COMBINING SPACE SYNTAX AND SHAPE GRAMMAR TO INVESTIGATE ARCHITECTURAL STYLE:

Considering Glenn Murcutt's domestic designs

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Abstract

The syntax and grammar of a design are, respectively, reflections of its socio-spatial and formal properties. Combined approaches to syntax and grammar potentially offer new ways of understanding a particular architectural style, as well as allowing for the production or assessment of variations of that style. Despite this potential, the combined generative and analytical capability of the two computational theories which are used to investigate these ideas - Space Syntax and Shape Grammar - are not well understood. This paper presents a new framework for selectively merging aspects of these two approaches into a single technique for investigating the properties of an architectural style. To support the framework, this paper develops a Justified Plan Graph grammar and then examines the grammar using both rule-based and syntax-based approaches. This new framework and associated technique is demonstrated using four designs by architect Glenn Murcutt. The findings of this paper suggest that the new combined framework facilitates the exploration of the patterns and inequality genotypes of Murcutt's houses. The paper concludes with a discussion of the way the JPG grammar could be used to examine both architectural design solutions as well as to investigate generative design processes. Through this research the study contributes to the growing interest in combining Space Syntax and Shape Grammar approaches.

Keywords: Space syntax; Shape grammar; Convex space analysis; Design style; Glenn Murcutt; Justified Plan Graph (JPG) grammar

Theme: Architectural Design and Practice

1. Introduction

While researchers have previously argued that Space Syntax offers a possible conceptual seeding technique to support new design and decision-making paradigms, practical advances in this area have been limited. In particular, it is not yet clear how such an approach might be used to generate or inspire new designs. For example, past studies (Bafna, 1999, Hillier, 1999) have suggested a variety of approaches to this issue including weighting the importance of a spatial analysis or topological configuration using graph theory, while a small number of studies (Heitor, et al., 2004, Ostwald, 2011b) have focused on the potential generative or analytical application to particular design styles. To further explore the second aspect of this field of research, the present study combines facets of two different computational approaches: Space Syntax and Shape Grammar. The particular part of the theory of Space Syntax being addressed in this paper relates to the process of generating conceptual structures and topological design rules by way of a variation of convex space analysis (using a Justified Plan Graph or JPG). Conversely, Shape Grammars are patterns of rules that are used to configure architectural form.

Space Syntax is conventionally used to develop an understanding of spatial topologies and the social relations implicit in various architectural or urban settings or types. Shape grammars deal with formal typologies that allow for a design style to be described, analysed and generated. Both approaches have a variety of techniques and offer differing perspectives on design. In particular, the former tends to result in numeric data while the latter highlights graphical outcomes. The present paper describes and demonstrates a new way of combining the two approaches to allow for both the analysis and the generation of design instances from a particular architectural style. However, given the complexity of connecting these two, rich and divergent approaches, this paper has a focus on the graph-based analytical techniques used in Space Syntax, rather than the explicitly social, and a simplified rule-based variation of the theory of Shape Grammar. Through this limited application, the paper aims to develop a framework for combining the two approaches.

The paper commences with a presentation of a conceptual framework for combining syntactical and grammatical aspects of a design. This new approach relies on three stages, the construction of Nodes, Links and Shapes, to develop a way of understanding both spatial relations in a design. These spatial relationships are used to provide topological rules to propose typical or possible design variations. However, rather than using convex space, this paper uses six functional sectors or zones for the generalised mapping of space – Exterior, Hall, Common, Private, Transit and Garage – to develop the rules for the generative process, which the authors have named a "JPG grammar". Integration (*i*) values are used in this analysis to develop genotypes. The combined nature of the connection and location of each sector, along with its *i* value, forms the key topological design structure and variations of the style being analysed.

The first two stages (Nodes and Links) of this joint application of Space Syntax and Shape Grammar are then demonstrated using four houses designed by Pritzker Prize winning architect Glenn Murcutt. The paper uses the JPG grammar to construct a graphical and mathematical analysis of the spatial configuration of Murcutt's famous rural houses. Murcutt's architecture is ideal for this purpose because it has been the subject of both Shape Grammar and Space Syntax research in the past. The results of the analysis of Murcutt are presented in Section 3 of the paper, and then reviewed against the evidence of his designs in Section 4. Section 5 concludes by outlining directions for future work.

