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Use of an online interactive space analysis tool to understand student perceptions of four secondary schools

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Abstract

With the sheer complexity of the built environment, understanding the aspects of the building that directly impact the occupants can be prohibitively difficult. Previous methods have been largely split between low-number, high-detail methods (photo-surveys or interviews), or high-number, low-detail methods (questionnaires). This study presents an alternative to these methods; creating an online tool that represents a navigable building, enabling the occupants to freely identify any aspect of the building that they feel is important. This online tool deliberately works in a manner similar to Google Street View, taking advantage of this familiarity to reduce the learning curve and maximise immersion. Using spherical images captured with a special camera or smartphone, each space in the building is captured and then uploaded into the online tool. Whilst in the online version of their building, the respondent can navigate through the building, make unguided comments about any part of the building.

Using this tool, four recently built secondary schools were imaged and online versions created. In each school, students from three ICT lessons aged between 11 and 14 explored the online version of their school and marked parts of the building that were important to them. The students were asked to follow a typical day in the school, moving from lesson to lesson and to the spaces they use at breaks. The tool collected both the movement data and the comments, allowing analysis of not just the occupant attitudes, but also the route the students take through the building.

The movement data for each school was compared to the visual graph analysis of the building, showing that the movement of the students within the tool resembles patterns seen elsewhere; configurational logic with attractors. The rich data that is generated in parallel with the movement data allowed insights into the way in which the students moved through the space and what was important to them.

Keywords

Schools, occupant feedback, POE, VGA.

1. Introduction

With the increased focus on sustainability and the energy performance gap evident in the newly constructed building stock (CarbonBuzz 2013), Post-Occupancy Evaluation (POE) has becoming increasingly common. This drive to understand the relative successes and failures of a project is something that is common in many other industries, but relatively immature within the construction industry. This was largely re-launched by the successful Probe studies of the late 1990's (Cohen et al. 2001). Reflecting this change in attitude, the Royal Institute of British Architects (RIBA) has updated their Plan of Works 2013 to incorporate a specific stage that deals with POE, hoping to embody the process within new projects.

While POEs are not rigidly defined, they tend to fall within three overlapping areas: environmental performance (air quality, temperature for example), energy performance (gas and electricity consumption), and occupant satisfaction. Each area needs a distinct toolset to investigate and draw out conclusions, but with the sheer complexity of the built environment, this can be prohibitively difficult. Within these areas perhaps the least understood, and arguably most important, is the occupant satisfaction. One of the barriers to understanding occupant satisfaction is data collection. Energy and environmental performance can be measured and recorded using sensors due to their quantitative nature (see Chatzidiakou et al. (2014), and Burman et al. (2012) for recent examples), but the qualitative nature of occupant satisfaction makes data collection less straight forward. Instead many methodologies exist, each with their own particular characteristics that explore the perceptions of the occupants.

Within this work, the methods of obtaining occupant perceptions will be explored, identifying the balance between qualitative and quantitative analysis that faces built environment researchers. In response, a new research tool will be put forward, aiming to enable detailed occupant data to be captured quickly. This tool will then be tested at four English secondary schools to understand its characteristics and efficiency. Using the tools within space syntax analysis, the data from the tool will be examined to understand how the occupants move within the tool compared to how they would be expected to move.

2. Background

Determining the correct method to draw out the perceptions of the occupant is a question that has faced many built environment researchers, typically framed by the issue of quantity versus quality. This spectrum of quantity and quality is typified by two extremes; questionnaires and interviews. Questionnaires such as the successful Building User Survey, BUS (Leaman & Bordass 2001) or Berkeley's Center for the Built Environment IEQ questionnaire (Zagreus et al. 2004) are highly popular within POEs, with Peretti and Schiavon (2011) identifying 10 questionnaires available to researchers in this area. Multiple choice questionnaires are particularly popular due to their ability change qualitative data into quantitative, enabling high scalability, well developed analysis methods to be used (Ben-Akiva and Lerman (1985) for example), and good repeatability.

However, the process of converting the occupant perception to quantitative data poses a number of additional issues. Heavily guided feedback, such as in multiple-choice questionnaires, only allows the occupant to respond to the asked questions, potentially missing aspects more important to the occupant. A common issue within schools is a majority of the occupants spread their time throughout different spaces within their building. Within questionnaires, such as the BUS (Leaman & Bordass 2001), building-wide questions are asked that can be difficult to answer if there are spaces that are particularly poor (or good). Additionally, questions need careful consideration to ensure that the question is read in the same way by all respondents (Willis 2004).

At the other end of the feedback spectrum are the interview techniques, such as cognitive interviewing (Willis 2004) or photo-surveys (Moore et al. 2008). These techniques provide incredibly rich data, allowing the researcher to explore the respondents' thoughts to establish underlying motivations for an opinion. This is an advantage that enables the researcher to focus on the most

important aspects of the building from the occupants' perspective. The photo-survey method allows completely unguided feedback, with the respondents asked to photograph aspects that are important to them during a typical day, which are then discussed with the researcher to ascertain their importance.

It is clear that interview methods allow greater insight into occupant perceptions than questionnaires, but at the cost of speed (both data collection and analysis). For exploratory work underpinning future research this may be acceptable, but when trying to ascertain building performance this may prove limiting. Within any interview technique there is bias from the researcher, whether intentional or not, which may skew results rendering the work difficult to compare between research teams (Beatty & Willis 2007). There is also difficulty of analysis, with the largely qualitative data requiring another layer of analysis before any statistical tools can be used.

From these two extremes of the feedback spectrum it can be seen that there is a balance between the richness of data and the quantity. In practice most researchers use a combination of the two methods, using the initial interviews to guide the final questionnaires as discussed by Amartunga (2002). However, a mix of the scalability of the questionnaires and the rich data from the photo-survey method within one tool could provide an elegant method of capturing the occupant perception. With large scale unguided feedback, the occupants would automatically focus on the most important aspects of the building, illuminating the hierarchy of environmental aspects within their space.

