can be analysed qualitatively through observation of the image or quantitatively through geometrical measures of the generated isovists polygon (Benedikt, 1979; Psarra and McElhinney, 2014; Benedikt and McElhinney, 2019). Although a very important technique, the selection of places to generate the isovist from, can be time consuming, can involve subjective decision from the researcher, and, in a domestic space, may not represent the exact place the user will be, since they are free to move inside a space.

To solve this, isovists can be generated not only from a single point but from a complete convex space (Hanson, 1998; Amorim, 1999). The convex isovist can display, in a single image, the complete area possible to be seen from a specified convex space. This technique allows the researcher to uncover a bigger and more complex isovist polygon. Consequently, this polygon can mark visible regions that were not expected if separated points were used for developing several isovist images. For domestic spaces, a convex isovist generated from the social spaces can display visible areas – inside and outside – helping analyse privacy requirements and visual interpenetration with outside areas.

Visual Graphic Analysis (VGA), another important technique, was proposed by Turner and Penn (1999) based on the use of isovists on architecture developed by Benedikt (1979). It can determine the most – or the least – visible points inside a specified area. It can display fluidity of space – complete building or specified areas – and can relate more clearly with movement. Since it is a coloured representation of calculated values, it displays a gradient variation comparing every analysed node (Turner and Penn, 1999; Turner et al, 2001; Koutsolampros et al, 2019). However, VGA considers the area disregarding function and conceptual separations. It is not possible, for instance, to identify places on private sector visible from the social sector, or places inside the houses that allowed visibility to the outside. In other words, VGA can compare points to all other in a system, but can't separate areas for a relational comparison among these areas. Visibility is a key element in space organization and not only associated with the possibility of movement. This limitation guided the development of a tool that could represent what was needed in this research.

## 2 LET'S SEE WHAT WE HAVE HERE

In the current implementation of VGA, the space of interest is subdivided in a group of nodes. After the nodes are created, each direct connection between two nodes in the system is counted (Figure 1.1). Barriers between the nodes are considered, implying occluded areas and generating different connectivity values throughout the collection of nodes (Figure 1.2). After the connectivity values are applied to each node, a chromatic representation is generated to facilitate its observation (Figure 1.3). The variation of visual connectivity indicates the most visible places on the system, in other words, the nodes that have more connections to other nodes.

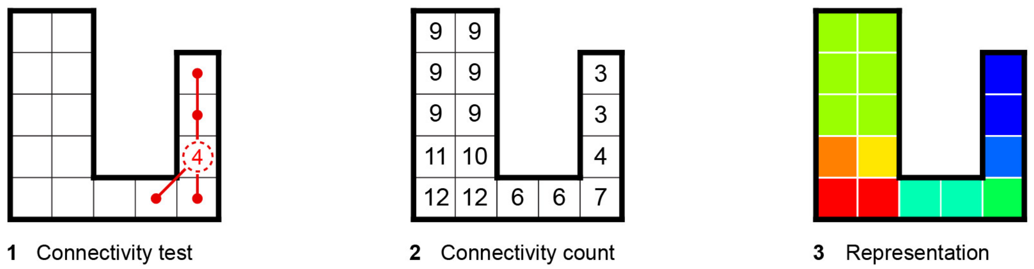


Figure 1: Current VGA steps

Spatial continuity is considered in VGA since all nodes in the system represent the possibility of view and movement. Continuity is an important characteristic of modernist and contemporary houses specially associated with new ways of delimiting spaces. However, these buildings present a diversity of physical and visual connectivity relations and these relations cannot be analysed completely with the existing set of tools.

In several buildings, the user is able to see spaces that are not physically accessible by direct axial movement between spaces. The visual continuity can impact on privacy or social segregation such as the visibility of a bedroom – or bathroom – from a social area. User intentional seclusion is related to social codes, and can be presented in justified graphs by topologic distance. Although, it can be affected by an unexpected glimpse of an unauthorized user.

Conceptually divided spaces such as inside and outside, or social and private sectors, are not always separated the same way. Interior and exterior spaces can be physically separated but visually connected by transparent panels. This relation was emphasized in the modern architecture and marked by technological advancements, especially in social spaces. However, visual continuity is not desired in every domestic situation. On the contrary, private spaces must be visually protected from visitors even if it’s given a possibility to see outside.

As a side note, VGA is also constantly used considering the connectivity information to generate Integration values of each node. This allows a clearer relation between visual continuity and movement possibility. Considering that the main intention of developing a new technique was to identify visibility even without movement, Integration calculations were not included in this paper.

## 2.1 Aiming at the target

A new technique should consider, at first, the separation of physical connectivity – movement possibility – and visual connectivity. For this to happen, not just continuous space must be analysed. Continuous spaces are being considered in this paper as the complete area that a user can move without barriers, but inside some kind of boundary, like the interior of a house with all doors open. Discontinuous spaces are being considered as physically separated areas without direct movement among them, like a bedroom visible through its windows from the living room and not directly accessible. For this new technique work, it’s important to examine connectivity between nodes inside different discontinuous areas, or nodes inside a continuous area but without a possible direct movement between them (Figure 2.1). This is not possible to achieve with the current tools available.

