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SYNTACTIC RESILIENCE

054

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ABSTRACT

In many fields connected to architecture and urban design, the term 'resilience' has grown common and tends to stand for a variety of different things. What this paper intends to do is to work with the term under a rather basic understanding – that of systems capable of performing even after being altered. Specifically, this means the extent to which a spatial configuration is sensitive to smaller or larger changes, where these sensitivities can be found and the degree of impact should the links be severed. Building on investigations by Hillier, Shpuza, and Conroy Dalton and Kirsan, the intent is to take one step further and set the term in relation to what a spatial configuration operates as social and cultural interface. Thus, a system that is considered as syntactically resilient is a system where inhabitance (use, identity) can follow similar principles as before the change, whereas a non-resilient system is one that can suffer big changes in the spatial logic by ostensibly minor local changes, thereby putting considerable strain on or enforcing change of inhabitance. The paper furthermore establishes some basic methods and measures for how to measure and analyse this, and also discusses the pros and cons of different spatial models for the ability of analyzing the question at hand.

Concretely, the investigation begins with a conceptual, methodological discussion that is then followed by analysis of a small number of buildings to investigate the validity of the proposed methods and measures. The paper investigates the use of a series of existing measures as well as proposes new measures of configurational sensitivity. Finally it discusses how these measures relate to on the one hand security issues, and on the other generic questions in architectural design.

Keywords: *spatial configuration; architecture; resilience; spatial logic*

Theme: *Modelling and Methodological Developments*

Introducing a term such as 'resilience' may seem a bit precarious, as it is today widely used with a wide range of different meanings somewhat connected to ideas of sustainability and possibility to survive or resist various forms of changes, often but not always connected to one form of damage or another. The term is from ecology, introduced by Holling (1973) as a way to understand nonlinear dynamics in natural systems – for instance in how ecosystem can maintain themselves in face of apparent disaster (e.g. fire, floods).

The wide range of uses, however, allows to specifically discuss *one* interpretation of the word under the umbrella concept 'syntactic resilience', providing the overall discussion of resilience with specific morphological knowledge that contributes to the overall discussion. The point is thus not to propose 'the' resilience measure, but to investigate how on the one hand space syntax is well-posited to analyse resilience, and on the other, develop knowledge otherwise not quite present in the discussion. As this paper constitutes a first step, it will only reach partway; the target is to understand a specific set of features of architecture or in extension cities relevant for issues of spatial resilience. Central to this investigation is the idea of space and society as intricately interconnected (Hillier and Hanson 1984), and the interconnection materialising itself through spatial configuration.

Behind the coming discussion lies a wide study of literature dealing with security in relation to architecture, such as Crime Prevention Through Environmental Design (CPTED), which gives remarkable little attention to spatial configuration, or to architecture as a plastic, changeable material – rather treating it as a 'given' to be somewhat moderated at best (c.f. Németh 2010, van Rompay, Vonk and Fransen 2009). It is not considered neither as means nor as method, and issues 'in space' are rather solved by additions of other types of elements – be they bollards (often 'aesthetically' formed; c.f. Benton-March 2007, Gournay and Loeffler 2002) to prevent car access or lamps to light up 'dark and threatening places' (c.f. Roberts 2005) – or by camera surveillance (c.f. van Rompay, Vonk and Fransen 2009). Security, it should be noted, has been addressed in space syntax already in investigations of relations between configurative properties of cities and crime (Hillier 2004, Hanson 1996). This type of security, however, is not the topic of the current paper. Finally, because of the background in a security project, some of the data can only be presented as statistical results and general models. We will strive to provide clear descriptions of methodology, and analyses of buildings not directly included in the specific research project in order to show details of how various reasoning plays out. While stemming from security research, the intention is to define generally useful terminology in design thinking. Therefore, the 'changes' investigated in this paper are primarily chosen to investigate geometrical and configurative properties; i.e. looking at measures of 'change' as a generic, architectural question.

In order to reach our goals, we will go through a small series of steps: to define from what perspective we discuss 'resilience', to review space syntax research contributing to the line of research, to develop the ideas through a small set of case studies, and to review the analysis and concepts thus far and first, refine 'syntactic resilience', second, point to problems that remain to be solved, and third, what further steps need to be taken in research.

BACKGROUND: RESILIENCE OF *WHAT* AND FOR *WHAT*?

Considered in its most generic view, a 'resilient' syntax of space could arguably be a system as distributed as possible, so that any link broken has as little impact as possible on permeability. This would further build towards a general conclusion where a resilient building would be as close to a grid (or otherwise distributed system) as possible, with as porous boundaries as possible (i.e. as many entrances/exits as possible). Such a concept of *generic syntactic resilience* is, naturally, important to put forth, and relates directly to generic adaptability or flexibility as shown by Matela and O'Hare (1976) using the term 'perfectly cyclic graphs'. These also allow the widest range of social organizations to inhabit them (Steadman 1983). While these studies make simplified models of the relations between spatial and social or functional entities, the generic concepts of adaptability and flexibility can still be reviewed in this way. However, for a range of reasons, such a concept is problematic as a way to study *specific* syntactic resilience in that first, it provides a normative goal, and second, that a measure comparing distributedness compared to highest distributedness (essentially Relative Asymmetry, possibly adapted for geometrical constraints) only gives an overall view and not specific answers to *where* within the system alterations have larger impact, *how many* of these locations there are, or the *degree* to which they are sensitive. This primarily because, simply put, most buildings are for various reasons *not* fully distributed, and other measures for an overall spatial or operational resilience work in other directions, i.e. through partitions and control points. Furthermore, as noted repeatedly within space syntax research, there are many social and cultural investments in spatial configuration that serve other ends than purely pragmatic. As Hanson notes, cultural identity seems to be the strongest factor for the configurational layout of homes (Hanson 1998), and as Shpuza develops on offices:

> "The study highlights the distinction between constraint and determination. Floorplate shapes exercise underlying constraints upon the integration of interior layouts but they do not determine it. This is highlighted by the difference between the strength of correlation between floorplate shapes and internal integration depending on whether we insert hypothetical layouts in actual floor plate shapes or study the actual layouts that are accommodated in these floorplate shapes at some point in the buildings life. Actual layouts bear the influence of factors ranging from design program to design approach. The effect of shape compared to such other factors becomes statistically less powerful." (Shpuza 2006, 242).

