Abstract. In this paper, the authors consider the problem of architectural spatial qualities and their potential as spatial performance indicators for assessing and comparing computer generated design. The identification and analysis of meaningful and relevant spatial qualities is the target of investigation. The paper presents a parametric spatial analysis schema and spatial database structure for the restricted, but still significant, domain of residential housing. A process for the capture and comparison of different types of architectural spatial data is described where analysis focuses on a series of 2D metric and topological spatial measures. The process is then demonstrated in our discussion of a descriptive scenario.

Keywords. Parametric design; precedent, spatial analysis.

1. Introduction

In this paper, the authors consider the problem of architectural spatial qualities and their potential as spatial performance indicators for assessing and comparing computer generated design. The identification and analysis of meaningful and relevant spatial qualities is the target of investigation.

A variety of research efforts over the past decade has seen the development of numerous conceptual design evaluation methods for architectural design, highlighting an opportunity for parametric design software to be used for performance-driven design. However the work to date has been focused on structural, material and environmental criteria (Littlefield, 2008; Toth et al., 2011; Holzer, 2010; Janssen, 2004). Further, whilst attempts have been made to quantify spatial qualities using theories and techniques associated with space syntax (Hillier and Hillier, 1984), the development and evaluation of spatial qualities have been limited in parametric and scripted conceptual design.

The paper presents a framework for architectural spatial analysis, using a parametric-based schema, for the restricted, but still significant, domain of residential housing. The framework presents a process for the structuring, capture and compar-
ison of different types of architectural spatial data where analysis focuses on a series of geometric and topological spatial data extracted from the 3D building model. The paper’s focus is limited to the presentation of the framework and schema for architectural spatial analysis, including the method of data extraction and computation of metrics describing spatial qualities – and is therefore a precursor to spatial performance assessment and optimisation. The framework is demonstrated in a simple descriptive scenario focusing on a residential building design and assessment of spatial information using the associative parametric software Grasshopper.

2. Background

“The task of organization today requires a more explicit and more elaborate repertoire of organizational patterns and more explicit, precise criteria for their evaluation than what can be reasonable expected from the tacit knowledge and accumulated wisdom of an experienced architect” (Schumacher 2012).

Schumacher highlights the increasing complexity of organizational patterns expected in contemporary design and the difficulty in problem solving organizational layouts without decision support. The key theories that can enhance organizational intelligence include set theory and network theory which have been tailored for architecture under the theory and practice of space syntax (Hillier 1984). Computational implementations of space syntax have been constructed but are typically used for the analysis of urban networks; some examples include Batty (2004), Turner (2007) and Jiang et al. (2000).

The most comprehensive use of space syntax for the analysis of residential design is Hanson (2003). Hanson’s study compares a variety of London houses through a series of visual comparison techniques including justified graphs grouped by network size and configuration type, shaded integration distribution overlaid onto floor plans, tabulated quantitative data and isovist rays (representations of the visual field at any given point in space). This study demonstrates the possibility of comparing the organisational logic of residential homes.

Methods for capturing spatial topological metadata of apartment layouts for information retrieval have been proposed (Hwang and Choi, 2003, Jeong; and Ban, 2003). These studies demonstrate a capacity to code spatial networks into databases for querying. This study extends this work by introducing parametric software for capturing and comparing the spatial data. The introduction of parametric software allows relational geometry to be constructed (Woodbury, 2010), with this research proposing an advanced toolset for encoding and querying spatial data. Section 3 describes a framework for architectural spatial analysis that incorporates the use of parametric techniques whilst Section 4 will briefly outline the benefits and opportunities available of utilising such a framework.
3. A Framework for Architectural Spatial Analysis

This section describes the proposed framework for architectural spatial analysis, through parametric design techniques. The framework describes a methodology to capture the metric and topological properties of residential buildings and spaces. There are three components to the framework which are: (1) the construction of a structured CAD drawing, (2) a parametric schema for spatial analysis, and (3) data storage through a structured MySQL database. These components are shown in Figure 1.