Additionally, this new technique must be able to differentiate two kinds of spaces, assuming them separated by physical or conceptual barriers. Physical barriers are being considered in this paper as walls and closed doors. Conceptual barriers are being considered as the separation of spaces only by its function or meaning and not by physical barriers, such as: the separation of living and dining area; the separation of sectors, such as private and social; or the separation of inside and outside, even with all doors and windows open.

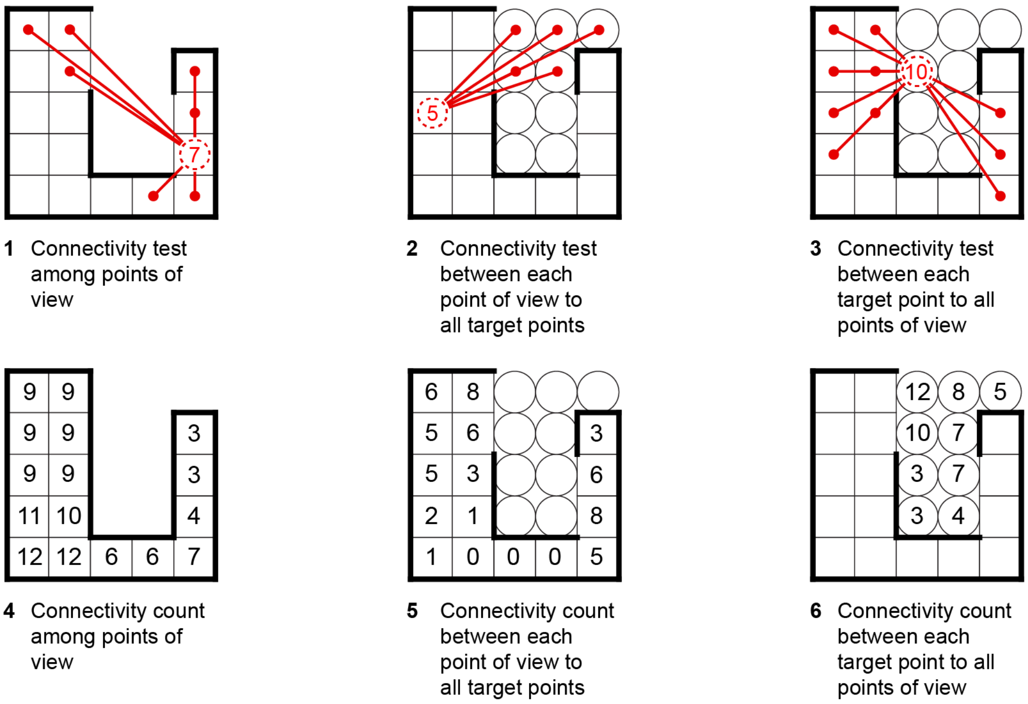


Figure 2: Proposal for new possibilities of visual connectivity

The first kind of space, should be the possible user points of view represented as a group of nodes, as usual. Let's assume, for instance, the interior space of a house. The second kind of space, should be the regions that could or could not be seen by this user and will be named from now on as target point. It could represent, for instance, the exterior space of the house (Figure 2.2 and Figure 2.3). This new approach to VGA analysis, will be called Target Mode. This technique is very similar to the construction of a convex isovist.

A computational tool for this kind of analysis should test the intersection between two lines segments: the first segment, composed of one point of view and one target point; and the second, representing a barrier to the sight. In a delimited space, if there is an intersection, it means that a visual connection between the point of view and the target point does not exist. If there is no intersection, the connection between the point of view and the target point is counted. In this mode, the tool would not count connection between nodes of the same type (between two points of view, for instance), meaning the possibility of view between different kinds of spaces.

## 2.2 Seeing with new eyes

A new command line tool was developed using Python to test the Target Mode Analysis and applied to the research of the houses. The decision of creating a software without graphical user interface was made to avoid long development time and to improve code quality for the identification, counting and representation.