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2. Research framework

2.1 Background

Several important precedents (Ostwald, 2011c, Bafna, 1999, Hanson, 1998) have confirmed the mathematical potential of the Justified Plan Graph (JPG) approach for longitudinal design analysis. For example, Ostwald(2011b) highlights the construction of a simple statistical archetype from the various genotype examples in the longitudinal set of Murcutt Houses. His research uses JPGs and configurational analysis to examine inequality genotypes – "the ranking of programmatic labelled spaces according to their mean depth or integration values of the nodes" (Hillier, et al., 1987, Bafna, 2001) – and understand their relationship to particular design styles. While Ostwald's (2011a, 2011b) research contributes to the present paper, his statistical genotype is effectively an average condition, rather than an attempt to capture an underlying set of design rules governing both social patterns and formal or stylistic decisions. In order to overcome this difficulty, the present paper uses the theory of Shape Grammar to assist in constructing a new archetype before considering the way in which this might be used to support design analysis and generation.

Shape grammar, invented by Stiny and Gips(1972), specifies a set of rules delineating how designs can be composed with shapes by starting with an initial shape and then proceeding recursively by applying rules. This paper highlights the rule-based formalisms derived from Shape Grammars. In order to create an architectural design many researchers (Cagdas, 1996, Stiny and Mitchell, 1978, Hanson and Radford, 1986a) adopt sequential design stages. For example, Stiny and Mitchell(1978) use eight stages: grid definition; exterior-wall definition; room layout; interior-wall realignment; principal entrances-porticos and exterior-wall inflections; exterior ornamentation-columns; windows and doors; termination. Hanson and Radford(1986a) use 12 stages to generate a Murcutt style house, starting with urban form and ending with glazing on east and west walls. These sequential stages establish a possible way for understanding an architect's design process. The process of generating a set of spatial permeability relations (embodied in a JPG) could be regarded as a general design stage. It is similar to a functional zoning process which occurs at the early stage in the design method. It is also one of the most significant stages in housing design (Hanson 1998). Once the broad zoning has been established then decisions about form can be made, while seeking to maintain the underlying social and functional pattern represented in the JPG. Thus, while the three – space, permeability and form - are not necessarily connected in a perfect linear way, they could be regarded as part of larger conceptual and sequential framework consisting of, respectively, nodes, links and shapes.

2.2 Node, link and shape

Examples exist of the combination of Space Syntax and Shape Grammar into a single process (Heitor, et al., 2004, Eloy, 2012). Such research typically starts at the generation stage using Shape Grammar and it ends with the analysis of the decision-making stage using Space Syntax. However, the present study investigates appropriate design types by starting with spatial or syntactic issues (JPGs) and then using JPGs as the basis for form generation using Shape Grammar. Thus, this new approach inverts the more common relationship where grammar is privileged over syntax. The new computational framework consists of three stages for defining, Node, Link and Shape, which are described in Table 1.



Table 1: Node, link and shape stages of the research framework

The first stage in the framework involves identifying significant spatial groupings and defining them as nodes. While this process is conventionally focussed on convex spaces or room functions, the present framework adopts Amorim's concept of dwelling 'sectors' (Amorim, 1999) to define broader zones within a plan. The second stage defines the connectivity or relationship between these sector nodes, typically expressed in a graph. The combination of sector nodes and links is critical to the proposed JPG grammar developed here. The grammar, consisting of nodes and links, combines both Space Syntax and Shape Grammar methods to allow for an investigation of sequential design decisions about sector relationships (expressed in terms of JPGs). Finally, the third stage extrapolates a set of shape-based extensions of the JPG grammar.

