

INVESTIGATING VISIBILITY PROPERTIES IN THE DESIGN OF AGED-CARE FACILITIES

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Abstract. This paper uses a Space Syntax approach - a computational and mathematical method using graph-based measurements - to undertake a comparative assessment of the visibility properties of three architectural plans with unusual spatial requirements. Specifically, the method is used to compare the spatio-visual properties of an idealised plan for a residential aged-care facility with the actual plans used for two facilities. The purpose of this analysis is to begin to examine the ways in which syntactical values and isovist properties can be used to capture spatial and social characteristics of plans designed for the physical and cognitive needs of an ageing populace. The application of this approach seeks to support a better understanding of the relationship between spaces and their social properties in the design of aged-care facilities.

Keywords. Visibility analysis; Space Syntax; spatial cognition; social property.

1. Introduction

Since the 1970s, a growing number of computational and mathematical methods have been developed for optimising various aspects of architectural space planning. For example, Space Syntax methods (Hillier and Hanson 1984) have been used for predicting patterns of pedestrian movement, improving surveillance, reducing crime through observation, and understanding access and control issues. While many of these approaches have been embedded in contemporary software tools, and are in use in commercial architectural practices today, there are surprisingly few applications to assessing spatial and social properties in environments which are dominated by single age groups. In particular, the problems of an aging population - including social isolation, mental health and limited physical mobility - have rarely been considered using these methods.

The most challenging factors in the design of retirement villages and aged care centres include isolation, loneliness and confusion, all factors associated with spatial visibility (Gardner 1994). A capacity to understand an environment and socialise in it, both of which rely on levels of visual connectivity, are critical for the design of successful aged-care facilities. But equally, carers and nurses in these environments need to be able to monitor residents, but not constantly invade their privacy.

This paper, therefore, aims to present a computational analytic framework to capture visibility properties from the perspectives of different user groups and spaces. For verification purposes, the framework is applied to compare the properties of three plans, the first being a hypothetical or idealised plan, based on theorised medical and social needs (Eastman 2013) and the second and third are recent Australian designs identified by the International Association of Home and Services for the Ageing (2014) as representing recent industry practice. However, the primary purpose of this paper is not to analyse or criticise the three designs, but rather to begin to consider which aspects of the syntactical computational method will be most significant for assessing a building type which has unusual social and cognitive challenges.

This paper firstly investigates computational approaches to visibility analysis which affects the cognitive and social properties of architectural plans for residential aged-care facilities. A discussion of various methods and techniques and an application of a visibility analytic framework to three architectural plans are then presented. This paper concludes with a discussion about the results and the need for future research.

2. Literature Review

Research into the relationship between people (and their behaviours) and spaces (and their properties) is at the heart of several major theories of architectural analysis and prediction. In particular, environmental and behavioural research (Hayward and Franklin 1974; Nasar and Jones 1997; Stamps 2005a; Stamps 2005b; Sadek and Shepley 2016) identifies that enclosure is an important property of an environment, because it limits or shapes movement and perception. Multiple theories have attempted to explain how these spatial properties shape human responses and social interactions. For example, Appleton's habitat theory and prospect-refuge theory (Appleton 1975) are two of the most well known in architecture. Gibson's ground theory (Gibson 1950; Gibson 1979) and Kaplan and Kaplan's information theory (Kaplan and Kaplan 1989) are also used to explain human responses to space. Such theories use psychological, verbal constructs to analyse environments and because of this, their results are not always reproducible (Stamps 2005a) and they can be difficult to apply in architectural planning. Furthermore, these theories tend to assume that human responses are relatively universal (or at least that statistical patterns can be derived from them that reflect universal tendencies). While there is statistical evidence to support the general use of several computational methods for modelling and understanding socio-spatial properties of plans, relatively few examples exist of attempts to accommodate the needs of particular demographic groups. These issues are developed in this literature review section

which has two parts. The first briefly examines the computational methods that are conventionally used to analyse visibility in architectural plans and the second examines the application of these methods to healthcare facilities or those for residential aged care.

2.1. ANALYTIC METHODS

The two most common computational approaches to visibility analysis in architectural plans involve graph-based abstraction techniques, typically associated with syntactical approaches, and isovist based techniques or viewshed analysis. These two are also combined in visibility graph analysis (VGA).