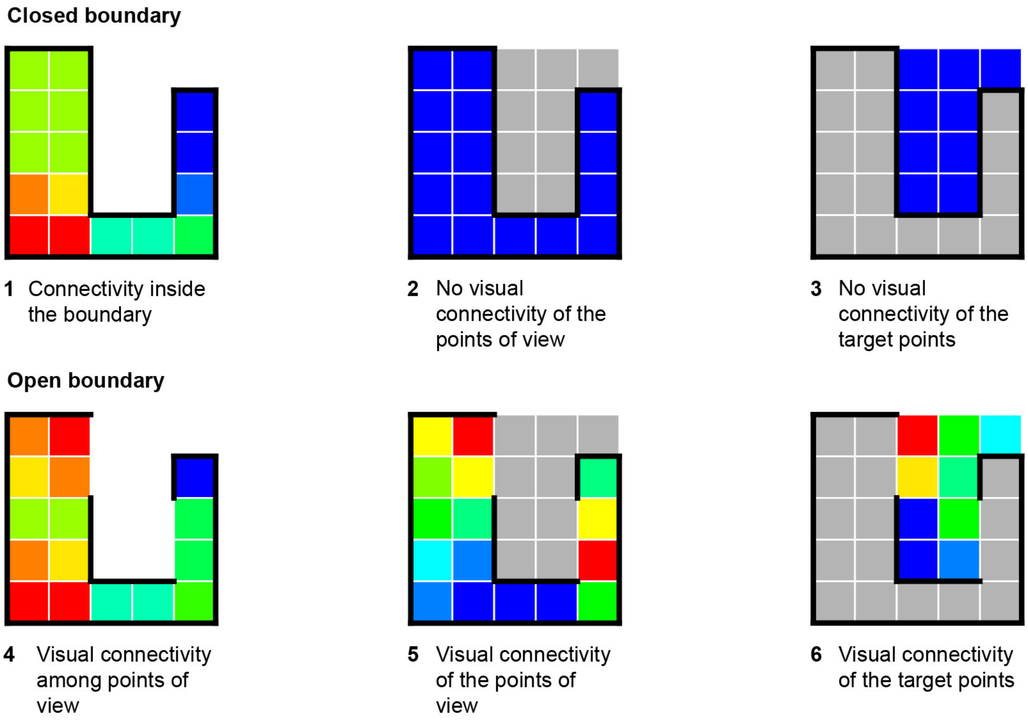


Figure 3: Sample of generated images

The developed tool receives a file with the representation of the building plan containing three possible objects: walls, points of view and target points. During the process of development, it was chosen SVG files since they are free, open, vectorial graphic files that can be produced using several image applications. This file type can be read with internet browsers, such as Chrome or Safari, and graphic applications, such as Illustrator and Inkscape. Because it's vectorial, the image can be enlarged or reduced in size not affecting the resolution. Since it can store textual information, in web browsers, values can be displayed on clicks. The tool makes the connectivity tests and returns a new SVG file. To have clear results of the analysis, this new SVG file have three images for comparisons (Figure 3).

The first image is a chromatic representation of connections between the points of view, similar to the regular VGA analysis (Figure 3.1). However, the tool can consider possible visibility between separated areas, not directly accessed by movement, such as windows (Figure 3.2). The difference between visibility inside a continuous space boundary and outside this boundary is possible due to the differentiation between wall objects (lines) and visibility points (nodes). In the tool, analysing these different possibilities is done by using a completely enclosed boundary line or not, depending on the read file. This can uncover hidden spatial relations, as the visibility of a social space to a bathroom in the private sector.

When both points of view and target points are considered for analysis, different images must be generated, since there are two possible measures: visual connectivity in each point of view and visual connectivity on each target point. The second image generated is the representation of visual connectivity of the points of view accompanied with the target points as grey nodes

(Figure 3.2 and Figure 3.5). The third image is the representation of the visual connectivity of the target points, accompanied with the points of view as grey nodes (Figure 3.2 and Figure 3.5). The decision about keeping grey nodes is important for the chromatic representation since in each case there are nodes without values: when points of views are being analysed, target points have no values and vice versa.

Complementarily to the graphical representations, the tool was developed to create a histogram of connectivity value for the nodes. This helps to understand the distribution and quantity of nodes. The histogram shows the quantity of nodes for each band of colour and the maximum, minimum and median values of the distribution, examples will be displayed in the next section.

## 3 LOOKING BEYOND

The tool is already being used in research of contemporary houses in Latin America. In this paper it is presented the case of a house designed by Terra e Tuma, a Brazilian architectural office, located in São Paulo. This house was built in 2015 in a plot with 4,8 meters wide and 25 meters deep, and is arranged in two floors. The first floor is composed of garage, social spaces, service spaces and the main bedroom, and in the second floor a guest bedroom. It was designed for a woman living alone, but with the possibility to receive guests.

The house is organized by three volumes surrounding an open terrace. The first volume, connected to the garage, and the main access of the house, contains the social areas. The second volume, containing a bathroom, the kitchen and the laundry, acts as a corridor and connects the social areas to the third volume. This last volume contains both the bedrooms, each one in a different floor. The terrace is an important space in the house since it brings daylight in, allows outside activities such as entertainment and drying clothes, and is a place of contact with a garden (Figure 4).


Figure 4: House plans and photographs

During the analysis of the house, visibility of interior spaces should be considered since they are where the majority of daily life activities occur (Figure 5.1 and Figure 5.2). Furthermore, exterior spaces generally have large areas with fewer number of activities and can affect the distribution of the connectivity values of interior spaces. In this scenario, it's important that the analysis consider cross visibility between physically discontinuous areas in the house (Figure 5.2).