Understanding the relationship between built form and usage processes is often beyond the reach of occupant feedback tools, but space syntax as a field provides the tools to explore this relationship. Creating links between the school as a space and the occupant perceptions/usage patterns will help to greatly understand the influence of the building, while adding to the space syntax community knowledge, where schools= buildings are under-represented. While under-represented, there have been some investigations into the space syntax of schools, notably Pasalar (2004; 2007), and is best surmised by Sailer (2015). Pasalar found that the form of the building had a direct bearing on the way students created friendships, encouraging or preventing interaction between age groups.

3. A New Feedback Tool

To understand the school built environment from the perspective of the students, this balance of quantity and quality required a new approach, optimising existing methods. The initial impetus was the photo-survey method, as successfully used by Powell (2010) and Adams et al. (2007). Building on the idea of unguided feedback using the building as a prompt, alternative methods of capturing this concept in a scalable, online format were investigated. The most famous method of experiencing a place online is through Google's Street View[1], where roads are mapped with a spherical image that can be navigated, emulating the experience of being in the space. This has had the advantage of development by a world leading technology firm, and the interface has been refined to improve the user experience. As such, it has a wide user base and is familiar to a majority of regular internet users. Using Google Street View as a method for collecting data has already been undertaken by Stickyworld[2], a platform to enable stakeholder engagement. The main aim of Stickyworld is sharing thoughts by placing 'stickies', which are visible to other users of the site, creating a dialogue that can be used to inform future designs. Using both Street View and Stickyworld as examples of ways to experience environments and solicit opinions respectively, it was decided that a new bespoke Interactive Space Analysis Tool (ISAT) was required.

Before development on the ISAT started, it was necessary to outline the principals of operation and the key outputs to ensure its usefulness as a research tool. As such, the following requirements were placed on the system:

[1] www.google.com/streetview
[2] http://www.stickyworld.com/

- Analysis
  - Record background demographics of the user
  - Allow comments to be located to specific positions
  - Store images from the comment locations
  - Record movement through the building
- Interface
  - Be internet based
  - Simple/familiar interface
  - Accurately represent the building
  - Work on a number of devices
  - Load quickly
  - Allow immersion in the space
- Flexibility to analyse different spaces

By creating a simple, familiar interface, the learning curve for the tool can be minimised and the amount of time collecting relevant data can be maximised. For this reason, the ISAT will be based on Google Street View, although for simplicity it will be limited to horizontal movement. The space itself needs to be the key element of the interface, as such the interface will be dominated by an image of the space, with ancillary information pushed to the edges. Interacting with the interface will be through conventional techniques, predominantly using common mouse-based methods (for example clicking, scrolling, and dragging).

Comments within the ISAT will be captured using the mouse, clicking on part of the space that represents the aspect that is important to them. This creates a virtual photograph of the aspect analogous to the photo-survey method, a box containing a sentiment selector ('Good', 'Bad' or 'For Information') and space to enter the comment, representing the 'tag' that goes with the image. Each space will be represented by a 360° panoramic picture, which will be rotatable to enable the user to see the whole space. Movement between the spaces will be accomplished by creating natural links between each space, such as doors, where the user can click to progress. As such the ISAT version of the building will be a series of discrete points navigated largely by vision.

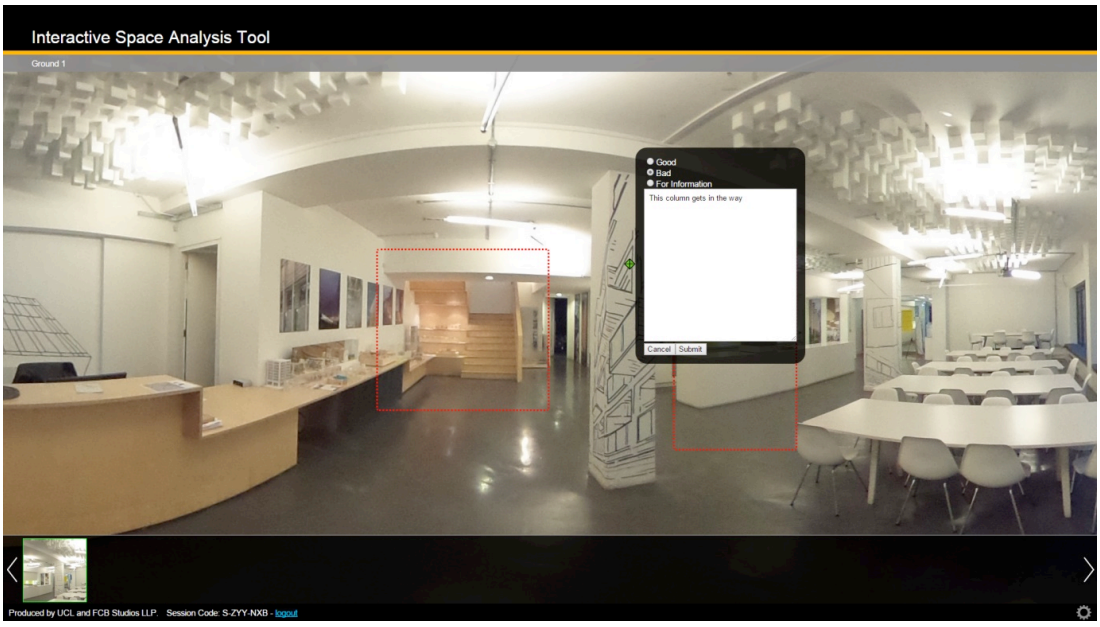

Figure 1: Screenshot of the ISAT interface, with links to other spaces highlight by the red box, the comment box hovering next to the selected point, and the previous comments for that space at the bottom of the screen

Building on the need for an accessible web-based environment, the tool predominantly used JavaScript, connecting to an SQL server using ASP.Net. This method was chosen over other languages (such as Adobe's Flash or Java applets) to enable cross-device compatibility, particularly with tablets and phones for future iterations. Figure 1 shows the final interface of the ISAT following login, completion of the background questionnaire and reading of instructions.

