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SPATIAL DESIGN ANALYSIS WITHIN AN ATRIUM

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Abstract. This research examines issues of identifying connectivity within vertical spaces in a courtyard / atrium building, via experimentation with space syntax visual feedback mechanisms. Methods of analysis involving three-dimensional multi-level spaces such as atria are not reliably informative using two-dimensional analysis tools, and new analysis tools are needed for understanding complexity and connectivity within the three-dimensional world. This paper presents a number of different ways of tackling the visibility-accessibility paradox, tested here on a world-class example of heritage architecture in Dubrovnik. Visual connectivity is contrasted with physical connectivity in the third dimension, requiring new means of analysis more complex than traditional isovist-based diagrams such or Visibility Graph Analysis (VGA). These new methods unveiled here include First Person Perspective Analysis (FPPA), Particle Generated Projection Analysis (PGPA), and Accumulated Projection Analysis (APA). Results of the new methods of analyses are presented as forms of visual feedback for rapid assessment of spaces and their connectivity, potentially crucial to the assessment of complex spatial forms and urban environments.

Keywords. Space syntax; atrium; spatial analysis; Dubrovnik.

1. Introduction

This paper explores an area of architectural science that intersects with spatial analysis in a number of fields. It identifies a gap in the research around spatial analysis of atrium design, and offers examples based on work carried out on a heritage atrium building: the Dubrovnik Dvor, or Rector's Palace, in the UNESCO World Heritage city of Dubrovnik. It examines which spatial analysis tools work within this atrium space and how can 3-D digital tools provide a more robust analysis than existing computer based technology such as Depthmap. It offers an insight into new computing analysis tools, moving on from the methods traditionally selected for space analysis in the field of space syntax.

2. Differences between physical and visual connectivity

This research examines the anomalous gap between physical and visual connectivity, a feature strongly apparent in building design involving atria. Connectivity refers to the amount of connections between locations, as well as the ease of achieving the connection. The type of connections may vary: visual connectivity refers to how much one place can be viewed from other places, while physical connectivity involves actual physical connections. A strong physical connectivity implies a high number of, or directness of the physical connections. By comparison, a weak physical connection may refer to an indirect route, perhaps through other intermediary spaces, or even other intermediary floor levels. While a number of ‘traditional’ methods such as townscape (Lynch, 1960), clearly identify a strong link between physical and visual connectivity, the use of a single ground plane renders it difficult to be applied in a multi-level environment such as an atrium.

2.1 THE VISUAL-PHYSICAL PARADOX

The key difference between analyzing a single-level building and a multi-level building, is therefore the variation between areas of physical and visual connectivity. When on a single level, the physical connection paths can co-exist on the same paths as the lines of visual connection, i.e. where you can see (visually connect), you can walk to (physically connect). This condition does not apply in an atrium: you can see (visually connect to) a lot more than you can possibly walk (physically connect) to. Therefore, a key concept for analysing atria is the ability to analyse and illustrate connectivity.

While space syntax has become an invaluable tool for some architects and city planners, who use it to analyse how possible variations to roads and buildings can help facilitate better urban environments to cities, its use has so far been confined primarily to 2 dimensional arrays – i.e. that of the X and Y dimensions only. ‘Traditional’ space syntax methodologies are therefore somewhat limited when it comes to analysis of more complex three-dimensional spaces, and key researchers agree that 3-D analysis is a relevant method to explore for more suitable methods. This research is part of that work.

3. The central atrium of the Dubrovnik Dvor

The atrium selected was part of a larger study, and is an exemplary instance of gothic architecture of fine quality, with a well-proportioned and welcoming central (open) courtyard atrium. In the Dvor the atrium acts as a focal point, an organising centre, a prime circulation route within the building, a social mixing pot, a public meeting venue and, at times, a theatre. It contains one major stair, and several minor stairways. The building contains two main floors (and a minor mezzanine) and so is a relatively simple public building on which to test spatial analysis software. The arcading of the perimeter corridors to the courtyard is prominent and readily accessible, with colonnades to all four sides of the central courtyard, perforating the boundary of the colonnade / courtyard spatial interface.

Although the origins of the building are ancient and complex, and the original architect's intentions are unknown with the design, what can be understood from the building as it stands is that the primary staircase - in the centre of the courtyard – acts as the social circulation hub of the building. The atrium performs not only the general functions of an atrium (daylight, fresh air, security) but through the provision of one main stair, ensures that for important people (users of the main stair), a high degree of connectivity is likely travelling both in and out of the building.

4. Space syntax theories

Hillier and Hanson's space syntax theories expressed in *The Social Logic of Space* and *Space is the Machine*, are highly relevant to this research, with Hillier noting that: "related spaces, almost by definition, cannot be seen all at once, but require movement from one to another to experience the whole" (Hillier, 1996). This particularly relates to atrium spaces.