For the first of these approaches, the properties of an architectural plan are typically abstracted into a set of nodes and edges in a graph, which can then be mathematically analysed. This method can reveal the relationship between spaces and the social properties which necessitate or sustain such relations (Hillier and Hanson 1984). Two of the common approaches to spatial analysis using graph theory are convex and axial maps. Convex maps allow for the analysis of programmatic spaces and their connectivity, conceptualised, respectively as nodes and edges, while axial maps capture behavioural characteristics including movement potential. An axial map is defined as the set of the longest lines of sight or movement that pass through and connect all of the habitable spaces of a plan (Hillier and Hanson 1984). Using graph mathematics, various quantitative, mathematical descriptions of the built environment can be derived from convex and axial maps. These include connectivity (the number of direct connections to other lines or spaces), integration (the normalised mean depth being compared to D-value) and intelligibility (the correlation between connectivity and integration). Connectivity describes the mutual relationship between all lines or spaces, while integration values indicate how well one space is connected to all others in a system (Hillier and Hanson 1984). It has also been suggested that integration values - including local and global integration - can be used to shape the design of healthcare facilities. Guney (2007) argues that “visibility structures work together with and enhance permeability structures” and both influence how an environment functionally spatially, as well as how it is experienced and understood.

The second major approach to plan analysis, isovist analysis, has been linked to the work of Tandy (1967), an isovist is defined as “the set of all points visible from a given vantage point in space” (Benedikt 1979, p. 49). The properties of the isovist’s geometry or construction can then be measured. Past research has identified the mathematical properties of isovists that have potential correlations with human spatial perceptions. For example, Stamps (2005a) argues that several isovist properties - Horizontal size, Boundary permeability, Variation in distances to boundaries, Concavity, Boundary predictability, Elongation - can influence behaviour. Dawes and Ostwald (2014a; 2014b) highlight five isovist properties - isovist area, radial line, length, occlusion and drift - which possess a level of correlation with empirical research and Dosen and Ostwald (2017) demonstrate a statistically significant correlation between measures and perceptions of spatial exposure and enclosure. Franz et al (2005) note that the different spatio-visual analytical approaches used in architecture also correlate closely with the major

models of spatial cognition.

The set of isovists in a plan is the 'isovist field' and the relationship between isovists in a plan can also be conceptualised and measured as a graph. Thus, syntactical and isovist methods come together in visibility graph analysis (VGA) (Braaksma and Cook 1980; Turner et al 2001). Because both syntactical and isovist approaches have various levels of empirical support, VGA analysis seems to offer the potential for developing insights into the design of buildings that have particular visibility requirements.

2.2. APPLICATIONS TO HEALTHCARE FACILITIES

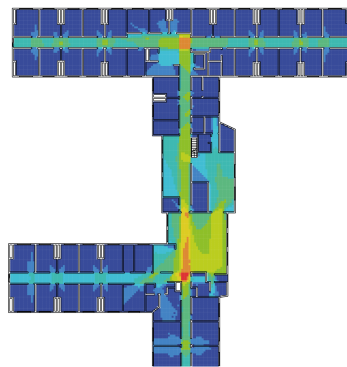
A growing body of research suggests that the spatio-visual properties of physical environments have an impact on a variety of health-related outcomes (Seo et al 2011; Haq and Luo 2012; Sadek and Shepley 2016). Because of this, various computational methods have begun to be used in the analysis or optimisation of health facilities, including nurses' behaviours (entries to patient rooms and spatial positioning, walking patterns), patients' preferences and satisfaction (preference for bed privacy, perceived quality of care), and visitor movement in hospitals (Haq and Luo 2012). For example, Seo et al (2011) investigate the impact of hospital unit design focussing on nurse behaviour. They suggest that the characteristics of routes from intensive care units (ICUs) to patient rooms and medication areas contribute to behavioural patterns. Setola et al (2013) study the role of spatial layout in hospitals and analyse the integration of both public and staff spaces. The research captures the patterns of relationships between patient and medical staff (P-M) through the density of interactions and accessibility maps. Lu (2010) measures the structure of visual fields in nursing units and Lu et al (2009) develop a targeted visibility analysis that is correlated to distribution of people and their interactions within an intensive care unit. Carranza et al (2013) present a spatial position tool with paths and interactive diagram with a low complexity isovist algorithm for assisting health design. They measure healthcare effectiveness through visibility, accessibility and contact between caregivers and patients. Sadek and Shepley (2016) classify a series of variations of Space Syntax tools for use in healthcare facility analysis including Target Visibility Analysis, Spatial Positioning Tool (SPOT), Weighted Isovist Area, Multi-Layered Network, Place Syntax, and Team-Base and Peer Distances. Such tools effectively demonstrate the usefulness of analysing spatial characteristics in terms of the perspectives of patients, visitors and staff. However, despite these valuable lessons, almost all of these examples are concerned with hospitals, not residential aged care facilities.

Research into the design of residential aged care facilities has gradually noted a change occurring in the way they are planned and has also developed a series of ideal solutions. For example, Brawley (2006) classifies two types of residential aged care plans; the older, 'double loaded corridor' variant, and the newer, 'race track' variant and Eastman (2013) offers an ideal design for residential aged care, taking into account medical and social research. Brawley (2006) argues that the planning of these facilities has evolved over time in response to research into the challenges of ageing.