That is, even for offices, organizational ideas, identity, self-perception and similar questions have a larger impact on the spatial configuration than the shape of the building, even if the latter sets the range of possible solutions. A *specific* syntactic resilience, then, reasonably acknowledges and allows this instead of insistently pushing towards overall distributedness.

Thus, while resilience as a generic measure is of interest, it is important to consider from what perspective it is to be studied. What *we* mean with 'resilience' is not preserved rational functionality or, for instance, maintaining the possibility of evacuation. While for instance traffic research *does* study whether traffic systems are 'functionally' resilient in that damage to one node should not incapacitate the whole, or large parts of the system, our proposal is somewhat more socially or even socio-culturally oriented.

In brief, we consider a building as an interface (Hillier and Hanson 1984, Hanson 1998, Peponis 2012), and specifically as a gradient interface that mediates on the one hand relations between people, places, activities and things *within* a building, as well as between these, and a similar set of entities *outside* a building. This allows some further refinement. If we further consider this interface to operate in the field of social relations and practices, and within this field on the levels of functionality (can relations be maintained and practices performed?) and identity (how are the inhabiting social constellation and practices mediated to 'themselves', to visitors, and to 'the public'), then much more than simple questions of 'can x or y be done' needs to be taken into account. As it furthermore been found that syntactic properties are central for wayfinding (Ortega-Andeane et al, 2007, Haq 1999, Peponis and Wineman 2002), and then specifically integration, this becomes an interesting key measure from this respect as well. This involves 'free' and 'targeted' exploration behaviour.

Spatial configuration is thus considered to respond to a range of social relations that serve social, functional, rational, and cultural purposes, to name a few. Such complex sets of relations are inherently contradictory, often on many levels, and architectural solutions by necessity depends on priorities being made of which to support at the expense of which, and a weighting of specificity versus generality in this process. With this in mind, and bearing in mind how Markus (1993) points to that buildings are 'useful' for a purpose in as far as they through space, form and function formulate something that is meaningful as a response to this complex and saturated set of relations, it is also important to point to that they also enforce a certain adaption of social practices and identity through the very inability to fully respond to this complexity. This adaption in itself further contributes to the emergent social relations and identity of the building, and of that which makes use of it. It also means, that there is no direct relation between 'a function' and 'a solution', but that it is always a kind of negotiation between ideals and priorities on one hand, and spatial conditions on the other, why 'syntactic resilience' in relation to architecture as a material social object cannot be limited to solely functional, pragmatic, or security concerns.

REFINING THE CONCEPT

With this background, it becomes possible to state that analyzing *syntactic* resilience deals with not generic degrees of change in a spatial system, but *degrees of change of interface and identity mediation*. A simple way of outlining it, is to say that it deals with to what extent, after a change, a building can operate with similar relations, practices, and identity as before – or, to what extent this needs to change. Indirectly, it also includes measures that from this perspective on one hand studies degrees of adaptability (i.e. to what extent is the system sensitive to interventions), and on the other strives to identify specific locations in the system that are sensitive. From this point of view, the measure becomes generally of architectural interest as it responds to 'adaptability' of a system in a specific way, and to degrees of impact of configurational changes.

A few studies within the field become immediately relevant. The basic geometrical investigations of Hillier (1996) in 'the laws of the field', for instance, studying how alterations in a square grid affect depth. This study shows clearly, how even a generic square field is not neutral but that the impact on depth differs on the one hand between different locations of intervention (centre versus periphery), and on the other hand between from where the change is considered (the impact is largest close to the change and can be close to none from far away). This approach is further developed by Ermal Shpuza (2006, Shpuza and Peponis 2005) to study the relation between permeability systems and floor plate shapes, finding that in relation to floor plate shapes, circulation systems have logics in where they are most affected by interruptions that can be zoned into – in a square building – close to the perimeter or far away; zones that can be extended along the extension of perimeters in more complex shapes to define areas within which difference in impact of changes are negligible, but between which the difference is large.

Shpuza furthermore finds interrelations between floor plate shapes and generic permeability structures, such as 'fish bone' or 'grid' systems are differently adaptable to and affected by different floor plate shapes – and also become differently sensitive. To a certain extent, some of Shpuza's studies respond to the question here from the point of view of the 'internal' interface formulated by spatial configuration. It is, however, more focused on the floor plate shapes and permeability structures than the configurative systems 'themselves'.

Conroy Dalton and Kirsan's (2005) study of graph isomorphism also becomes of central interest, as it investigates the similarity of graphs through various changes as a means to understand the impact of design decisions that change spatial configuration. The measure of isomorphism comes from graph theory, and the study is explorative in order to find out whether it can provide interesting information in a design process. An issue with the method, they note, is that the measure of isomorphism is location-neutral; that is, when analyzing a building in this way, the result does not take into consideration whether a change is close to entrances or not. This makes it interesting from the point of view of view of spatial configuration responding to social relations internal within a building, but it has significant problems in how inhabiting social organizations relate to the outside/the public, or how the building operates as an interface for visitors.