3. Node and link

3.1 JPG grammar

Approaches to developing a permeability graph from an architectural plan are well documented (Hillier and Hanson, 1984; Osman and Suliman, 1994; Hanson, 1998; Ostwald, 2011c). These typically commence with the partitioning of an architectural plan, using a predetermined protocol, into a series of spaces (nodes) connected by edges (links). The protocol determines whether the analysis is of rigorously defined convex spaces (Hillier and Hanson, 1984) or programmatically defined areas (Bafna 1999) as well as the nature of potential connections between each (including definitions of trivial and non-trivial loops). Nodes and links in the present paper represent, respectively, 'sectors' and 'functional adjacency'. This implies that instead of extracting convex spaces or programmatic areas from a plan, in this research zones with similar programmatic needs are grouped into sectors. Similarly, rather than defining doors as links in a graph, sector-based zoning defines a link as a characteristic of functional adjacency; that is, at least one, but possibly multiple, direct connections exist between sectors. While a sector-based variation of the JPG grammar could more explicitly consider convex spaces or permeability, for demonstration purposes, in this paper it is restricted to the consideration of

relations between functional sectors. Thus, this study using programmatic adjacencies cannot be used to examine the complete range of epistemological questions which convex space analysis has been used for in the past.

Six functional sectors are used in the present research. There are four 'enclosed' sectors; common (C), private (P), hall (H) and garage (G). The first of these sectors (C) includes living rooms, dining rooms, foyers and kitchens while the second (P) contains bedrooms and bathrooms. The third category (H) includes corridors, hallways and linking spaces and the fourth (G) is focused on the storage of cars, but also includes workshops, laundries and service areas. In addition to this, there are two types of 'open' sectors, transit (T) and exterior (E). Transit spaces are intermediate zones between interior and exterior, or occasionally between two interior spaces. Transit spaces are usually roofed, and semi-enclosed, but are still open to weather conditions. The exterior is simply the outside world, and it is most closely associated with ingress and egress relationships.

Because connections between sectors are less clearly defined than they are between rooms or spaces, this research is also informed by Hiller's notion of four topological types of spaces (Hillier, 1999). Hiller explains that a-type (cut-link) is associated with occupation, whilst b-type (tree-link) is more relevant to movement. Ring-link nodes are divided into a single ring-link node (c-type) and a node containing at least two rings (d-type). These categories of node and link relationships allow for defining the possible type of each sub-complex.

Once the graph of sectors (nodes) and functional adjacency (links) is prepared and justified, then mathematical analysis determines total depth (*TD*), mean depth (*MD*), Relative Asymmetry (*RA*), integration (*i*) and control (*CV*) (Hillier and Hanson, 1984; Osman and Suliman, 1994; Hanson, 1998; Ostwald, 2011c). These mathematical values can be used to assist to identify a genotype (Ostwald, 2011b), or to support an understanding of a range of topological types (Heitor, et al., 2004). For example, using only four sectors (Exterior, Hall, Common and Private), Figure 1 shows three topological types. Each common sector node in this example is represented by C and located at the second order of depth (D2 in Figure 1) but it has a different spatial relationship type and the syntactic values depend on the number of nodes and links in each type.



Figure 1: Examples of the sector-based JPG

Thus, Figure 1 also shows the results of the mathematical analysis of each of these archetypal sector relationships. However, even if the mathematical approach enables us to compare spatial types, how can we generate the possible sector-based JPGs for distinct architectural types? Such a method could suggest a new way of understanding the generation process of design layouts as well as providing topological variations. In order to investigate the process, this paper proposes a 'JPG grammar' to construct a particular type of sector-based JPGs.

In order to construct a JPG grammar, the following should be considered. A JPG consists of nodes and topological links. It can therefore be formed by two basic schemas ($x \rightarrow node(x)$ and $x, y \rightarrow link(x, y)$): see Figure 2. This basic schema is then specialised into several sequential rules corresponding to the generation steps. This procedure is in line with rule-based formulations developed for Shape Grammars (Cagdas, 1996, Stiny and Mitchell, 1978). Shape Grammars have been developed to represent a range of distinct architectural design types.