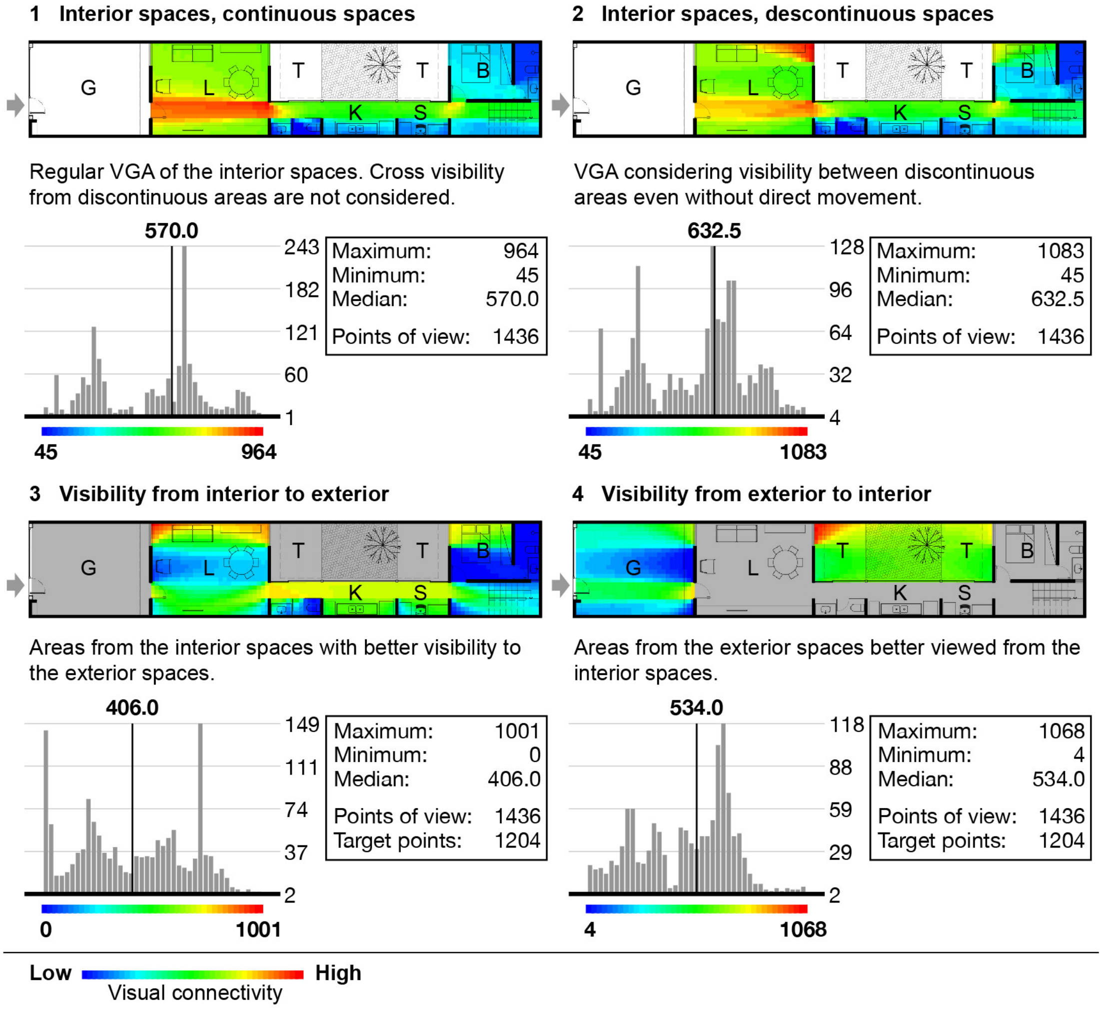


Figure 5: Visibility in interior spaces and between interior and exterior spaces

This analysis shows that from the social spaces, only areas close to the openings have high visibility to other spaces of the house, but not to the areas where the activities are made, such as the kitchen, laundry and bedrooms. Additionally, the bedroom can be viewed from the corridor, the terrace and the social space, affecting privacy. Service spaces (kitchen and laundry) are very protected.

Visual and physical continuity between interior and exterior is an important feature of modernist houses, extending space and creating smooth transitions. For Brazilian modern houses it became a common design decision, due to climate conditions and natural landscape, exterior space allowed outside activities with visual connection with the interior through transparency (Santana, 2019). In most cases, this visual continuity occurs in social spaces, but in some, when properly protected from visitors, also occur on the bedrooms. The visible areas of the exterior space (Figure 5.4) or the interior areas that allow visibility of the exteriors (Figure 5.3) increase comprehension about the spatial configuration and possible design intentions. The garden/outside space is an important configurational element in contemporary houses also. In retrospect, this was the main motive for the development of this new tool: find patterns of visibility between exterior and interior. For clarification, all VGA representation showed from now on were generated by the proposed tool.