MEASURING IMPACT OF CHANGE

With the two basic positions that the building is analysed as an 'interface', and that wayfinding is a key property of interest, a key measure for the analysis is *integration*. That is, if there is on one hand a logic of private-public that roughly correspond to integration, and on the other that integrated spaces are important for wayfinding, then these can be seen as 'spatial logics' to which both visitors and inhabitants relate. If people then tend to go to integrated spaces either when (a) lost, or (b) exploring (Ortega-Andeane et al 2007), then a radical change to integration patterns is likely to conflict with perceptions and cognitive models of the environment (c.f. Tversky 2003, Kuipers, Tecuci and Stankiewicz 2003, Peponis 2012). In this sense, we can compare measures of 'can' with measures of 'would', in that a dual analysis can be performed of whether there *is* still permeability, and whether this permeability has a similar integration interface as before the change. If the question relates to visitors or the public, at the very least, such a question reasonably deals with the exterior and therefore so should the model. It should be noted here, that integration is chosen over step depth (which would show the minimal distance to the nearest chosen exit) because of this relevance for wayfinding – even if in many situation integration and step depth are similar if weighted to an exterior. We also focus on the relation to the exterior as this is something lacking in both Conroy Dalton and Kirsan's and Shpuza's work, why in some sense their respective work can be seen as complementary. In the following, we will discuss two ways of measuring this pattern: measures of *sameness* and measures of *similarity*.

For the purpose of this discussion, we will present results from analysis of an object which plans and identity are not possible to disclose more than as general figures due to conditions of the research project, from here on labeled 'House A'. However, in addition we will present analyses from additional buildings both – it is of interest to note as the research stems from a security project – decommissioned in the form and for the purpose for which they were built and in which state they have been analysed here, and for their current use radically altered. These are the Federal Reserve Bank of Minnesota by Birkerts & Associates, and the Debenhams department store in Stockholm. House A is a building that operates as a public interface (i.e. a public/visitors-oriented programme) with one entrance, where the publicly accessible parts reach deep inside the building but are mainly focused to the ground floor.

DEGREE AND CHARACTER OF CHANGE

Sameness can be measured in a rather simple manner by correlating the values *before* and *after* a change. However, while the correlation figure itself may be of interest, there are additional things to learn from such a measure through the scatterplot between the *before* and *after* change. This can be investigated through scatterplots of changes to a building as marked in Figure 1.

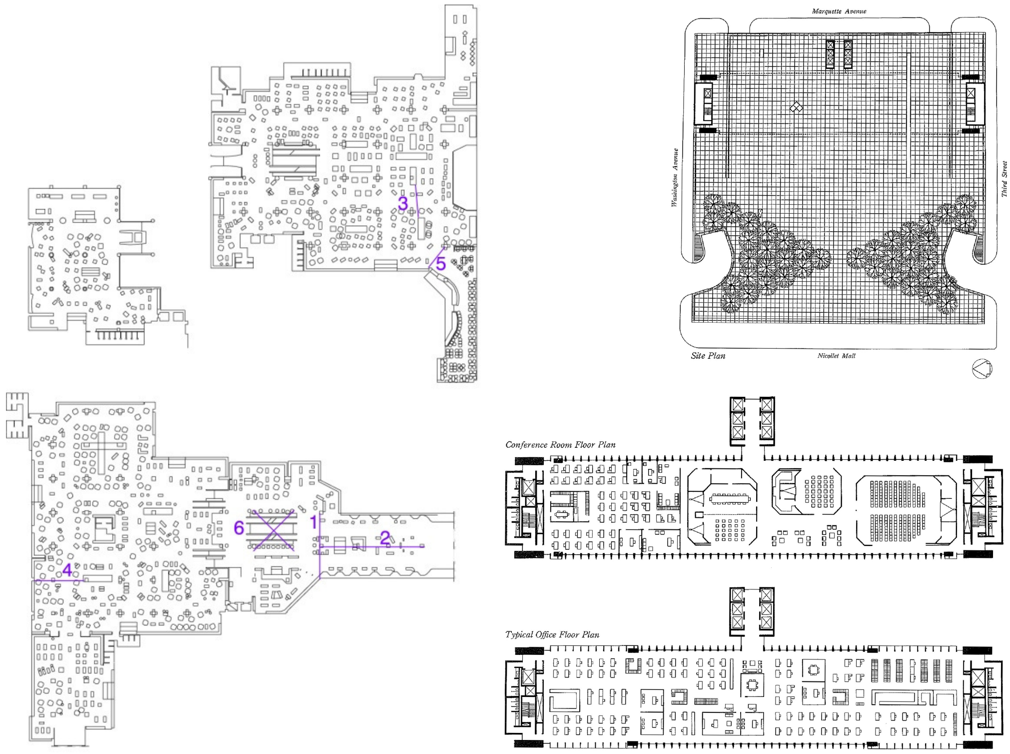

Figure 1: Plans of Debenhams department store in Stockholm and originally published plans of Birkerts & associates federal reserve bank in Minnesota. Both now rebuilt and used in other ways. The Debenhams figure show where the 'blocks' have been introduced to test values. For the Birkerts building, the analysis has been limited to an arbitrary number of floors.

In House A, the 'blocks' are placed so that one closes a doorway into a large hall on the ground floor, one inserts a wall along the centre of the same hall (without touching the far end walls) and one removes a staircase connection between top floors in the deep end. Similar experiments in Debenhams are somewhat more difficult to do as it is much more open-plan, and therefore a larger number of links 'interruptions' have been inserted to test a variety of measures out, of which we here represent six: one *across* the aisle by the main entrance, one *parallel* to the aisle by the main entrance, and three removing links in deeper portions of the building. Finally, in Birkerts' and associates bank office similar operations have been made, focusing on blocking the main vertical communication, this time somewhat outside of the integration core, blocking a slightly off-central portion of a floor, and blocking a segregated but narrowly connected part of a floor. Scatterplots of all these imagined changes appear as in Figure 2. These locations are chosen in relation to Shpuza's (2006) zones of impact and need to further be compared to the investigations of Hillier (1996).