4. Case Studies

To test the ISAT, it was decided to explore four recently completed secondary schools, detailed in Table 1, all designed by Feilden Clegg Bradley Studios to ensure consistency of design philosophy. Schools represent a regularly occurring, complex building, with a significant impact in shaping society. in a recent study by Barrett et al. (2013) the built environment was shown to account for 25% of the academic performance of primary school students, but many gaps in knowledge still exist. Higgins et al.'s literature review (Higgins et al., 2005) highlighted not only these gaps in knowledge, but also the conflicting evidence within the existing research. This is particularly true of the influence of the built form, which is more subjective than the other environmental aspects such as air quality (L. Chatzidiakou et al., 2012), light levels (Heschong et al. 2002), or acoustics (Shield & Dockrell 2003). However, colour of the school (Wollin & Montague 1981), maintenance quality (Durán-Narucki 2008), and layout of spaces (Betoret & Artiga 2004; Martin 2002) have also been shown to influence the performance of the students. Using unguided feedback into the school environment will identify the environmental priorities of the students, assisting with future research into school built environments.

Table 1 : Details of the four schools studied in the bottom-up approach

	School A	**School B**	**School C**	**School D**
Location	Kent	Central London	Northamptonshire	Sussex
Setting	Suburban	Urban	Suburban	Rural
Construction Date	2010	2009	2006	2011
Type	State school	Academy, Sponsor Led	Academy, Sponsor Led	Academy, Sponsor Led
Gross Internal Floor Area (GIFA)	8,257 m^2	10,960 m^2	11,921 m^2	11,660 m^2
Number of Floors	2	6	2	2
Spatial Configuration	Atrium	Compact	Courtyard	Fingers
Number of full-time equivalent pupils (as of September 2014)	724	840	1376	618
Pupil density	11.25 m^2/pupils	13.05 m^2/pupils	8.66 m^2/pupils	18.87 m^2/pupils
Gender	Mixed	Mixed	Mixed	Mixed
% of boys on roll	50.1%	58.1%	53.6%	48.5%
Age Range	11-16	11-18	11-18	11-18

The schools were imaged during a half term, using either a mobile phone and Photosynth[3] software (schools A, B, and D), or a specialist spherical camera (school C). All spaces accessible to the students were intended to be photographed (excepting toilets), but due to maintenance work and extra lessons, not every space could be imaged. Through discussion with the schools' management, it was identified that the ideal opportunity to use the ISAT with the students was during an existing ICT lesson, using teaching time and the access to PCs to facilitate the process. Three classes participated at each school, covering ages 11 to 14, and the students were given a maximum of 40 minutes to follow a typical day in the school using the ISAT. Older students were not available due to upcoming GCSE commitments.

The tool was introduced by the researcher, who was on hand during the feedback process to help with questions about the tool. Students were asked to comment on any aspect of their building that was important to them, with a reminder to give positive as well as negative feedback. In order to get an understanding of how they interact with the building, the students were asked to follow a typical school day, moving between lessons and breaks.

5. Analysis

The data from the ISAT falls into two groups: navigation data and comment data, which will both be analysed using different methods. Navigation data from the ISAT will be used to ensure the virtual movement is consistent with real movement, validating that the users approached the virtual building as they would the real building. Comment data will be used to explore the users' perceptions of their building.

To establish realistic movement within the ISAT tool, the visit count for each space will be compared to Visual Graph Analysis (VGA) undertaken using depthmapX (Varoudis 2012). VGA has been chosen because of the very nature of how it analyses the building form, discretising the building into a series of points and analysing the mutual visibility between these points (Turner et al., 2001). This mutual visibility between points represents the isovists of an occupant within the space and has been used to derive metrics that reflect the movement through the space. The 2-dimensional visual nature of VGA closely resembles the movement within the ISAT, with scrolling fixed to horizontal panning and moving between the spaces identified through visual cues.

Modelling of the schools within depthmapX will take into account vision within the schools at a nominal 1.5 metres above floor level, allowing views across atria, modelled using the visual link tool using the methods outlined in Sailer (2010). As the tool cannot record movement to the same level of accuracy as the VGA furniture will not be modelled within classrooms, greatly simplifying the model and comparison between the ISAT and VGA. The raw visibility of a space is directly related to the size of the building and spaces, as such other measures have been developed to enable dimensionless comparisons between buildings that are better suited to analysis. The most commonly used is the visual integration, first proposed by Hiller and Hanson (1984) for use with axial line maps, but appropriated by Turner et al in their work outlining VGA (Turner et al. 2001). The integration has been correlated to movement in schools by Pasalar (2004; 2007) and in other types of buildings, such as museums (Peponis et al., 2004; Turner et al., 2001; Tzortzi, 2004) and offices (Sailer 2007). As such, integration shall be used to understand the movement within the ISAT, although it should be noted that occupants can be significantly affected by attractors, reducing the efficacy of integration (Sailer 2007).

The main output of the ISAT is the comments from the occupants, giving their unguided opinion on the building. With such data, it was decided that grounded theory would be used to draw out any conclusions as it is ideally suited to areas with no defined theory (Stern 1980). By creating a framework for the collected data rather than fit it into an existing one, the analysis is far more robust and relevant (Eisenhardt 1989). This has been widely applied in areas of research where prior knowledge is not directly relevant (such as in the exploration of the office environment by Sailer

[3] https://photosynth.net/ (last accessed 05/02/2015)

(2010)). Applying the grounded theory principals and the open coding (Corbin & Strauss 1990) method to the ISAT data creates four distinct steps:

1. Initial coding of each comment based on initial reaction
2. Recoding of the comments until no new codes emerge
3. Analysis of generated codes to create general properties that represent the codes
4. Generation of overall dimensions that group the properties into larger themes

Each comment could incorporate more than one property, and as such could refer to more than one dimension. Additionally, the sentiment of each property will be recorded, positive, negative or neutral, so that overall sentiments to each property and dimension can be analysed. This will be particularly useful in comparing the schools, identifying the performance of different strategies at each school. As the data will generate the properties, it can also be inferred that the properties identified are those of highest importance to them.