The current focus of space syntax utilises three main concepts of space:

- Axial line analysis (straight line visibility, i.e. a possible path following a sight line),
- Convex space analysis (an occupiable void, i.e. where all points within a space are visible to all other points within the space),
- Isovist analysis (a visibility polygon, i.e. the field of view from any particular point).

These concepts are now discussed in further detail.

4.1 AXIAL LINE ANALYSIS

Axial line analysis is highly relevant in a 2-D world where all floors are at the same level. The straight sightline implied by an axial line strongly indicates a possible and likely pedestrian path. It is difficult to depict all options in 3-D spaces and Axial line analysis is restricted in atria.

4.2 CONVEX SPACE ANALYSIS

Described as “the minimal set of shortest and fattest non-over lapping convex polygons covering a space”, convex spaces are relatively simple to draw on a plan of a building. As a concept it is closely aligned with axial line analysis and works relatively well with 2-D flat space, but is difficult to represent in 3-D space such as atria. Although methods of analyzing convex space on staircases have been examined (Koch, 2009), it is not a straightforward method to apply to a 3-D space such as an atrium. While stairs may be visually connected simply as either part of floor A or floor B, within an atrium the space could be linked as part of any number of floor spaces. For this reason, this means of analysis has not been pursued in this research.

4.3 ISOVISTS

Closely aligned with ‘viewshed analysis’ in landscape architecture, an isovist is only a 2-D plan depiction of a 3-D field (Batty, 2001): a moment in time, analysed as a thin, flat plane floating in space; rather than the full, 3-D immersion that is undertaken when a person walks within and fully experiences a space. It was resolved to create isovist fields based on a simple, direct route from entry to atrium and up the main stairs.

4.4 DEPTHMAP

Depthmap is a Space Syntax spatial analysis tool using axial line analysis to create isovists and depict them in a 2-D plan format. It was developed at the Space Syntax laboratory in London (Turner, 2004) and is an industry standard for spatial analysis of buildings and urban areas. It was resolved to test this software on plans and sections of an atrium and provides a starting point for further research in this area. Depthmap software is straightforward to use:

- input a DXF file of floor plan or section,
- assign a scale for the grid to cover the scope of the plan drawing,
- fill the space with empty squares,
- set it to run the analysis.

The software mathematically analyses the connections and relative integration of each individual grid square highlighted within the plans, derives a number based on how many connections it has to neighbouring cells, and then depicts results by means of a colour band based on a sliding scale. This VGA plan output is the traditional form of space syntax output, more commonly seen on single storey buildings.

This system works well for 2-D spaces, and produces outputs with highly visible intuitive feedback in a rainbow of colour. Areas of increased connectivity are, by nature, ‘hot-spots’ and as such are depicted in warm reds and orange. Cooler, less active areas are marked with a dark blue colour. Intermediate activity areas are yellow and green. The resulting plan clearly indicates where the space is active, and where it is inactive.

5. Analysis of the Dvor’s Atrium

Analysis of the Dvor was undertaken primarily in the atrium courtyard, follows a path from the main entry gate to the Dvor, into the central courtyard, and up the primary stair to the *piano nobile*.

5.1 ISOVIST ANALYSIS

A number of isovists were generated at regularly spaced intervals and a series was assembled to form an isovist field that follows the path described above. To test for connectivity, the visibility of vertical connection features (i.e. staircases) was noted. A series of individual isovists were drawn in a journey through the atrium at the heart of the building. The accumulated individual isovist viewsheds were then combined via a series of semi-transparent layers using Photoshop software, and produced as an overall isovist field. A darker blue colour showed an area that received more views, whereas a pale blue showed that this area was visible for only a small part of the journey. Clear white space indicated an area that is not visible at all on this journey.

In order to test isovists applicability to the analysis of 3-dimensional space, a series of isovist diagrams was also created in section as well as plan. In section views, the isovist fields show the great exposure that much of the upper floor of the Dvor has to the public zone within the atrium. Visual connectivity between ground and first floors is strong. Once inside the impregnable walls, views through to the upper floor were open to view from the central atrium. This illustrates that incorporation of the third dimension is, of course, an essential factor of the spatial analysis, one that is missing from the more 2-D based software on offer.

5.2 DEPTHMAP ANALYSIS

Depthmap analysis was run several times over the digitized drawings of the building, as described in 4.4 above. While this analysis confirmed that at the ground floor the atrium is the most integrated space in the building, it does not pick up the importance of the stairs. Instead, Depthmap highlighted the south-east corner of the atrium as being more integrated. This is a surprising result, as in reality this corner of the atrium is a largely inconsequential back of house route. The reason may be that Depthmap utilizes axial lines and convex spaces to analyse spatial integration, and visually, this axial path looks prominent on plan. In reality however, the stair, off to one side, and the space of the atrium itself are far more prominent features and Depthmap could not perceive these features.