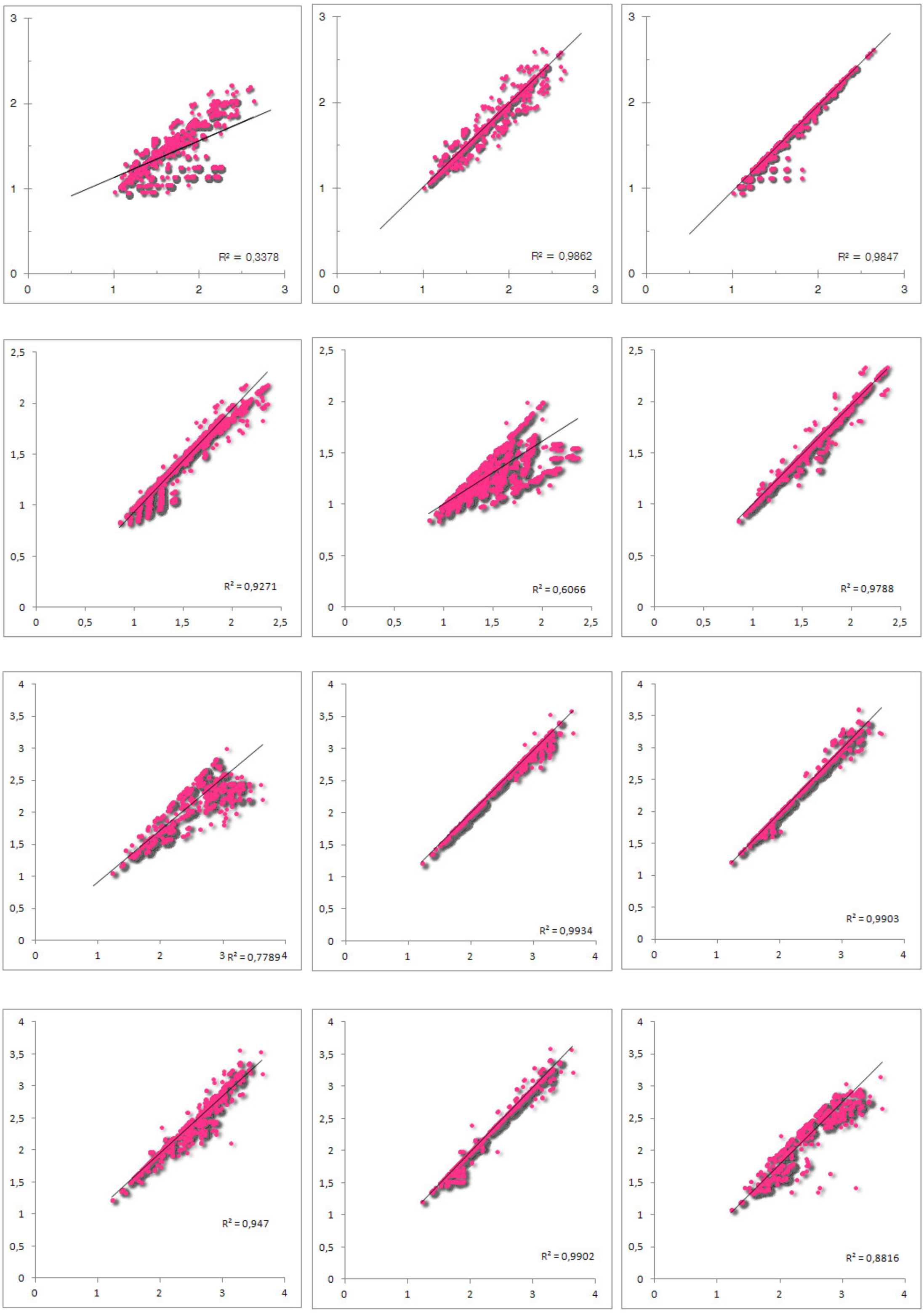

Figure 2: Scatterplots of the relation between integration measures in three buildings, top row of House A, second row of Birkerts & Associates decommissioned bank office building in Minneapolis, and the two last rows of Debenhams defunct department store in Stockholm. The interruptions run from A and alphabetically from right to left. In all figures, current integration values are on the x axis and new integration values on the y axis.

What can be seen is that the different ways of inserting 'blockades' in a building, as in shutting a door or adding a wall, have dramatically different effect on the one hand on *degree* of change, and on the other, on *character* of change. Some of the changes introduce large changes overall, whereas other changes have smaller impact on the overall pattern but has a quite noticeable *local* effect that becomes obvious in the scatterplot, whereas yet others have small effect on the overall pattern (high correlation) but increases the spread in the plot, which could be called 'noise' in the system. Furthermore, it seems that a more distributed and open-plan solution as Debenhams is more prone to 'noise', while less prone to dramatic overall effects (low correlations). Typically, the 'noise' introduction is tied to locations with low control values, and the local effects with low integration values. A more 'uniform' change – local or global – seems to belong to high control values. It also seems that spaces of local centrality as in breaking the cross-connection in Birkert's building on a floor is less powerful than breaking spaces of control as to the elevator package. This helps to understand the overall change of a system, as well as general ways in which changes operate (local or global, specific or 'noisy').

Similarity, which operates on another end of the spectra – arguably, at the end of whether the building forms a similar as before interface or not – can be discussed in a different way, as we are no longer talking about things being 'the same' or, that the building would be inhabited in *the same way.* Rather, the question becomes if a *similar* interface description is made by the spatial configuration before and after the change. This includes degree of interconnectedness and degree of stratification, as well as overall depth to the exterior on a basic level, and the distribution of values and interconnectivity patterns on another.