6. Results

The ISAT was used at each school, towards the end of the heating season on the following dates:

- *School A*: 20th May 2014 and 21st May 2014
- *School B*: 11th April 2014
- *School C*: 29th April 2014
- *School D*: 15th May 2014 and 16th May 2014

The comments received were split into relevant and irrelevant, with irrelevant comments ranging from those about the ISAT itself, about themselves, duplicates, blanks, and those that were unknown (such as seemingly random letters). These were removed from the analysis pool during the grounded theory process. Within each school, it can be seen from Table 2 that the percentage of relevant tags varies in each school (from 59.7% to 69.3%), with a mean relevance rate of 64.4%. Additionally, the number of relevant tags per user varies substantially (from 3.3 to 6.6 relevant tags per user), with a mean relevant tag rate of 5.1 tags per user.

Table 2: Number of 'tags' received by school, along with number of users and tag/user ratio

School	Users	Total tags	Total tags per user	Relevant tags	Relevant tags per user	Percentage of relevant tags from each school	Percentage of relevant tags from overall tags
School A	48	410	8.5	284	5.9	21.8%	69.3%
School B	61	337	5.5	202	3.3	15.5%	59.9%
School C	71	790	11.1	472	6.6	36.3%	59.7%
School D	73	502	6.9	344	4.7	26.4%	68.5%
Total	*253*	*2039*	-	*1302*	-	-	-
Mean Average	63.25	510	8.0	326	5.1	-	64.4%
Range	25	453	5.6	270	3.3	20.7%	9.5%

7. ISAT Navigation

Visually comparing the patterns of navigation within each of the four schools to the predicted movements from the VGA analysis finds that the pattern of movement is very similar for all schools (see Figure 2 and Figure 3). Splitting up the schools, as shown in Figure 4, shows that there is variance between the schools, although at each school there is a significant relation between the integration of the space and the number of visits within ISAT. Schools A, C and D have stronger

correlation coefficients (R^2=0.573, R^2=0.625 and R^2=0.515 respectively) than school B (R^2=0.323), which also has the lowest mean integration (1.9) of the four schools (see Table 3).

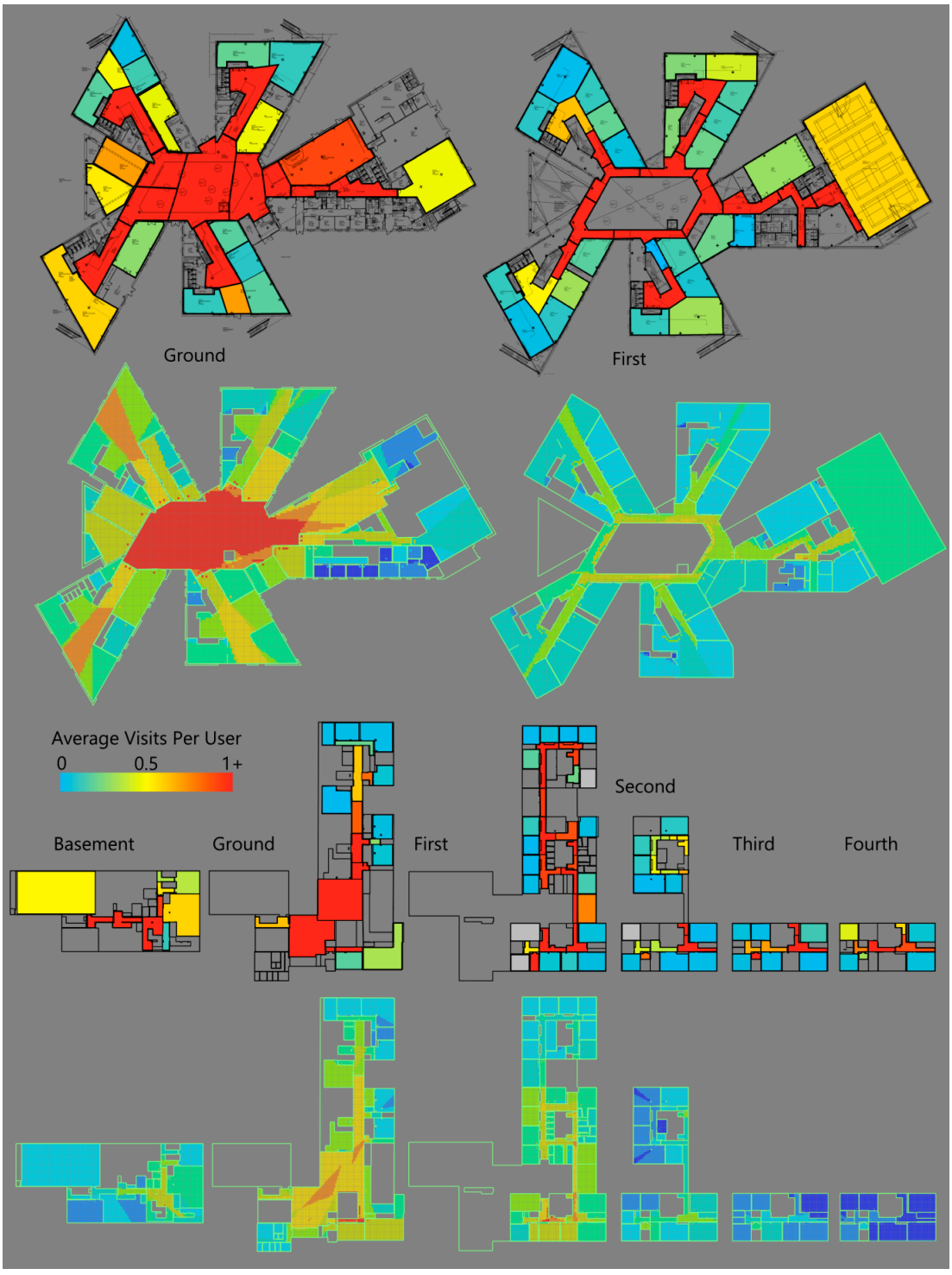

Figure 2: ISAT navigation compared to VGA integration. Top: School A (with ISAT results on the top row), and bottom school B (with ISAT results the top row). Note the ISAT scale is typical visits per person, with red representing 1 or more. The VGA scale uses the same colour scale.