In this house, there are two exterior spaces: the garage, that increases the distance of the house from the street; and a terrace, separating social space from the bedrooms. The analysis (Figure 5.4) shows that certain areas of the garage are visualized from the interior, with overall low visibility. The terrace has higher values of visibility, especially closer to the social space window. From inside (Figure 5.3), there are several areas with low or none visibility to exterior, such as parts of the bedroom. The central part of the social space has very low visibility values. The social space has low visual continuity to exterior but the main corridor and consequently the service spaces are visually and physically connected to the terrace. This visual protection allows the terrace being used as an extension of the laundry when needed, and creates a second separated entertainment area.

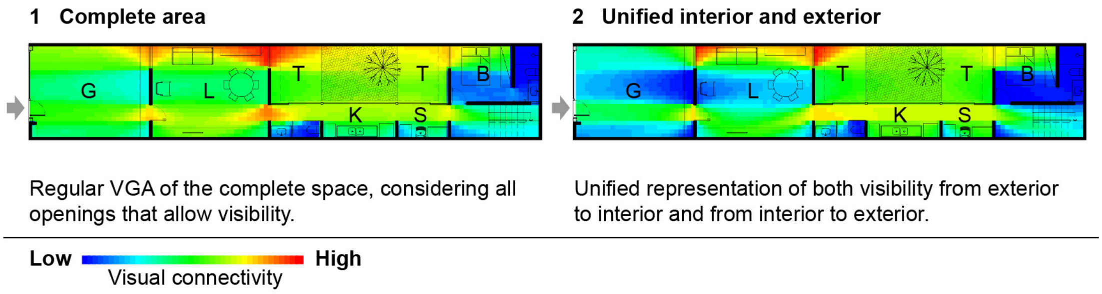


Figure 6: Comparison between current VGA implementation and the new possibility

The complete space analysis (Figure 6.1) shows higher values in the two main visibility axes: the main corridor that connects the three volumes; and the sequence of aligned windows from the social spaces to the bedroom, that allows only visual connection but not movement. The image also shows lower values in places that should be more visually protected due to privacy: the bedroom and both bathrooms.

Although the tool was created to represent two separated images for the Target Mode, a unified representation of interior and exterior spaces relation was created (Figure 6.2) for comparison with the regular VGA of the complete area of the house. Regular VGA is the current implementation of the technique. The comparison shows the difference in variation and distribution of visual connectivity among the nodes. The separation between points of view and target points can show relationships not possible – or not clear – with the regular VGA. Since, in the new technique, the connectivity count does not consider spaces of the same kind, the garage, the social space and the terrace have different values since they have low cross visibility, especially away from the windows and doors. In the current VGA implementation (Figure 6.1), since bigger areas have a great number of nodes, their values increase due to the number of connections.