These concepts can be tentatively translated to *mean integration*, the relation between *minimum and maximum* integration, and the *distribution of integration values*. Most of these are measures removed from the specific plan, but this is partially intentional: the question is not whether the values are *in the same place*, but of the building *offers a similar range of spatial differentiation* and *configurative characterization* as before the change. In order to make a more descriptive yet simple estimation, the values have been considered to be 'equal' if they are within an integration value of 0.025 from the original value, and a difference of more than 0.25 has been marked with double signs.

House A	Block 1	Block 2	Block 3
Mean integration	--	=	-
Max Integration	--	=	=
Min Integration	-	=	-
Integration differentiation	--	=	+
Max-avg	--	=	+
Min-Avg	--	=	+
Max-avg/min-avg	++	=	-

Debenhams	Block1	Block 2	Block 3	Block 4	Block 5	Block 6
Mean integration	--	=	=	-	=	--
Max Integration	--	-	=	-	-	--
Min Integration	--	=	=	=	=	-
Integration differentiation	--	-	=	-	-	--

Max-avg	--	-	=	= (+)	-	--
Min-Avg	--	=	=	-	=	-
Max-avg/min-avg	-	=	=	-	=	-

Birkerts & Associates	Block 1	Block 2	Block 3
Mean integration	-	--	=
Max Integration	-	--	=
Min Integration	-	-	=
Integration differentiation	-	+	=
Max-avg	-	-	=
Min-Avg	-	-	=
Max-avg/min-avg	-	+	+

Table 1: Character of change in the three buildings in relation to 'original' values, where anything within the range of +-0.025 has been treated as 'same' (=), and everything larger than +-.25 has been given double-signs.

Of note is, that the changes with largest effect on 'sameness' in the analysis above in two cases has made the integration range *lower* but *flatter*. By decreasing the overall integration of the building, and to some extent increasing the number of low integrated spaces, the *differentiation* of integration is *smaller*. Furthermore, both maximum and minimum integration values are lower. That is, an *increased homogeneity* of space, where the increased homogeneity is *of more segregated space*. Differentiation seems to increase when a link that is of local or semi-local strategic location, outside the integration core, is removed (House A and Birkerts & Associates Block 3 respectively). This points to that tree-like or series-like structures with several branches has an overall more similar syntactic character globally, than one with a more varied configurative structure between integrated and segregated. It also points to that while the overall *degree* of change may be different, it is another question whether the system becomes *relatively more differentiated or similar* as a whole. While a side-issue at this point, it may be of generic importance.

What we see is that in House A, is that one introduced 'block' causes change across the board, and almost exclusively decreases values except the differentiation, one retains similarity across the board, and one introduces changes but alters between increase and decrease – plus that in general, signs are reversed except for mean and minimum integration, which in general is logical as the changes introduced are typified by decreasing connectivity. In comparison, the effects on Debenhams are more uniform in retaining or decreasing values. That House A has a set of changes that alter integration patterns differently in that it increases integration differentiation is, by and large, because of a single-entrance situation together with a limited ringiness on both local and global scale. That is, in Debenhams or Birkert's building, there are several entrances and more small scale rings, and because of this there are few single links that if removed can simultaneously decrease integration enough across the board for an increased difference between 'highest' and 'lowest'. It furthermore stresses the impression that in most situations, with decreased overall integration follows a decreased differentiation in integration. This is, of course, something that needs to be further developed and which should be further researched in relation to Shpuza's (2006) studies of the relations between floorplate shapes and route fragmentation, as well as impact zones, even if, in general, the results herein correspond to Shpuza's. The main difference is that these figures are weighted by original integration whereas Shpuza's investigate depth increase generically.

Furthermore, again with somewhat self-evident explanation, open-plan solutions are less sensitive than others since they allow far less easy 'cuts' – although a caveat of the method used in the investigation is that it does not easily lend itself to splitting off entire branches of a building. This is not a technical difficulty however, and could be done but the choice has rather been to remain within investigations that allow the properties of the 'whole' of the original with the new situation which has necessitated a 'secondary' access to all places addressed.

IDENTIFYING POSITIONS OF IMPACT

The most problematic question at this point is to identify the positions which are sensitive to change; that is, the positions in the systems where introducing a change would have the largest impact on overall configuration and syntactic character of spaces. While this question again necessitates the question of 'impact for what', we now refer back to the earlier discussion: what we seek are the effects on, on the one hand, the spatial configuration as interface, and on the other hand, the use of spatial configuration in wayfinding, which both have been shown to in different ways relate to integration – one in a socio-spatial mediation of cultural and social relations, and one in how spaces are used and remembered cognitively and psychologically in processes of both open and targeted exploration. While this does not say that integration *is equal* to cognitive maps of space, or directly linked to the psychology of wayfinding (c.f. Kuipers, Tecuci and Stankiewicz 2003, Koch 2012), it seems the kind of generic closeness centrality integration shows captures properties important for these questions.

Studying the results mentioned above closer, there are some properties that seem to become clear. First, the impact of 'materially' large changes can have rather small effect especially on a global scale. This may seem obvious but is important to point out. This means, generalized, that measures that capture local change of properties are of little interest unless they *also* capture global change of properties.

Secondly, changes that take place in more integrated spaces have larger effect than changes in more segregated spaces. This is, again, somewhat expected. However, this is predicated by the same note as above. For the change to be large, it has to also cut off circulation/connectivity on a larger scale.