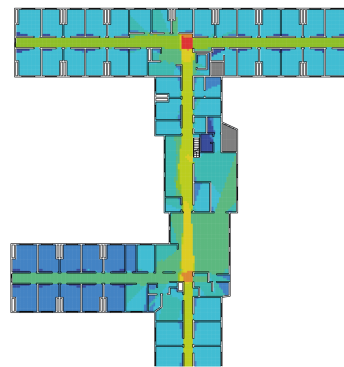
A VGA analysis of Brawley's (2006) two plans (figure 1) identifies the syn-

tactical values of her two different aged-care planning types. Curiously, they have similar levels of holistic integration (5.03 and 5.06), although the race track variant has higher levels of connectivity ($6.18.63 > 516.89$) and commensurately higher intelligibility because of this. As such, the race track variant could be regarded as providing a higher level of cognitive clarity in the space, which might respond more effectively to the needs of dementia patients. However, beyond such general observations, large scale VGA analysis of this type is not especially revealing. Nevertheless, following Sadek and Shepley's (2016) lead, a more focussed analysis of VGA and isovist data, from the perspective of different user groups and spaces, could be more useful. This approach is taken in the next section.

a. Double Loaded Corridor

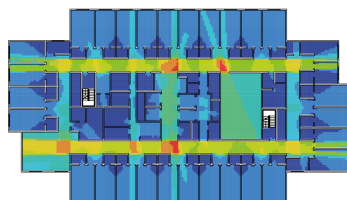


Connectivity = 516.89

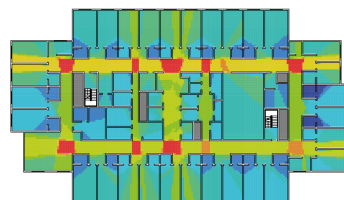


Visual Integration HH = 5.03

b. Race Track



Connectivity = 618.63



Visual Integration HH = 5.06

Figure 1. Connectivity and visual integration of two building typologies.

3. Case Study

The planning of three aged-care facilities is examined in this section. The first is derived from Eastman's (2013) ideal plan for an assisted living, group residence. The other two plans (Au1 and Au2) are contemporary Australian designs published in 'architecture for an ageing population' by International Association of Home and Services for the Ageing (2014) (table 1). All three cases are designed for a special care residence as well as a skilled nursing care. They are all multi-level buildings

for special care residents, although the second Australian case has a bigger site and building area. Thus, the comparative study in the next section uses mean values of measures from observation points to allow for more useful comparisons to be made. Importantly, the ideal plan has no site constraints whereas the other two do.

Table 1. Two Australian cases.

Name	Au1: Nambucca Head UnitingCare Ageing	Au2: Port Macquarie UnitingCare Ageing
Project type	Special care residence/ Skilled nursing care	Special care residence/ Skilled nursing care
Location	Nambucca Heads, NSW	Port Macquarie, NSW
Site size	3,853 m ²	14,677 m ²
Building footprint	1,921 m ²	3,635 m ²
Building area	5,463 m ²	7,225 m ²

3.1. APPLICATION AND RESULTS

The methodological framework used to analyse the three plans is VGA. It is applied in two ways.

1. Measurement of mean results for each plan for visual integration, isovist area, isovist perimeter, drift angle, drift magnitude, maximum and minimum radial and occlusivity. These measures provide a holistic indication of various spatial properties of the plan.

2. VGA analysis of isovists centred in four selected locations in each plan. The four locations are: visitor lobby, staff kitchen and common area, corridor from the perspective of nurses' viewpoint and corridor in residential units from a resident perspective.

For the first of these approaches, table 2 indicates the mean values for spatial properties of each plan. Interestingly, the visual integration value for the hypothetical case (H1) is higher than the Australian designs ($3.61 > 2.84$ and 2.54). This might be because the hypothetical plan has no site constraints. In general, a higher integration value represents a shallower or more assessable space (Hillier and Hanson 1984). More dramatically, H1 has a mean isovist area which is more than double that found in Au1 and Au2 ($88.48 > 36.40$ and 35.33), although its isovist perimeter is only in the order of 20 - 30% more ($61.74 > 48.45$ and 47.50), and the drift magnitude (often described as 'strength of enticement' or 'visual pull') is of a similarly higher level of difference. The mean occlusivity measures are notably similar across all three plans, meaning that they possess a similar level of mystery or a similar capacity to hide (23.40, 23.39 and 22.48).

Table 2. Mean values of spatial properties (H: Hypothetical case, Au: Australian case).