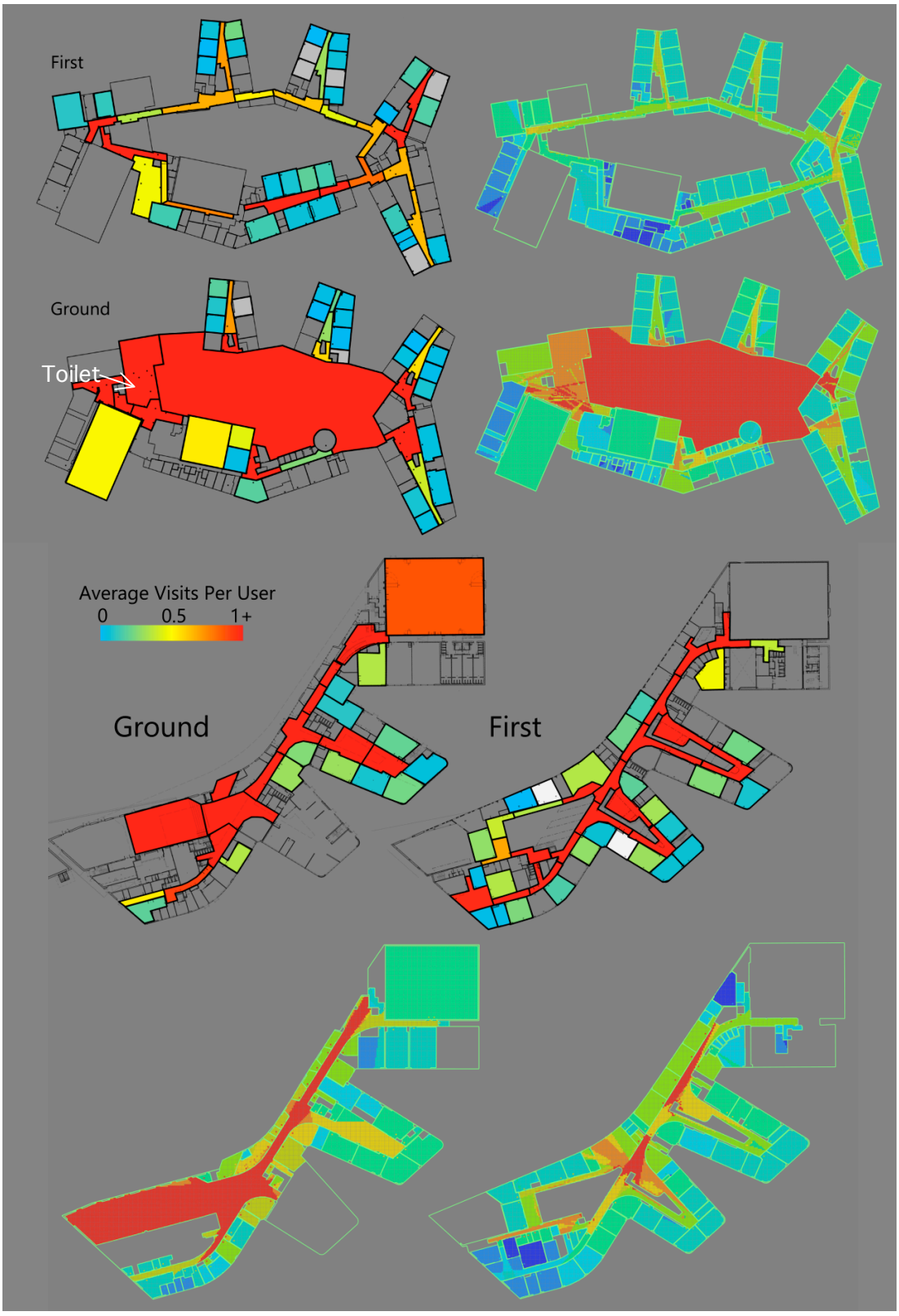

Figure 3: ISAT navigation compared to VGA integration. Top: School C (with ISAT results on the left), and bottom school D (with ISAT results the top two). Note the ISAT scale is typical visits per person, with red representing 1 or more. The VGA scale uses the same colour scale.

The overall low levels of integration in school B stem from its nature as a school on a constrained site, which meant the school had to rise across a total of six floors (compared to only two floors for the other three schools in the sample). The analysis seems to point to two different phenomena: on the one hand natural movement (Hillier & Penn 1991; Hillier et al. 1993), where the navigation follows the configurational logic of spaces (as represented by relatively high, significant and consistent correlations); and the deviation of movement flows in the navigation introduced by the presence of significant attractors as defined by Sailer (2007), notably the sports halls, drama spaces and assembly halls in each school.

To help understand the relationship between the VGA and ISAT further, the circulation was separated from the other spaces that could act as attractors through their end-use (such as the sports hall). Within Table 4, the correlation between the integration and the number of visits for each space shows that circulation spaces have higher correlation than the other spaces, except in school B, where the converse is true. This suggests that the movement between spaces is guided by vision in buildings where higher integration exists, but the non-circulation spaces are likely to be visited for reasons other than vision, namely lessons or dining.

The fact that circulation spaces show higher correlation coefficients in the four schools than other spaces highlights that pupils did follow the brief of replicating a typical school day in their navigation patterns, meaning that the routes around the building were used most frequently. It also underlines again that navigation followed visibility patterns, thus validating the tool and supporting the influence of configuration in a situation where attractors are taken out of the equation. In school B this pattern is not evident, caused by the lower mean integration of the building as a whole, with routes far more defined and less opportunity to deviate from this route.