Thirdly, it seems that changes that cover spaces characterized by high *control* have larger impact than other changes. That is, by letting a change cut off along and through a stretch of high control value, it is likely the change has a larger effect on the system than if the change takes place in areas with low control value. Of note, of course, is that this is not a universal measure, since even low-control spaces in a rastered isovist analysis can hold keys to large changes but tend to require more 'material effort' to implement. It is further of note that this should be compared to the distribution of integration – if changes cut *across* the extension of (higher) integration values it has larger effect than if it cuts *along* integration values.

Fourth, changes that operate where there is a close possibility to circumvent the introduced barrier have little effect at all, no matter where it takes place, and even less if it does not go 'against' the extension of integration. To a certain extent, this means perpendicular to the isovist extension in the high-control area, but this again is predicated by more orthogonal layouts and need to be better studied to say for sure.

Finally, the more and the more spread entrances there is to a building, the more difficult it is to change its overall interface pattern, and the more difficult it is to increase internal differentiation.

This leaves some to wish for, however, as it is a process that is difficult if not impossible to automate due to its high dependency on judgment – even at the 'logically' clear identification method above. This leads us, finally, to bring up another point, which is an issue with the rastered isovist analysis – namely, that it does not provide an analysis of discretised elements of space that separates out spatial entities and their connections. That is, any analysis of the kind makes many links per isovist, and often little differentiation between them, which leads to that a number of mathematical operations become difficult as it comes to this kind of analysis. The 'control' value, for instance, means something else and has a smaller 'reach' or 'impact' in a rastered isovist analysis than in an axial map or convex space analysis. Equally, it is less simple to identify rings and thereby degrees of impact, whereas, by ocular inspection, this is easy to do in a J-graph (Figure 3) such as the one below: the J-graph provides immediate information in that one can quickly identify rings (identified by a horizontal link, or two links from a node 'downwards' in the graph). The impact of a change then is, to a certain extent, proportional to the size of the ring. However, the J-graph does not offer a similar information of e.g. integration values, that is, of centrality of the node in the system – which is in many configurations disconnected to both number of and size of the rings it is involved in.

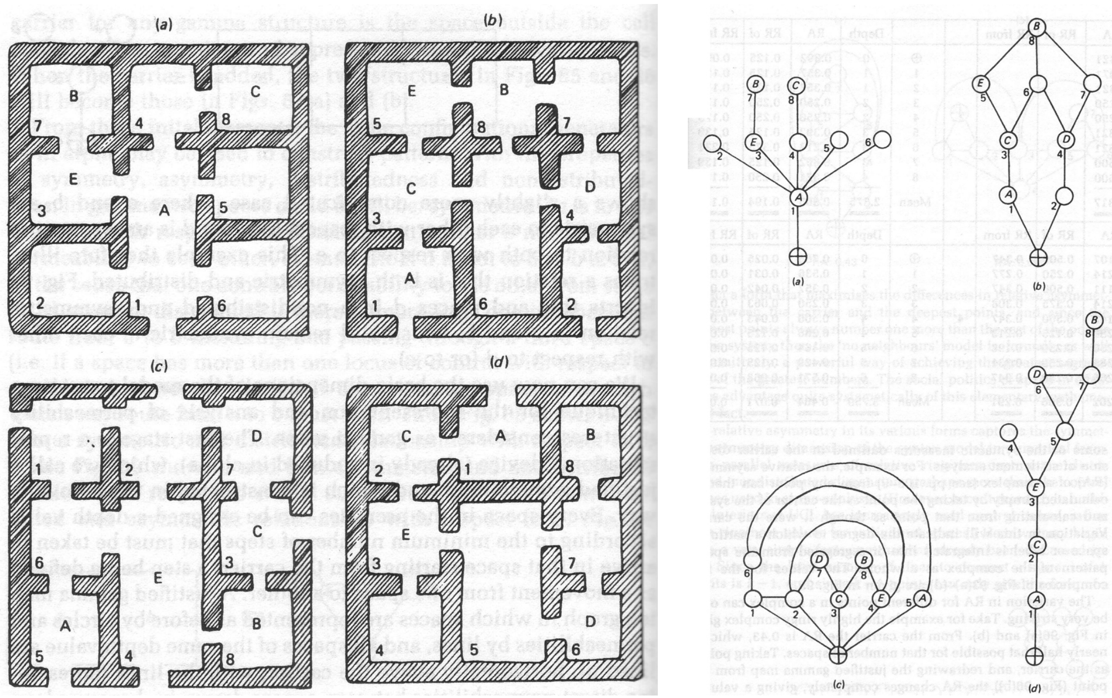

Figure 3: Configurations and J-Graphs from the Social Logic of Space (Hillier & Hanson 1984, 150-151). The J-graphs easily point to spatial rings, and the 'size' of the rings by simply counting number of nodes that need to be traversed to take the '2nd shortest route' between two connected nodes.

However, it does lead to an interesting opportunity, which is to further study this either directly in a discretised system such as convex space analysis or axial maps, or in a more integrated fashion. First, however, this necessitates identifying the way to measure 'degree of change' more quickly and in a fashion that can be made into a measure that can also be reasonably simply computed rather than relying on elaborate and heavy calculations, and second, that allows this to be calculated for the entire graph rather than select positions. However, there is much to learn from the findings above. One thing of importance is the need to combine measures of integration with measures of more local character. However, the measures of more local character cannot be too local, or they will provide irrelevant information (i.e. it will identify sensitivity in trivial rings). This means that the new measure looks something like [integration x local measure]. Secondly, the local character need to be connected to the degree of change – this is also why control has been useful until now, as it identifies a minimum size of impact. That is, since the control value has a certain reach it will highlight spaces where there is a small portion of trivial rings in its direct neighbourhood. However, it cannot differentiate impact beyond this, and thus becomes a weak measure – even if it is stronger in a more discretised system, as in Figure 4, which also (as discussed above) creates a mirror to focus integration around the entrance point. A dummy version of a sensitivity measure thus becomes [integration x control]. This, however, is not enough since control works by adding up sub-graph values.