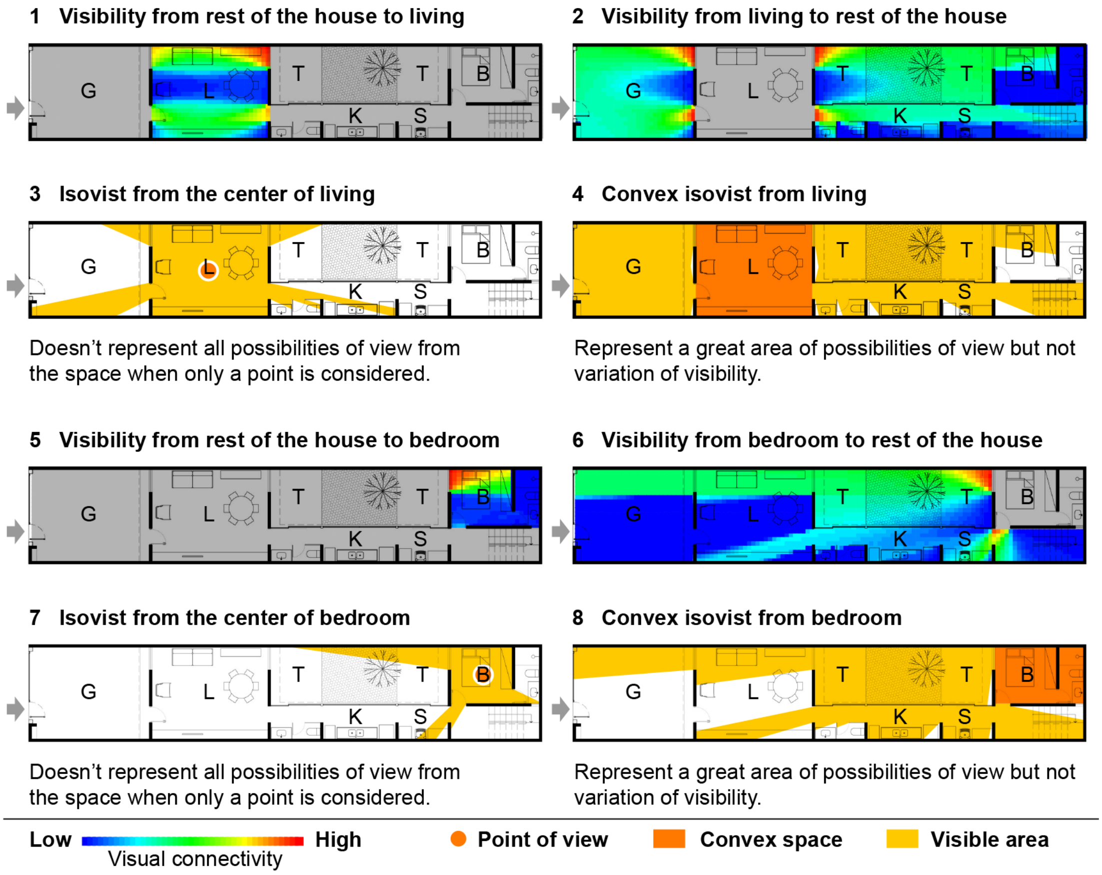


Figure 7: Visibility between a specified space and the rest of the house

As another possibility of analysis, visibility from a specified sector can uncover more clearly privacy requirements (Figure 7). From the social space, for instance, a large area of the house is visible, extending views to other spaces, but specific places are occluded – bedroom, laundry, kitchen and social bathroom – protecting the spaces from the view of the guests (Figure 7.2). From inside the social space (Figure 7.1), a large area has lower values of visibility (around dining area) to medium values (around the living area). From the bedroom (Figure 7.6), most part of the house has medium values and a large area has no visibility. Inside the bedroom (Figure 7.5), a large area has no visibility of the rest of the house with high values only very close to the windows. As inherited from modernist houses, the house is composed of an almost continuous space with doors only on bedrooms and bathrooms. The geometrical arrangement of walls and openings reinforces privacy for the inhabitant.

The comparison of this new tool representation to isovists is relevant for this research. Isovist, although a very good technique for analysis, shows a restricted area, displaying only the visible area from a point of view at a time (Figure 7.3 and Figure 7.7). They are not practical for spread areas in architectural plans, justifying the existence of the regular VGA. Convex isovists represent a larger area with all the possibilities of view from a certain convex space (Figure 7.4 and Figure 7.8). However, it's not possible do identify variations of visibility. Target Mode displays variations, indicating places with better (wider) or worse (narrower) views between spaces.

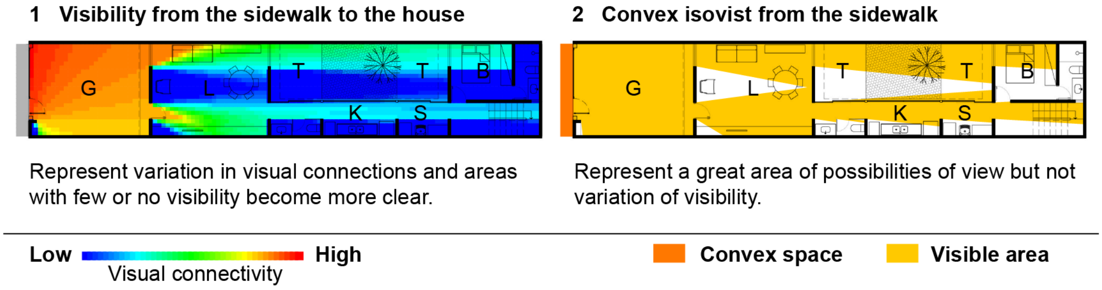


Figure 8: Visibility from the sidewalk

The house was designed in a way that the garage, with a metallic fence, would be an open space in front of the building. This contrasts with the neighbouring houses that touches all limits of the plot. The lack of a built volume so close to the sidewalk increases the visual field of the pedestrian and gives a sense of transparency. A small part of social activities can be seen from the sidewalk, and from the sofa there is visibility of what is happening on the street. The visibility from the sidewalk (Figure 8.1) shows that the transparency almost does not exist. There are high values of visibility on the garage but low values beyond the first wall, and no visibility at all in a great area of the house. In contrast, the convex isovist (Figure 8.2) displays a great visible area from the sidewalk, disregarding the variation of connectivity. In other words, it cannot display the most and least visible places inside the house.

The visibility analysis of several contemporary Latin American houses (research in development), using the proposed tool, enlighten the existence of social codes in the design decisions of space organization. It's possible to observe variable visibility generating a rich architectonic experience. Transparency and opacity are used to direct the user view to specified areas on the outside. Commonly, the is a greater area visible from social spaces, and great values of visibility in a certain region of the site. In contrast, there are certain areas that are not visible from the inside. Private and service areas have visibility to the outside, but regularly their views are directed away from the entrance.

The volumes organization inside the site boundaries may expose social areas to the entrance or completely away.