In order to generate the sector-type JPG, there are five steps in the grammar. Figure 2 shows the steps, schemas and example of the rules and the outcomes. The grammar considers a core node as an important sector including the main entrance (that is, a sector linking to the exterior). This is because the core node, being similar to the core unit (Koning and Eizenberg, 1981), plays an important role in configuring spatial programs as well as the shapes. Even though, for example, nodes emerging at the second and fourth step of the grammar may result in the same depth of the JPG, the core node has a different topological role. A link generated by the fourth step configures a sub-entrance into such a node or a garage sector node at the first depth, whilst the core node creates links to each sector node and then supports the generation of topological relationships. Finally, the grammar completes the JPG by adding additional links at the fifth step. These five steps are derived from a model of the design process which is common in Shape Grammar research (Stiny and Mitchell, 1978, Hanson and Radford, 1986a), but modified through a consideration of graph depth.

Step		Schema	Example	
1	Create the required sector nodes and then locate an exterior sector node as a carrier (Depth 0)	$x \rightarrow node(x)$ x={E,H,C,P,T,G}	node(E) + node(H) + node(P) + node(C) + node(T)	(H) (C) (E) (P) (T)
2	Create a core node link (Depth 1)	$x \rightarrow corelink (x)$	corelink (H) = link(E,H)	(H) E
3	Create a link between a given node and a functionally adjacent sector node	x, y → y-link (x)	H-link(P) = link(H,P) H-link(C) = link(H,C) C-link(T) = link(C,T)	(T) (C) (H) (H) (H) (C) (C) (C) (C) (C) (C) (C) (C) (C) (C
4	Create and configure a link between a sector node and the exterior sector node (i.e. inserting a sub entrance into a node or a garage sector node at the first depth)	$x \rightarrow E$ -link (x)	E-link (C) = link(E,C)	
5	Add a link between two nodes as required	$x, y \rightarrow link(x, y)$	link(H,T)	Pa Tc Hd Cd

Figure 2: Steps, schemas and examples of a JPG grammar

The mathematical values and topological types presented in a standard JPG are therefore also present in the new, sector-based JPG (Figure 1). However, by using the JPG grammar (Figure 2) we are also able to investigate possible design generation processes in particular dwelling types and their characteristics. In order to both demonstrate and verify the usefulness of this combined approach, the following section considers the domestic architecture of Glenn Murcutt using this JPG approach.

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3.2 Node and link in the style of Glenn Murcutt

Glenn Murcutt's architecture is characterised by a high degree of consistency and clarity in his approach to both space and form. As such, it has been the subject of both Space Syntax (Ostwald 2011a, 2011b) and Shape Grammar research (Hanson and Radford, 1986a, 1986b). The present paper analyses two early career houses (built in 1975 and 1980) and two later career houses (built in 2001 and 2005) considered in the previous research to establish and demonstrate the research framework. The first part of this section is concerned with the rule-based analysis of the JPG grammar and the second with the analysis of its syntax.

JPG rule-based analysis

The plans, JPGs, applied sequential rules and syntactic values of four of Murcutt's houses are shown in Figure 3 and Table 2. The 'applied rules' in the table are those used at each step of the development of the JPG grammar. For example, in order to generate the first case, 'Marie Short House', the following rules are applied:

- Step $1.x \rightarrow node(x)$: node(E)+node(T)+node(H)+node(S)+node(P)+node(T²).
- Step $2.x \rightarrow$ corelink (x): corelink (T).
- Step 3.x, $y \rightarrow y$ -link (x): T-link(H)+ T-link(C)+ H-link(T2) +H-link(P).
- Step $4.x \rightarrow \text{E-link}(x)$: E-link (C).
- Step 5.x, $y \rightarrow link(x, y)$: link(H,C)+link(P,T²).