	Visual Integra tion	Isovist Area (m ²)	Isovist Perimeter (m)	Isovist Drift Angle	Isovist Drift Magnitude	Isovist Max Radial	Isovist Min Radial	Isovist Occlusivity
H1	3.61	88.48	61.74	179.34	4.23	15.59	1.03	23.40
Au1	2.84	36.40	48.45	181.07	2.91	11.47	0.60	23.39
Au2	2.54	35.33	47.50	177.98	2.87	11.43	0.56	22.48

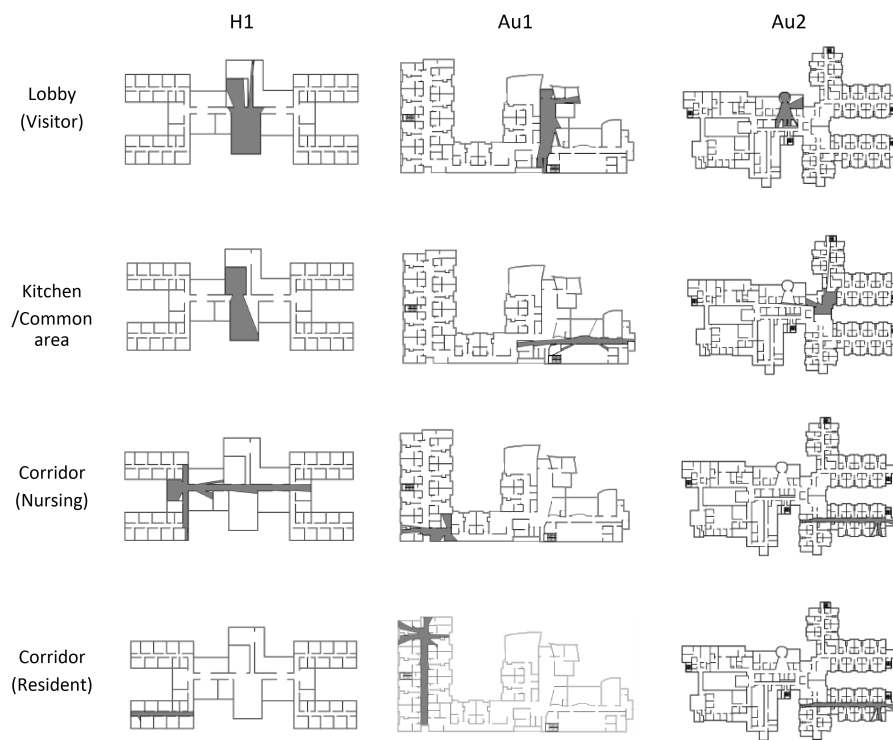


Figure 2. Isovist maps from four selected points.

For the second of the analytical approaches, isovists were examined in four locations in each plan (figure 2). Four properties - area, perimeter, max radial, and occlusivity - are measured and compared for each location (figure 3). When charted, these results reinforce some of the interpretations identified in the holistic examination of the plan, but they also point to several particular differences. One obvious example of this is seen in the chart for isovist area, which confirms that H1 does feature a large volume of visible space in the visitor's lobby, the kitchen and the nurses' station, but in the resident corridors, the three are similar. However,

isovist perimeter, which was on average higher in H1, is revealed to be less significant when examined from the perspectives of staff, nurses and residents. Only the visitor lobby has a significantly higher perimeter in H1. The results for occlusivity in H1 and Au1, broadly conform to the contemporary idea that lower levels should be present in the nursing station, than in any other area. Thus visibility should be clear for the Nurses. However, this is reversed in Au2, where the most visually commanding space is the kitchen.



Figure 3. Isovist properties from four selected points in each case.

4. Conclusion

This paper takes a step towards the much larger process of exploring the planning of residential aged care facilities and the computational methods which are most appropriate for analysing their visibility properties. The paper describes an analytic framework for investigating the syntactical values and isovist properties of different spaces in aged care facilities. The framework is demonstrated through a comparative study between an ideal, hypothetical design and two designs produced by commercial practices in Australia. All testing was undertaken using a combination of architectural plans, geometric data and software.

The initial results indicate that the framework allows the investigation of integration values and isovist properties of the main functional spaces. It also enables the capturing of spatial and social characteristics in the design of aged-care facilities. Interestingly, the hypothetical design (H1) has the highest integration value as well as the biggest isovist area and perimeter, meaning that it is both well connected spatially and has a large (relative to the other two designs) volume of visible space from most positions. The results also indicate the viability of using these measures

to differentiate between spaces in terms of their visibility properties. This computational approach contributes to advances in fundamental knowledge in terms of environment and behaviour in aged care settings. A future study addressing the relationship between spatial configuration and social cognition is planned by the authors with more cases and with cultural differences in designs.

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