Table 3: Characteristics of space 'visits' within the ISAT and integration from VGA

School	Integration	Average Visits Per User	Average Non-Circulation Visits Per User	Average Circulation Visits Per User
A	3.1	0.84	0.26	1.64
B	1.9	0.60	0.23	0.96
C	3.3	0.49	0.20	0.92
D	3.5	0.85	0.28	1.56

In addition to monitoring the route throughout the virtual building, the ISAT tool can also solicit feedback on why building users visit each space. Based on the distribution of tags in each space, we can start to identify whether the users were actively engaging with the building in the space, then compare this to the amount of visits the space received. Figure 5 illustrates that non-circulation areas received high amounts of comments; these are also the spaces that where visited more often than would be expected from the VGA analysis (such as the sports halls). Focusing on the non-circulation spaces, the number of comments and the number of visitors is significantly correlated for all four schools (School A: $R^2 = 0.816$, School B: $R^2 = 0.393$, School C: $R^2 = 0.572$, School D: $R^2 = 0.408$) with school B again showing the lowest correlation. It appears as though the students in the schools were travelling to these spaces to make comments as they were important to them, acting as the attractors Sailer (2007) found in offices.

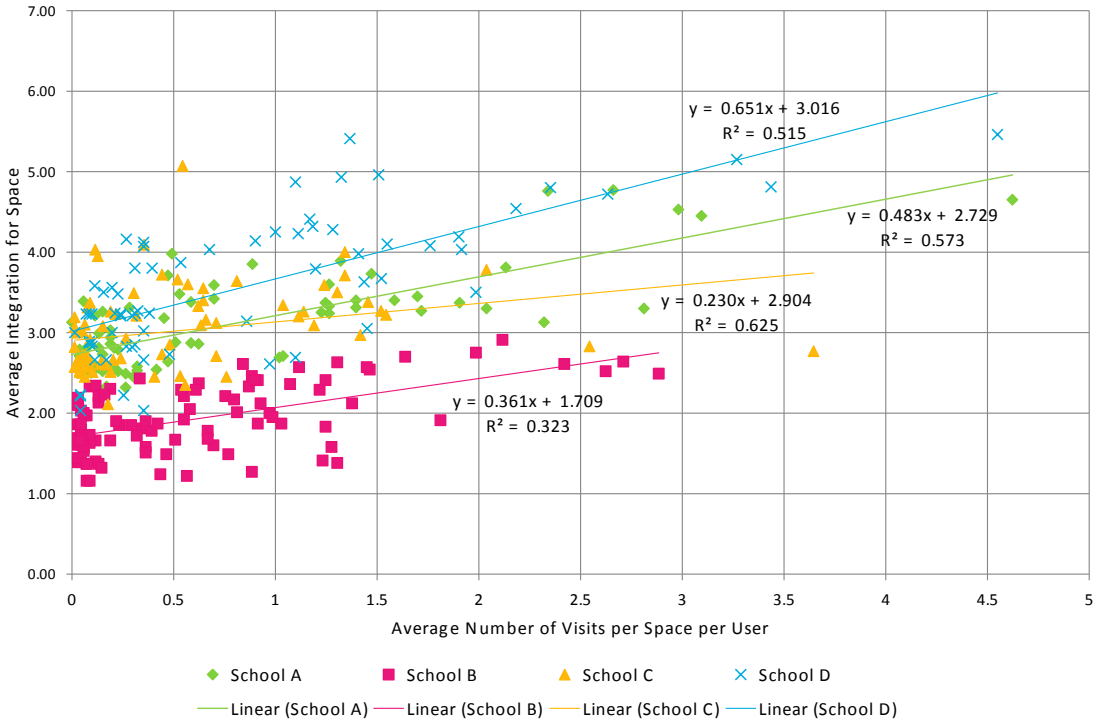

Figure 4: Scattergram showing the relationship between the average space integration and the average number of visits per user, split by school. Note all R^2 values are significant at $p<0.0001$.

Table 4: Table showing the correlation coefficients between the number of space visits within the ISAT and the visual integration, separated by school and space type

	Correlation coefficient (R^2) between number of visits in ISAT and integration	
	Circulation	Other Spaces
School A	0.434	0.286
School B	0.230	0.249
School C	0.435	0.412
School D	0.318	0.193

8. ISAT Comments

The main thrust of developing the ISAT is to gather opinions on the building from the occupants in a natural way. Through the comments we can start to understand what they think about when they move through their building. The comments of each school were collated using MS Excel, as a direct export of the SQL database. Applying grounded theory generated four main dimensions as shown in Figure 6. The four dimensions of interest were as follows:

1. *Building Management* – covering facilities management, FF&E and ICT
2. *Environmental Performance* – the internal environment of the school
3. *School Design* – the physical building design
4. *School Management* – closely related to the school climate

Each of these dimensions has a varying number of properties, coded as either positive or negative within the worksheet. Additionally, glazing, air quality, furniture, ICT, and control of spaces have sub-properties, with the additional nesting making it easier to spot the underlying pattern.