The first step of the JPG grammar identifies and groups similar programmatic areas into one of six types of sectors in the plan. Each functional sector can include multiple small spaces (alcoves, bathroom, toilets, utility cupboards) within its larger grouping. Thus, a grouping of entry foyer, living room and gallery might be a common space (C), while elsewhere in the same plan a second grouping of dining room, kitchen and music room, might be a second common space (C²). The six sectors used for the Murcutt house analysis are: (E)xterior, (H)all, (C)ommon, (P)rivate, (T)ransit, and (G)arage. That is:

 $x \rightarrow node(x)$, where $x = \{E, H, C, P, T, G\}$

This first step also configures the topological size of each house; a figure which ranges from 6 to 7 sectors in Figure 3. Three cases (1,2,4) consist of six sectors, but no case has all the six functional sectors. Thus, as previously stated, although two adjacent rooms that have a similar function are regarded as a sector, there may bea second or even third sector of the same functional type such as the second private sector (P²) or the second common sector (C²). There are four common nodes in all of Murcutt's houses: Exterior, Hall, Common and Private. The last two cases include a second private sector (P²) and a garage sector (G). The first two cases (1,2) have transit sectors and both use the transit sector as a core node. The transit sector tends to connect to a common sector (T-link(C) at the third step). A garage sector links to an exterior at the fourth step (E-link) of the grammar.

The second step in the JPG grammar generates a core node link. In the first case a transit sector (T) is the core node, while the others use a common and a hall sector as a core. As the two transit sectors and the hall sector which function as core nodes also link to a common sector, core nodes could be regarded as common sectors.

The third step generates sequential links starting from a core node. When generating links for

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Murcutt's houses, the next sector node is one of only four types: Hall, Common, Transit and Private. That is:

x, $y \rightarrow y$ -link (x), where x={H,C,T,G} and y={H,C,P,T}

H-link(x), representing a link from a hall sector node, occurs six times in the four cases. In two cases H-link(x) forms a tree-like structure – although it will be changed to a "ring-type" at a later step in the grammar– which may cause the high *i* and *CV* values in the syntactic analysis in Table 2. For example, 'H-link(T²) +H-link(P)' in the first case, the Marie Short house produces "tree-like" JPGs structures and result in the most integrated node (*i* = 10) and the greatest degree of control (*CV* = 1.67). The third step in the grammar for the four houses also features H-link(C or C²)two times and H-link(P or P²)three times. This implies that a hall sector node tends to link to both common and private nodes.



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Figure3: Sequence of graph generation for four Murcutt's houses

	Case 1			Case 2			Case 3			Case 4		
	TD	i	cv	TD	i	cv	TD	i	cv	TD	i	cv
Exterior	10.00	2.00	0.67	8.00	3.33	1.33	8.00	7.50	1.92	6.00	10.00	2.83
Hall	6.00	10.00	1.67	7.00	5.00	1.17	8.00	7.50	1.92	7.00	5.00	1.75
Common	7.00	5.00	1.08	8.00	3.33	1.25	8.50	6.00	1.34	8.00	3.33	0.58
Common				(C: 7.00, C ² : 9.00)			(C: 8.00, C ² : 9.00))				
Drivete	9.00	2.50	0.75	11.00	1.67	0.33	13.00	2.14	0.25	10.50	1.82	0.29
Privale							(P: 13.00, P ² :			(P: 11.00, P ² :		
							13.00)			10.00)		
Transit	8.00	3.33	0.92	8.00	3.33	1.67	-	-	-	-	-	-
Transit	(T: 7.00, T ² :											
	9.00)											
Garage	-	-	-	-	-	-	13.00	2.14	0.25	10.00	2.00	0.25
mean	8.00	4.57	1.02	8.40	3.33	1.15	10.10	5.06	1.14	8.30	4.43	1.14
st. dev.	1.58	3.24	0.40	1.52	1.18	0.50	2.66	2.73	0.84	1.92	3.36	1.12
max	10	10	1.67	11	5	1.67	13	7.5	1.92	10.5	10	2.83
min	6	2	0.67	7	1.67	0.33	8	2.14	0.25	6	1.82	0.25
Space Type	c-(50%)			c-(50%)			d-(57%)			c-(50%)		
	d-(50%)			d-(33%)			a-(43%)			a-(50%)		
				a-(17%)								

 Table2: Summary of syntactic analysis result

Another frequently applied rule is C-link(x). This general rule occurs five times in two cases (2,3). The common sectors of the other two cases show a "cut-link" type at this step. The five C-link(x) cases form tree-like structures using this rule, which may also lead to higher *i* and *CV* values. The general rule T-link(x), occurring three times in the first two cases, tends to be a particular variation of T-link(C). Although the JPG grammar construction has two more linking steps, the third step has the most significant impact on constructing the syntactic structure of each JPG. This step is also important because the frequency of the applied rules can be used to investigate the topological tendencies in the style of Glenn Murcutt.