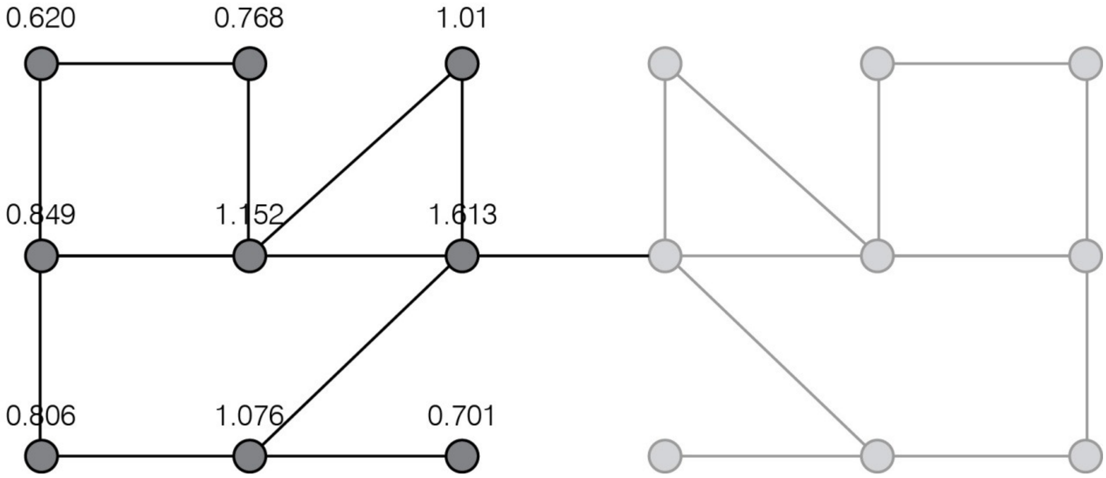

Figure 4: A simple graph of a space with integration weighted to the entry point by mirroring (shaded portion). Integration values calculated in JASS and rounded off to three decimals.

The key might be in the way control *excludes rings of a certain size.* In this way, it does begin to identify regions or neighbourhoods in graphs (i.e. sub-graphs). Bottlenecks in sub-graphs, by and large, identify many of the properties we look for, but risk failing to identify locations of interest, and also does not weigh in the 'impact degree' past identification. However, the concept of bottleneck- and sub-graph identification supports a similar idea as control, and points forward to the measure we would like to propose as measuring 'sensitivity to change', which is fairly straightforward and computationally trivial. It depends on for each node, calculate the 2nd shortest distance to its immediate neighbours, for nodes with several links to a neighbour this would then give the result 1. This value is thus calculated for the *link* rather than for the *node*. If there is no other way, the calculation 'fails' and should result in 0. Second, we reduce this new value by 1, which means that a link to a separated branch receives the value -1, links between two nodes that are duplicated by other links receive the value 0, and any other situation has a 'smallest ring size' value attached to them. This value, then can be multiplied by integration. This means, further, that complete 'tree' locations are easily located as they have negative values, and trivial rings are given a neutral value (0), while other values are weighed by degree of change as well as level of integration. This would work out as in Figure 5:

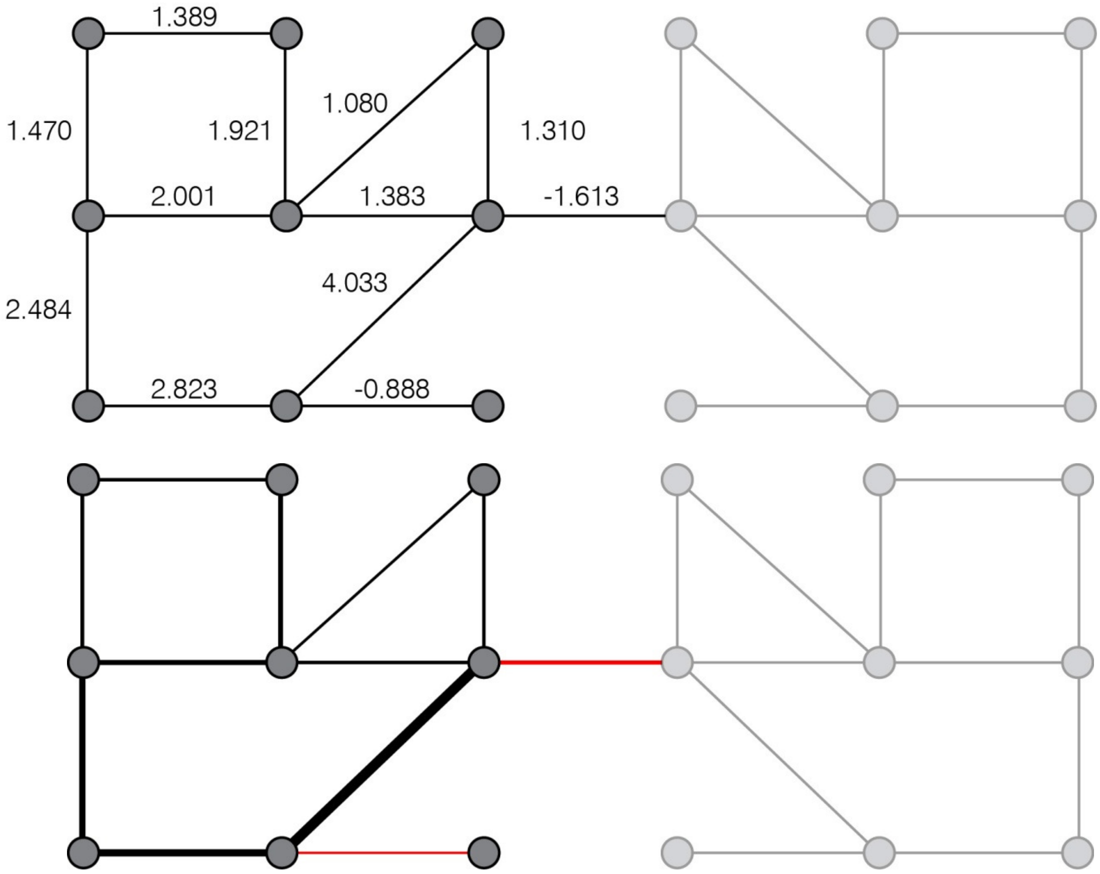

Figure 5: The calculated 'link sensitivity' of using the formula, in numbers (above) and represented for quicker reading through line thickness (below); the latter also has 'negative' numbers in red; i.e. these links severe portions of the graph from one another completely if removed.

As can be seen in the figure, this gives a higher value to larger rings but also puts focus on integration core. It could be argued, that there is a slight over-dependency on ring size, especially in larger systems or in maps made with high resolution. While acknowledging this issue, this is not by necessity an issue with the *principle measure*, even if it is worth having in consideration for the development of the *specific* measure. However, there is nothing that necessitates that 'additional steps' grows with size of the system, it is rather something that grows with resolution of the graph, and therefore, it cannot be made universal in the same way. It also depends on whether the interest is on the *impact of change* as compared to *centrality in the system*. This is something that also needs to be further studied.

In effect, this gives the formula:

$$\text{Sensitivity}=\text{Integration}*(\text{NewStepDepth}-1)$$

Or, when integration is calculated in the 'traditional' form via RRA, the sensitivity formula becomes:

$$\frac{\text{NewStepDepth}-1}{\text{RRA}}$$

This will lead to a link that cuts a tree branch off to have a negative value, a 'trivial ring' to have a value of 0, and all other changes to increase in weight with (1) integration, and (2) the size of the smallest ring in the system in which the current link is part. The exact weighting could be discussed – e.g. the square root of number of nodes could be used instead – but it would follow the same principle of measures. This formula works well for any discrete graph representation, such as convex space graphs, axial graphs, or segment graphs (although potentially step depth would be replaced by angular depth in the latter). It does not work for VGA simply because the relevant potential changes are usually larger than a single link or node. This makes it of high importance, that the representation holds a number of nodes that is validated as relevant and/or meaningful as a representation of the system, as the importance of the number of nodes grows exponentially (it has impact at least twice through integration and step depth). Furthermore, whether the 'integration' measure here is calculated in a convex space graph as above, or is gathered into a discretised graph (convex space map) from an underlying rastered isovist analysis seems to be a matter of judgment that is not resolved at this point. Technically, it could also be calculated 'backwards' as what the 'integrating benefit' of adding a particular link is.

CONCLUDING WORDS

This paper has attempted to discern some concepts and principles for measures defining 'node sensitivity' in relation to changes in a graph, specifically related to research within space syntax. It has done this in a way that allows impact from both degree of alteration in configurative terms, and centrality of nodes. It has further done this in an explorative manner that reasons its way towards a solution rather than employs existing measures directly, either from space syntax or from graph theory. Initially, correlation patterns were used to measure degrees and characters of change, providing a range of information on how alteration affected particular buildings. The method, however, provides information mostly of *sameness*; that is, the extent to which a graph remains 'the same' as before, rather than if it is *similar*. In response, effects on minimum, maximum, and range of integration values were analysed as a means to come closer to analysing *similarity*. Together, these provided knowledge that could feed into a measure of 'resilience', or perhaps better *link sensitivity*. It was further concluded, that link sensitivity measures are dependent on discretised graphs, such as the convex space graph. The last measure, again, handles impact on *sameness*, and can be complemented by e.g. graph isomorphism measures, which need be further developed.

Based on the discussion throughout, 'syntactic resilience' as a concept could be further defined to have to do with whether a system retains its system logic or not – i.e. if the *spatial configuration makes a similar socio-spatial interface description or not.* This means that measures of 'similarity' ought to, beyond the general measures of *mean, max, minimum, and integration differentiation* discussed above, also potentially contain measures of *ringiness, number of branches, degree of seriality, mean, max, and minimum size of rings,* et cetera. Furthermore, it can be argued that future research should find ways to differ *impact reach* and *impact type* more precisely than the herein discussed correlation patterns, noting that some changes have small overall impact but local, others have large impact, and yet others have small overall impact but introduces 'disturbance' in the whole system.

However, this paper points to both a need and a possible way forward for understanding what links in a graph are sensitive, in that blocking them would make dramatic changes in the interface description made by a spatial configuration, and which would make little difference, on an overall level, but also on a wayfinding level. Finally, the paper contains the proposal that within the overall discussion of 'resilience', and perhaps 'spatial resilience', there is a possibility and potential to define *syntactic resilience*, and that *syntactic resilience* specifically means the *degree to which a spatial configuration formulates a similar interface or not*. However, the paper also clearly shows that 'resilience' in this sense does not translate easily to morphology, and works better as a framework or overarching question than as a single particular measure. That is, a configuration can be resilient in a number of ways, and the way to measure it depends on the key question repeated throughout the paper: *resilience of what and for what*? It is our claim, that with this question answered, this paper presents knowledge on how to study it morphologically. The measures, however, can also be used for a range of other questions perhaps better understood as dealing with *alteration* or *adaptability*. – if we here consider 'adaptability' to be sensitivity or receptivity to *physical changes* of a configuration, and how this allows for various forms of inhabitance, rather than how well it, unchanged, responds to different forms of use.

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