![Figure 1. Framework for Architectural Spatial Analysis.](image)

3.1. STRUCTURED 2D CAD REPRESENTATION

The schema relies on the construction or extraction (from a 3D model) of a structured 2D CAD representation, consisting of room outlines represented by polylines that are allocated to CAD layers according to room type. A master set of layers is pre-defined including bedroom, bathroom, living etc. The allocation of rooms onto functional layers allows the parametric schema to extract data. A typical structured CAD drawing is shown in Figure 2.

![Figure 2. Structured Floor Plan.](image)

3.2. A SCHEMA FOR PARAMETRIC SPATIAL ANALYSIS

Once the structured 2D representation is complete, the parametric spatial analysis schema is applied to extract the spatial data into a specific format that allows the potential for spatial performance analysis. There are three data components of the
proposed parametric analysis schema, namely: (1) room data, (2) configuration data and (3) representation data.

The schema operates across metric, topological and geometric data and implements parametric systems to encode spaces as relational objects. The extent of captured data in combination with parametric systems allow for an extended set of spatial comparisons / queries compared to typical spatial databases, which are typically implemented for GIS data. Some of these possibilities will be discussed in Section 4. The following sections will describe the three types of data that define the schema.

3.2.1. Room Data

The room data collected is based on geometric and topological information that describe each individual room. Figure 3 shows the nine room metrics that are extracted. These include; centre point, room area, perimeter, number of vertices, bounding box area, room to bounding box ratio, length, width and proportion.
The parametric schema captures the spatial data in a structured format suitable for database storage. Each room is constructed as an object through object oriented programming techniques, with each room object containing the spatial metrics as properties. These properties are then encoded into a MySQL database which is described in Section 3.3.

The key benefits of using parametric tools to capture the spatial data include ease of data capture, and the potential for integrated spatial performance comparison through the same environment. Once the metrics have been defined parametrically, the user is able to reference different geometry (i.e. another floor plan) where calculations are then extracted automatically. Since the structured floor plan is constructed parametrically, comparable floor plans from the database can be easily recreated and visualised for comparison within the same parametric environment.

3.2.2. Configuration Data

The next set of data that is extracted is the topological data. This is extracted using a series of methods including visual and textual scripting in the associative parametric software Grasshopper. We use the plugin ‘SpiderWeb’ developed by Richard Schaffranek to incorporate graph functions, in particular, the ‘Graph from Cells’ method to convert the structured floor plan into graph data. This operation treats each room as a node and assesses each shape boundary polygon for contact. If the polygons touch, it places a link between the two rooms. This produces an ‘all connection’ graph which treats all polygons as spaces (including doors) (Figure 4). This is a misleading data set as doors and openings are treated as spaces and can distort the space syntax spatial depth measurement by suggesting rooms are deeper in the network than they actually are.

To calculate more suitable results that reflect the spatial network, scripting techniques are utilized to reconfigure the ‘all connection’ graph. To begin, the graph is reconstructed taking into account doors. The script bypasses doors and connects the two rooms directly. The link is assigned the associated meta data describing it as a “door” link. Spaces that are not connected through doors are allocated an “open” link. Once the doors are removed from the spatial graph, the graph must be renumbered and cleaned to form a ‘minimal graph’.

With the minimal graph, a series of space syntax measurements can be extracted including integration, control and spatial depth (Hillier and Hanson, 1984). Additional spatial data can be collected using isovist rays. Typically isovist fields are assessed visually (Hanson 2003), however the parametric schema collects metric data about the isovists for each space and stores it (with spatial association) in the database. This provides information about the visual permeability of each space.
in the context of the network of spaces. A number of metrics can be extracted from the isovist rays including the average isovist length, the maximum isovist length and an indicative view direction by connecting a vector from the isovist origin to the centre of the isovist polygon (Figure 5).
The schema capitalises on the relational capacity of parametric software to extend the isovist analysis. The isovist rays extend until they are obstructed by an obstacle, which in this case would be another space. Since the geometry is parametrically constructed, it is possible to determine and record which spaces the isovists are obstructed by.