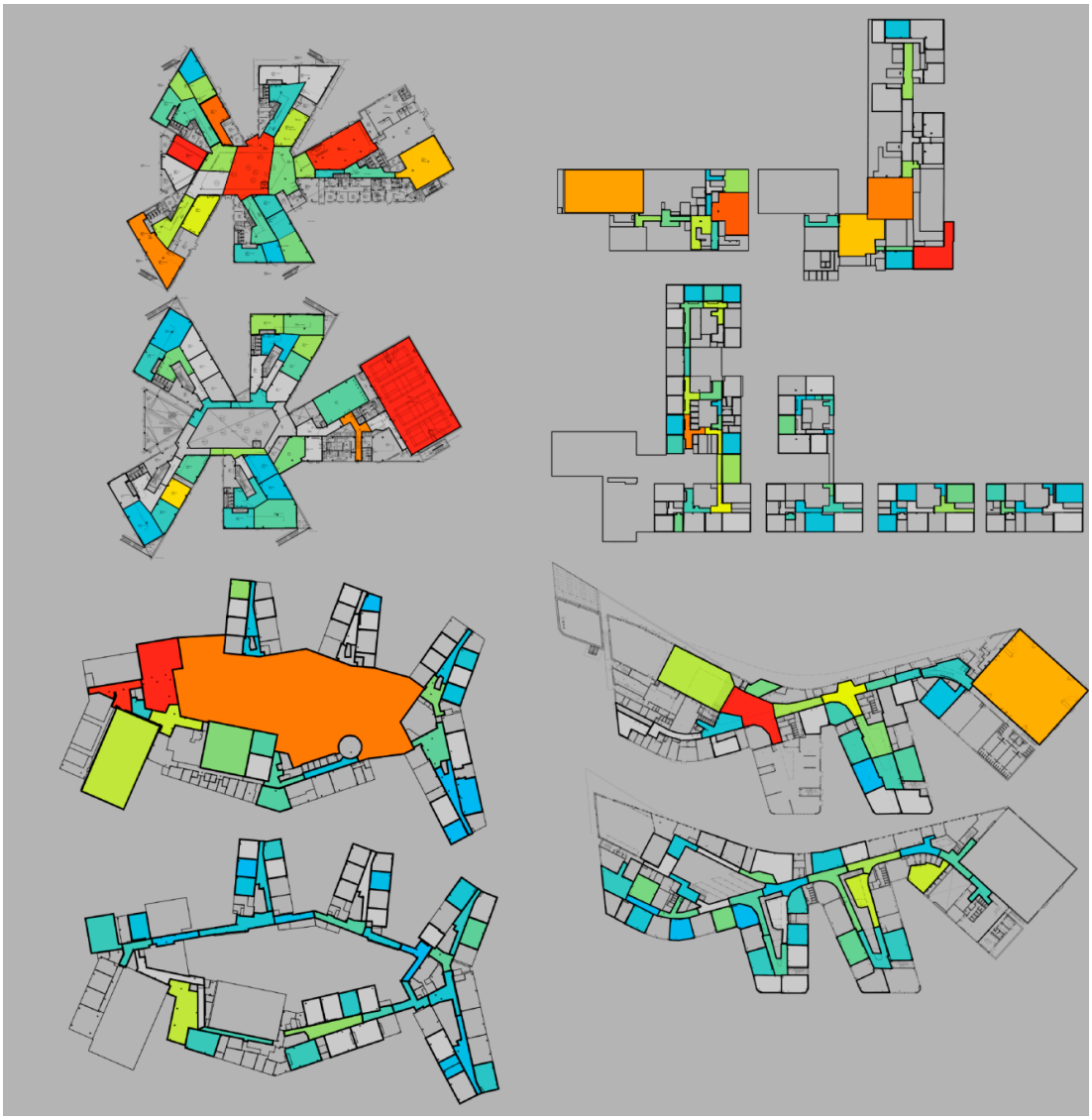

Figure 5: Coloured layout plans for each school, showing the areas which attracted the most comments as a percentage of the maximum number of comments received in a space in each school, with red representing the most, blue representing the least and grey receiving no comments. Clockwise from the top: School A, School B, School D, School C.

As all comments recorded by the ISAT are unguided, the magnitude of comments for a specific property can be treated as its relative importance. By comparing the magnitude of comments a scale of properties can be developed showing the key aspects of the school across all four schools (shown in Figure 7). As a comment can relate to a number of properties, this magnitude is calculated as a percentage of overall property occurrences.

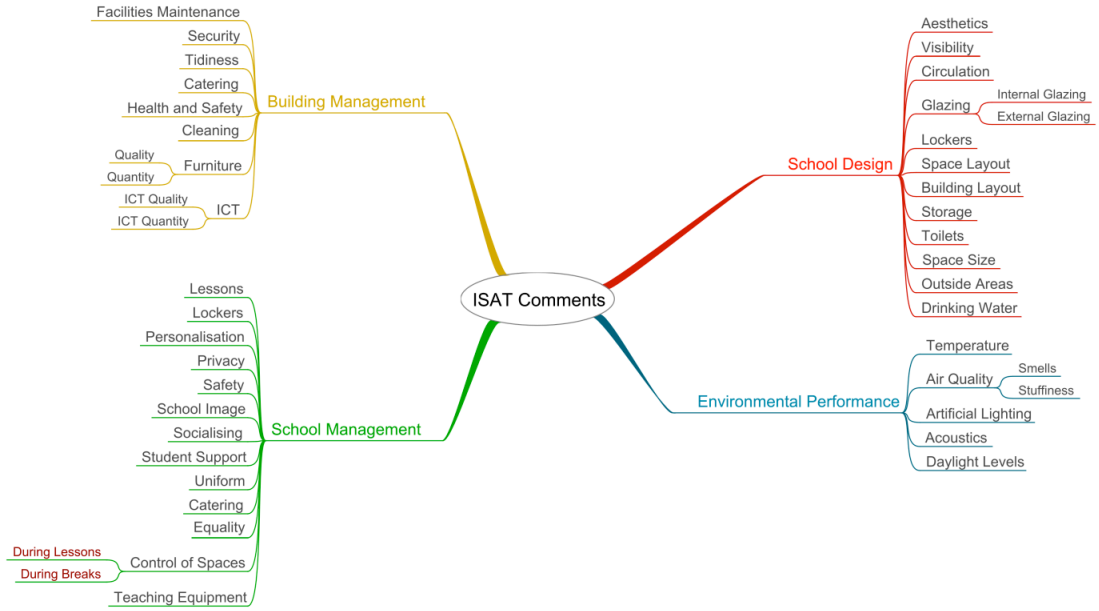

Figure 6: Map of the codes generated through the analysis of the ISAT results, with the four main dimensions and the dimensions that comprise them (note that irrelevant comment codes have been omitted)

Figure 7 shows that the top three occurring properties relate to the building design dimension; space size (10.2%), aesthetics (9.1%), and space layout (8.1%), with lessons and temperature the next most common properties (6.2% and 5.9% respectively). Overall, the dominance of the school design dimension is clear, with twice as many occurrences as school management (46% of occurrences compared to 23%), the next most regular occurring dimension. Both school design and school management have a similar number of properties (13 with each), whereas building management has 9 properties and environmental performance has only five properties. The number of properties highlights the importance of the dimension, but despite school management and school design having the same number, school design clearly attracted more responses, reflecting the visual nature of the ISAT. Building management was the third most popular property at 18%, closely followed by the environmental performance property (14%).