The fourth step in the grammar generates sequential links by creating a connection between a sector node and the exterior sector node. When generating these connections for Murcutt's houses, four sectors (Hall, Common, Private and Garage) are linked to an exterior node at this step. That is:

$x \rightarrow E$ -link (x), where x={H,C,P,G}

This rule (E-link(x)) is similar to the set of rules in the third step of the grammar, but it is separated to identify a link to an exterior sector node. That is, the rule is concerned with

inserting a sub entrance into a node or a garage sector node at the first depth. This general rule is used nine times altogether in four cases with the last two cases (3,4) using the rule three times each. The particular use of the E-link(x) rule is divided between E-link(C or C²) in each case and E-link(G) when a garage sector exists. That is, a common sector node and a garage often link to the exterior space. The fifth and final step in the grammar adds a link between two nodes. Two cases (1,3) apply the fifth step. With these five steps, a rule-based analysis, using a JPG grammar, is demonstrated. By analysing the applied rules which are used at each of the five steps, to generate four Murcutt houses, we are able to investigate the sequential syntactic structure of each JPG. The following section provides the syntax-based analysis of the outcomes from this JPG grammar for Murcutt's domestic architecture.

Syntax-based analysis

The outcomes of the application of the JPG grammar can be investigated by a combined graphical and mathematical analysis of the spatial configuration. The graphical analysis investigates the topological types of spaces, (that is, the space-type of each generated node), whilst the mathematical analysis highlights the *i* and *CV* results of the six basic sector nodes in Table 2. This process also produces a type of inequality genotype.

The sector nodes of the four houses generated here conform to the following of Hillier's four types: a-(28%), c-(36%) and d-type(36%). The ring-type (c-d-type) sector is dominant in each house. The first case uses only the ring-type sectors. In all the cases, the exterior, hall and common sectors are found as the ring type (c-, d-type), which also have higher *i* and *CV* values than other sector (like the private sector). The hall and common sector linking to the exterior, as a core sector node, provides a starting point for the generation of housing complexes, while they end with a cut-link space such as the private and garage sector. This is sequenced broadly in line with the theory of 'intimacy gradients' (Ostwald, 2011a), starting with the most public and ending with the most private. Based on the integration value (*i*) of each sector, the inequality genotypes of the four houses are as follows:

- Case 1: H(10) >C(5) >T(3.33) > P(2.5) > E(2)
- Case 2: H(5) > C(3.33) = T(3.33) = E(3.33) > P(1.67)
- Case 3: H(7.5) = E(7.5) > C (6) >G(2.14) = P(2.14)
- Case 4: E(10) > H(5) > C(3.33) > G(2) > P(1.82)

In order to clearly capture the pattern of each genotype, this paper highlights the six basic functional sectors. i values in the same functional sectors such as P, P2 and C, C2 are averaged. While the private sector of three cases (2,3,4) is the least integrated space, the hall sector dominates the genotype as the most integrated space. The most integrated spaces in the four cases also exert the highest spatial influence (CV).

The common sector is typically the second most integrated space. This pattern potentially arises from the most frequently applied rules, H-link(x) and C-link(x), in the rule-based analysis. In four cases the core sector node generated by the second rule ($x \rightarrow$ core link (x), where x={H,C,T}) is also the most integrated space. Figure 4 shows the charts representing the inequality genotypes of Murcutt's houses.