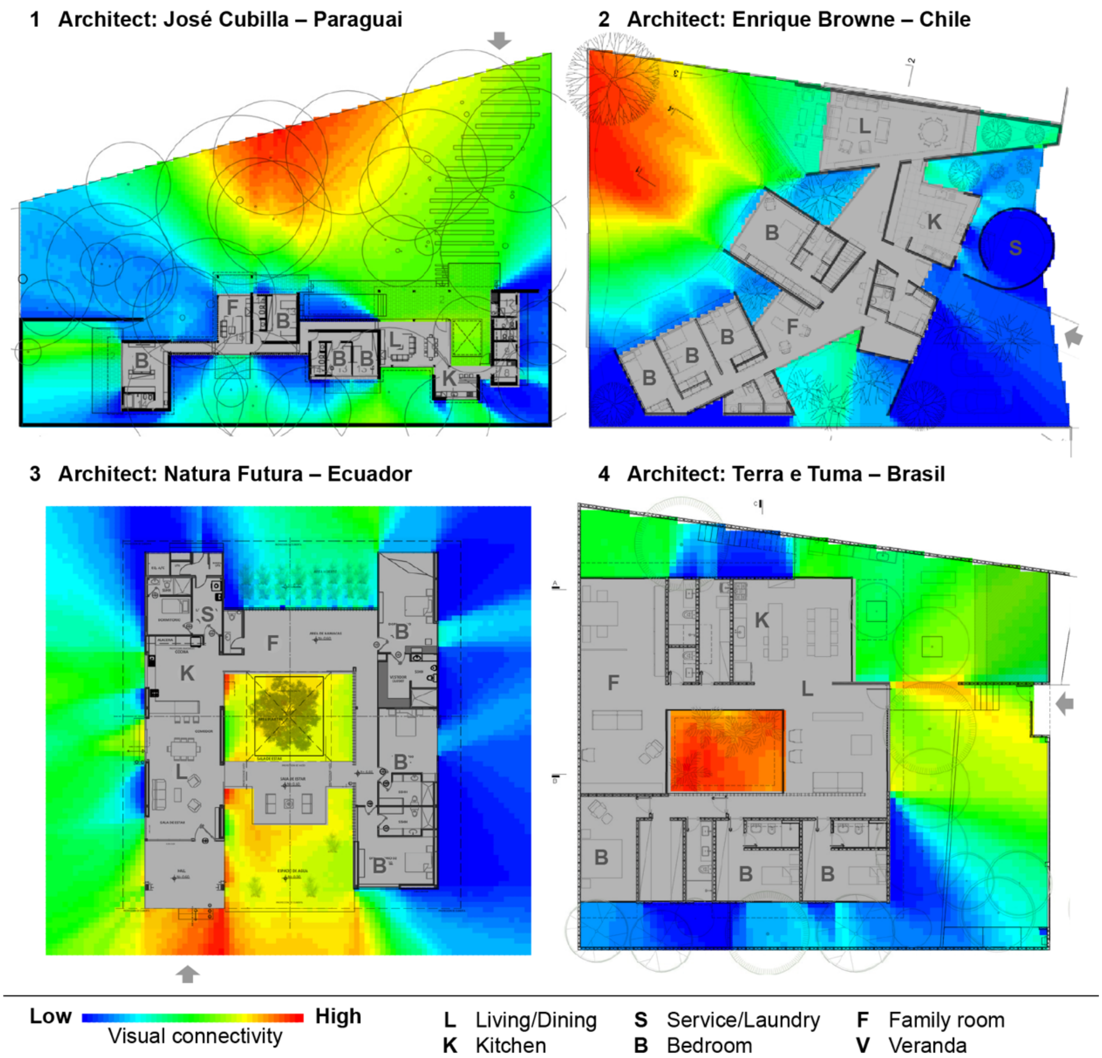


Figure 9: Areas of outside seen from the inside

Some houses (Figure 9.1 and Figure 9.3) have bigger distance from the main access of the site and are not on urban environment. This allows the social sector to be directed to this access and privacy not severely affected. Other houses (Figure 9.2 and Figure 9.4), in other hand, are located in consolidated urban environment. The house on Figure 9.4, although having social spaces directed to the access, have a boundary wall that blocks view from the street. The house on Figure 9.2, much more introverted, is viewed from the street, but doesn't allow visibility to the inside, directing the main views to the back of the site.

From the inside, visibility among different sectors is much more controlled, with greater values of visibility only near the physical connection. Following the modernist heritage, social spaces present a physical and visual continuity with reduced number of dividing walls. Other sectors are much more subdivided for functional and privacy requirements, with limiting walls and doors. Although adjacent to the social sector, the service sector is visually protected. Service sectors contain laundry, sometimes the domestic worker bedroom and kitchen. Kitchen, in several cases, are the same continuous space as living and dining; when separated, are well protected from view.