5.3 ANALYSIS COMPARISONS

By comparing the Isovist fields with the Depthmap VGA, large differences can be noted. While in the Depthmap analysis all spaces are evaluated equally (a logical outcome from a process which assesses the integration of each pixel in relation to each surrounding pixel), the use of an isovist field allows for the isolation of just the visual connections within a space. The results from the isovist fields taken at the First floor level confirms that visual connectivity is centred mainly around the central atrium.

The isovists clearly show that the visual presence of the atrium is a key role in its use within the building, reinforced by the main stair providing a prominent physical link. Physical connectivity is divided between the highly prominent (main public) stair and the 'back of house' stairs. A method was then sought to computerize this process and thereby speed up the analysis of the building – and hence also other atrium spaces.

6. New Methods of analysis

After the completion of the main part of this research, methods of computerized analysis were investigated. These methods approached the issue from a fresh perspective, looking at utilizing visual-based systems for analysis of what is, essentially, a visual-physical paradox issue. A key point to note with these solutions are that any recorded data would be limited in the way in which they could be analyses; recorded video data would need to be viewed on an electronic medium, appropriately translating this info into a written published document would limited the level of communication this method would require. The methods cannot be adequately illustrated via 2-D pictures in this paper and are being explored for commercial release. Details of the systems used are not being released at this stage due to potential commercial sensitivity.

6.1 FIRST PERSON PERSPECTIVE ANALYSIS (FPPA)

This method considers single points of user movement within the existing environment, using a form of 'projected information' to test from critical points within a space. Based on these critical points, information is projected out in a cone shape to test what surfaces in all three dimensional directions (X, Y, Z) are strongly perceived. The term 'projected information' here simply means that light bounces are projected in a direction as a method of producing volumetric visual information. This projected information is influenced by factors that affect human visual perception: factors such as comfortable visibility in the average person ranges between 6-8 meters with a depth of field of 112 degrees, as the standard "normal" vision for the average individual is 20/20 (feet) or 6/6 (meters) (Capó-Aponte et al, 2009). This method suggests the use of digitally rendered perspective frames that illustrate user perception within a space.

6.2 PARTICLE GENERATED PROJECTION ANALYSIS (PGPA)

This method also considers single points of user movement within the existing environment. The 'projected information' used here 'throws' actual physical information into volumetric/atmospheric space within the spatial environment. This method, like FPPA, is based on critical points, projecting out to test what surfaces in all three dimensional directions (X, Y, Z) are strongly perceived. The information analysed derives from how intensely the particles deflect, with the greatest level of deflection amongst the surfaces that are most perceivable. The projected information is influenced by factors that affect human visual perception. An advantage of this method is that it is based on pre-written scripts that could be re-used on any given 3-D internal spatial built form. However a key issue here is that this method relies of animated data collection (as does FPPA) as a means to present and allow for a holistic analysis of the overall internal spatial layout.

6.3 ACCUMULATED PROJECTION ANALYSIS (APA)

This method developed from the two previously tested methods and incorporates a single point from which data is perceived and recorded, but does so by breaking down the analysis at key points per floor. This method also assimilates multiple projection points, allowing the findings of the analysis to reveal any areas of poor circulation and connectivity. Recording are taken at two main points along each floor level; once at just above ground level, allowing data to be collected on movement connectivity and then again at ceiling height to allow the analysis to encompass the entirety of the internal floor in question.

Because it is a 3-D model that is tested in this manner and recordings are based on accumulated projections, a key point to note is that the recorded data takes into account not just the perceptible levels of what is actively seen, such as a plan section of the ground floor, but also the projected information that is relevant from the upper floors. This is best seen when looking at the built model in plan. This method produced highly visually informative results, and is the primary method that is proposed for further development by the authors.

7. Conclusion

The aim of this research was to ascertain what methods of analysis are the most appropriate to the study of 3-D atrium spaces. Key objectives for this research were to identify means by which space (inherently invisible) could be made visible: means of measuring connectivity are more readily identifiable if they are visually self-explanatory.

A number of avenues were explored, including the use of isovists and associated 'traditional' space syntax methods. The strong visual feedback of completed isovist fields and the associated VGA give a strong indication of connectivity within, by nature of the (largely self-explanatory) colour selection of the VGA graphs, but further graphic feedback was required.

It was resolved therefore to use methods that feedback to the user with visible and inherently self-explanatory manifestations of spatial connectivity. A system of objective criteria to compare different methods for measuring connectivity was produced, and iterations of trials have been made. Results from FPPA and the PGPA presented some interesting visual solutions, but APA appears to hold the greatest promise for investigation in the future, with strong visual feedback. The new methods of analysis explored and outlined here present a compelling route for continued research in this field.

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