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Figure 4: Charts representing the inequality genotypes of Murcutt's houses

The sectors of the last case, Walsh House, are comparatively deep (the average *i* value = 2) while the two early houses is found as having the highest average *i* value (3.33). In three cases (1,2,3) the hall sector dominates the genotype as the most integrated space. In terms of the inequality genotypes, the first two cases, the early houses (built in 1975 and 1980), consisting of two pavilions and transit sectors show the similar topological genotype (H > C > T). The early houses adopt transit sectors intermediating between common sectors and an exterior sector. The later two houses (built in 2001 and 2005), also have a similar topological configuration (E, H > C > G, P) regardless of their physical forms. Spaces in the later houses tend to connect directly to the exterior sectors. In the last two cases by applying the fourth rule (E-link (x)) three times, the exterior sector dominates the genotype as the most integrated space. This is a by-product of the long-narrow forms found in Murcutt's architecture, and one of the interesting findings of the longitudinal design analysis.

The syntax-based analysis presented in this section supports the analysis of the generation results of the JPG grammar and, by highlighting patterns in sector nodes and links, allows for an understanding of the style in Murcutt's domestic architecture.

4. Discussion

If architectural 'style' can be considered as being defined, at least in part, by a combination of gross spatial and formal relations, then the lessons uncovered in the JPG grammar of Murcutt's designs should be apparent, at some level, in the finished houses. Another way or saying this is that, if the proposed framework is useful, then its findings should be able to be interpreted through a close reading of the evidence in Murcutt's architecture, not just in the graph-based extrapolation of zone adjacency. Consider then, just one of the spatial and formal patterns uncovered by the JPG grammar, the recurring and indeed dominant presence of a particular ring-type (c-d-type) sector in each house.

In abstract terms, this particular spatial type comprises a hallway, a common sector (like the living space) and the exterior, into a core ring configuration. From this ring, various truncated or tree-like sectors lead to additional zones. That either the hallway or the living space is connected to the exterior is not unexpected, and indeed in many contemporary houses such a relationship exists. But in three of the four cases considered here, there is functional adjacency between both the hall and the common sector with the exterior. Such a dual relationship between the exterior and separate hallways and common zones would not be unique to Murcutt, but it is less common and it signifies the possible presence of multiple physical connections to the exterior and a less controlled relationship with the outside world than is common in many modern houses. Furthermore, it suggests the parallel presence of visual or formal relations between multiple spaces and the exterior.

A review of the plans of Murcutt's three houses that adhere to this pattern confirms that this relationship is both spatial (configurational) and formal (relational) as the JPG grammar suggests. For example, the Southern Highlands House, with its five exterior connections, two of which are

directly though common areas and two of which loop through common and hallway zones, represents a clear doubling of this design strategy in the same house; something which would be very rare in a more conventional design. The presence of this particular pattern across multiple houses and on multiple occasions in the same house, seems to suggest that Murcutt's style at the very least embraces this pattern, and while not necessarily unique to him, it is certainly a characteristic element of these four houses.

5. Conclusion

This paper describes and demonstrates the first two stages of a new approach, the JPG grammar, for analysing the spatial and formal pattern of architecture. The JPG grammar is derived by uncovering – through a sequential process of constructing and selecting – a topological design structure. A JPG grammar of this type allows for the analysis of an architectural design style as well as the examination of a possible design process which has been used to develop this style. The results of the syntactical analysis of the JPG grammar are also useful for determining some of the characteristics of architectural design styles and for supporting the evolution of designs by way of the topological relationships generated by the JPG rules. Thus, this study contributes to research focusing on Space Syntax as an analytic-generative theory for design and to an understanding of the implications of combining Space Syntax and Shape Grammars. Despite this, the JPG grammar-based framework presented here relies on programmatic adjacencies and so may not provide the same level of insight into social relations as it does for spatial topologies. Future research by the authors will seek to examine this limitation with a larger sample size and with the use of convex spaces instead of functional sectors. These two changes will also allow us to address larger epistemological questions raised by design.

Finally, while the larger research framework described herein consists of three stages – Node, Link and Shape – only the first and second stages are examined in this paper. These stages not only set up the larger framework, but they all suggest a new way of generating a statistical archetype for a designer. A future study will demonstrate the third stage highlighting architectural formal properties using Shape Grammars. The JPG grammar and the Shape Grammar will, in combination, support further exploration and development of particular design styles (like the architecture of Glenn Murcutt). The future work will also require an even more in-depth analysis to understand patterns of archetypes and the sequential processes of topological design.

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