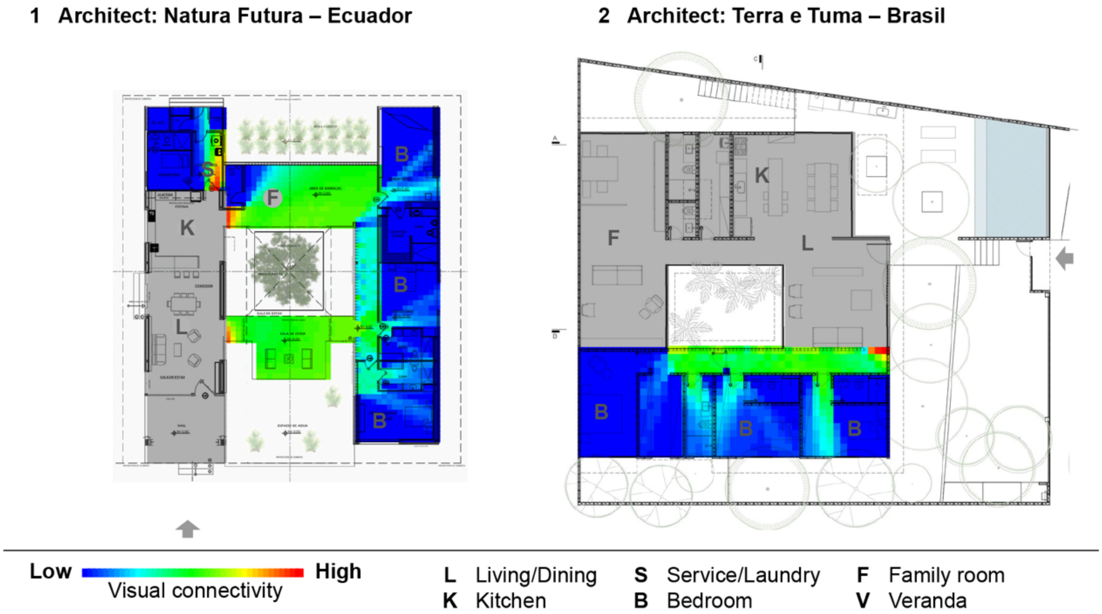


Figure 10: Areas of inside seen from the social sector

Visual protection between social and private is made, at first, by distancing. Topological distance through the creation of sequential spaces, and geometric distance by increasing length (Figure 10). Complementarily, geometric manipulation breaks the axiality of visibility. Associated with distancing, the use of gardens with different vegetation density or the use of hollowed elements create different transparency possibilities but hints of what is on the other side.

## 4 CONCLUSIONS

Visibility is part of the architectural experience and must be analysed and understood. It happens continuously and without the need of movement. Although, through movement, a change of possibilities gives the user new apprehension of the space. The control of visibility present accesses, pathways, activities of other users, but also, hides places that should not be viewed or accessed by some people. For the domestic space, privacy starts with the lack of visibility, even in small areas. Despite the existence of houses with "open plans", they are also arranged for hiding certain areas even when there are a reduced number of doors. This purposeful occlusion creates a scene for each kind of user, hiding untidy areas, domestic services or for personal privacy.

Controlled transparency in the houses creates framed landscapes, natural but designed. This interpenetration extends the visible boundaries of both inside and outside realms. For several houses, exterior activities are allowed: in one hand – more common – as an extension of living spaces; in other hand, as an extension of the service sector. Although transparency is present in almost all spaces, visibility to the exterior is severely controlled, and even spaces on the outside, in many cases, are not visible from the same sectors. Several houses have part of the garden only visible from the bedrooms, increasing privacy of these resting places, and allowing a landscape without movement of other users.

It is important to note that these houses present different levels of transparency: glass walls on different heights, different densities of vegetation over the openings and use of hollowed elements over the transparent panels. On the interior, breaking the axiality of the main circulation space blocks visibility of the private areas. As in modernist houses, a family living room increases depth in the spatial structure in several of the samples analysed. Complementarily, the commonly present internal garden and also a modernist heritage, is associated to the separation of social and private sector.

The intention of this paper is not emphasizing the limitations of VGA current implementation, but rather contribute for the technique evolution presenting new ways to calculate visibility. At the same time, it is important to differentiate visibility from movement possibility, especially in domestic spaces, regularly composed of small areas and short distances. The ability to graphically observe areas that can be seen – or those that present better visibility – is imperative for architectural analysis, especially when a pattern is displayed. This new tool is being used actively in research about contemporary Latin America houses.

## 4.1 Notes on development

New functionalities will be implemented. A second stage of development is including new ways to interact with the tools, making it easier, and practical, for other users, regarding creation of the input file and the layout of the output file. A third stage of the development will involve the creation of a graphical user interface. Also, as a parallel planning, three-dimensional visibility is also being considered, but in this case, as a plug in for existing applications, since visualization and navigation would not be part of the development.

The development of this tool encourages a new kind of visual analysis and open new possibilities in architectural studies. However, it's important to register in this paper two aspects of the development process: knowledge of existing techniques, procedures, and tools; and personal interest in improving them or creating new ones, even though no software development background. Comprehending and testing current techniques can improve research possibilities, but can make its limitations arise. These limitations are simply unexplored ways of approaching the research problems. It is uncommon for architecture schools to include teaching of programming languages in the formal academic knowledge. However, this kind of knowledge can stimulate the development of new tools for design and research.

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