Typically the computational implementation of space syntax techniques rely on finite analysis grids for calculation (Turner 2001) and hence are more akin to a raster approach of analysis. The parametric relationships reflect a vector approach to data capture, allowing the dynamic mapping of spatial data onto room objects.

### 3.2.3. Representation Data

The last set of data to be extracted is the representational data. In order to search and compare buildings and spaces, the structured floor plans must be in a format that can be reconstructed to allow re-representation. To do this, a vector is drawn from the centre of each space to the vertices of each spatial shape outline. This allows any space to be reconstructed parametrically using a point as the base geometry. In addition to the room vertex vectors, additional vectors are captured from the centre of the overall building bounding box to each vertex so that the whole building can be reconstructed parametrically from a single point.

### 3.3. DATA EXPORT TO STRUCTURED MYSQL DATABASE

A major component of capturing and comparing spatial data is the ability to store the data in a structured format that is searchable. A MySQL database has initially been selected due to the ability to read and write to a database through the parametric software and the ability to access the database through the internet.

The database must take into account the hierarchy of the building. Data must be captured at the level of a building, its spatial network and individual spaces. To accomplish this, a spatial database is constructed so as to contain the following:

- **Building** provides historical information about the building.
- **RoomType** is the lexicon of functional rooms.
- **Rooms** provides a list of actual rooms and room types per building with spatial measurements based on geometric data for each room.
- **Building Analysis** provides simple and calculated spatial measurements for the building including summations of room measurements.
- **Configuration** describes each spatial link and the type of link.
- **RepresentationBuilding** and **RepresentationRoom** describe each room as a relative vector from the centroid of the building bounding box and room outline respectively.
GlobalRoomAnalysis is a summary table that calculates averages and minimum and maximum measurements across the database. Table is updated when database is updated and allows parametric software to compare designs against whole database upper and lower limits.

Within these separate classes of information there are 100 different metrics. Therefore the structure of the database (see Table 1) has to be carefully considered to allow the storage of this complex data, which includes different geometry types which can be singular or multiple (i.e. a series of vertices consisting of x, y and z coordinates that constructing a room outline).

4. Discussion

In developing the schema, the authors hope to contribute to an understanding of performance measurement in architectural design, showing how precedent-based

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spatial data can be captured and compared, and once a complete design corpus is analyzed, how ranges of spatial qualities can be identified and used in a performance-driven generative design process. The processing power afforded by the schema for the capture and comparison of different types of architectural spatial data, specifically derived for use in generative design, is demonstrated here in this simple descriptive scenario.

A structured 2D CAD representation is constructed for a chosen design, which will be called Design X in this scenario. Using the schema described in Section 3.2, metric and topological properties are extracted from the representation of Design X. Since the database has a corpus of existing precedents, a variety of spatial property ranges can be queried using SQL queries.

At an individual room level, basic comparison queries can include the display of all bedrooms in the database. The query can be extended by displaying all bedrooms and those rooms connected two topological spaces deep to any bedrooms. An alternate query type will display results that are within a range of Design X’s performance. For example, a query to display all buildings that have an average integration value of +/- 10% of Design X’s average integration value (a space syntax measure for the relative topological depth of each space) can be readily made. Finally, the designer can make shape based queries, such as the comparison of dimensions and articulation of room outlines.

Capturing data at both the level of the individual room and the spatial network allows flexibility in comparison, with the designer having the potential to compare designs for individual room types or a series of connected rooms and evaluate according to existing precedent data.

5. Conclusion

The authors have described a schema for capturing and comparing spatial data using parametric software. The schema involves creating a structured CAD plan, extracting spatial knowledge using existing and developed strategies and storage into a MySQL database for querying. Future research aims to populate the database with a series of contemporary residential precedents and utilize the database for spatial performative design.

Acknowledgements

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References


Jeong, S.-K. and Ban, Y.-U.: 2011, Developing a topological information extraction model for space syntax analysis, Building and Environment, 46(12), 2442–2453.