Although the ISAT instructions ask for an equal number of positive and negative comments, there is a significant bias towards negative (N(positive) = 704, N(total) = 1934, $p < 0.001$). For the purposes of assigning importance within comments the polarity has not been important, however to understand the actual opinions of the students the polarity of the comments has to be reintroduced. Much of the responses are beyond the scope of this paper, but the comments regarding the *school design* remain pertinent due to connection to the perception of the building.

The properties for the *school design* dimension represent nearly half of the overall comments about the school. As noted earlier, the school design has the three top occurring properties, space size, aesthetics and space layout, and they similarly dominate the results shown in Figure 8. School A has significantly more comments than the other three schools for both space size and space layout due to the number of negative comments received, with these properties highly related (28 tags occur in both properties). Comments such as "*Art room is to small you cannot even walk around in it when there is a huge class full of students*" (Student at School A), and "*It's too crowded, too hot, and really hard to get around*" (Student at School A) illustrate the perceived lack of space in School A. Conversely, at School B, the comments are more favourable: "*Great place for lockers as it's not as crowded as other places"* (Student at School B). This is unusual given that there is relatively little difference in pupil density between the two schools.

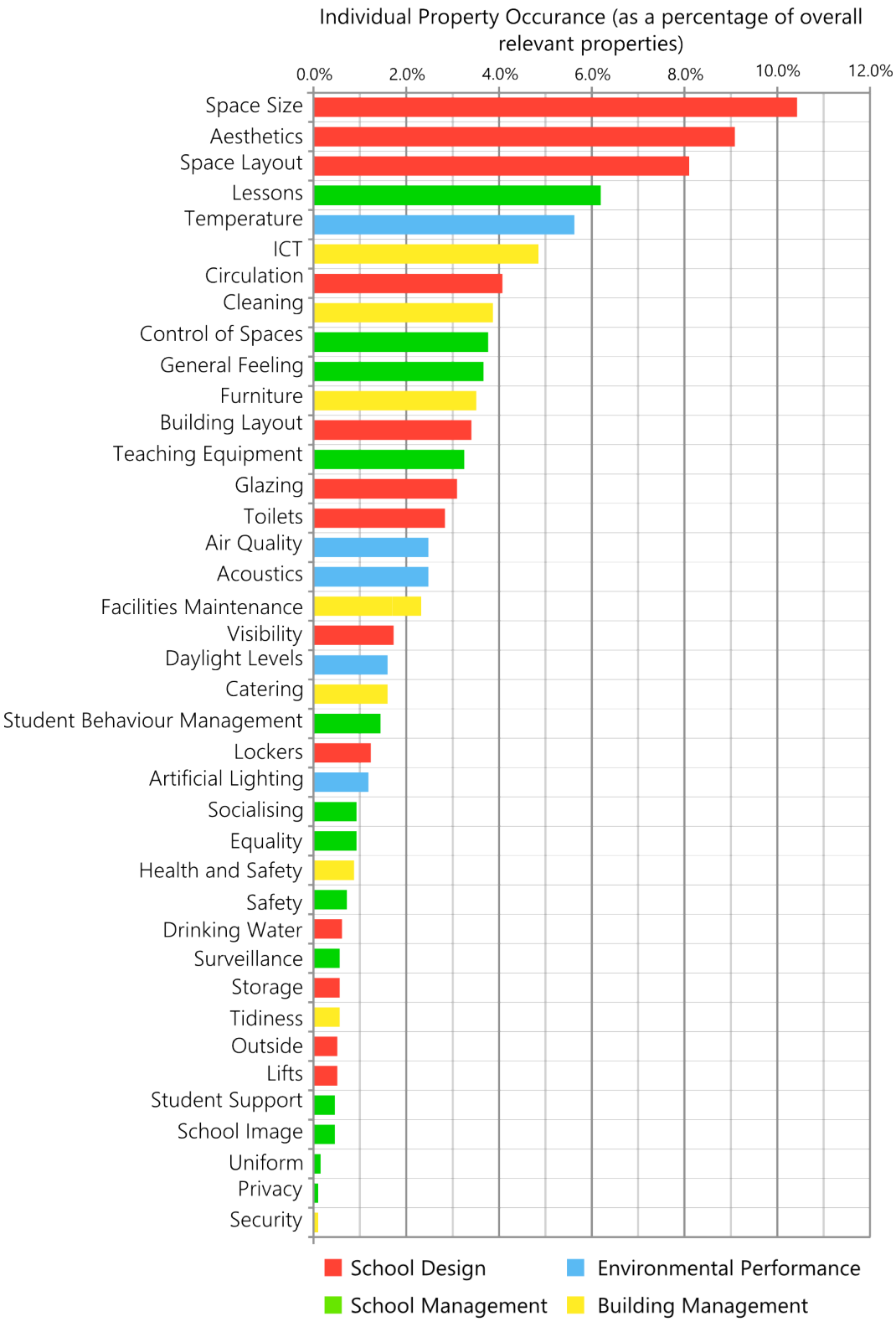

Figure 7: Graph showing the relative property occurrence within the relevant tags recorded using the ISAT, colour-coded according to the four main dimensions

From the quotes at school A, it is clear to see the overlap between layout and space, however the property space layout has other implications at School A, with the open plan classrooms dominating the comments: "*It's too small and its distracting looking at others outside*" (Student at School A),

"*Gets too noisy during my English lesson because it is a wide open space so I can hear all of the other classes screaming*" (Student at School A). This visibility between spaces was favourable at School B: "*I like how you can look in the window to see if you teacher or friends are in the class*" (Student at School B). With as many positive as negative points, the students at School D found the spaces tidier, and better laid-out: "*This room is very well spaced and well organised*." (Student at School D), perhaps reflecting that the school has the lowest student density.

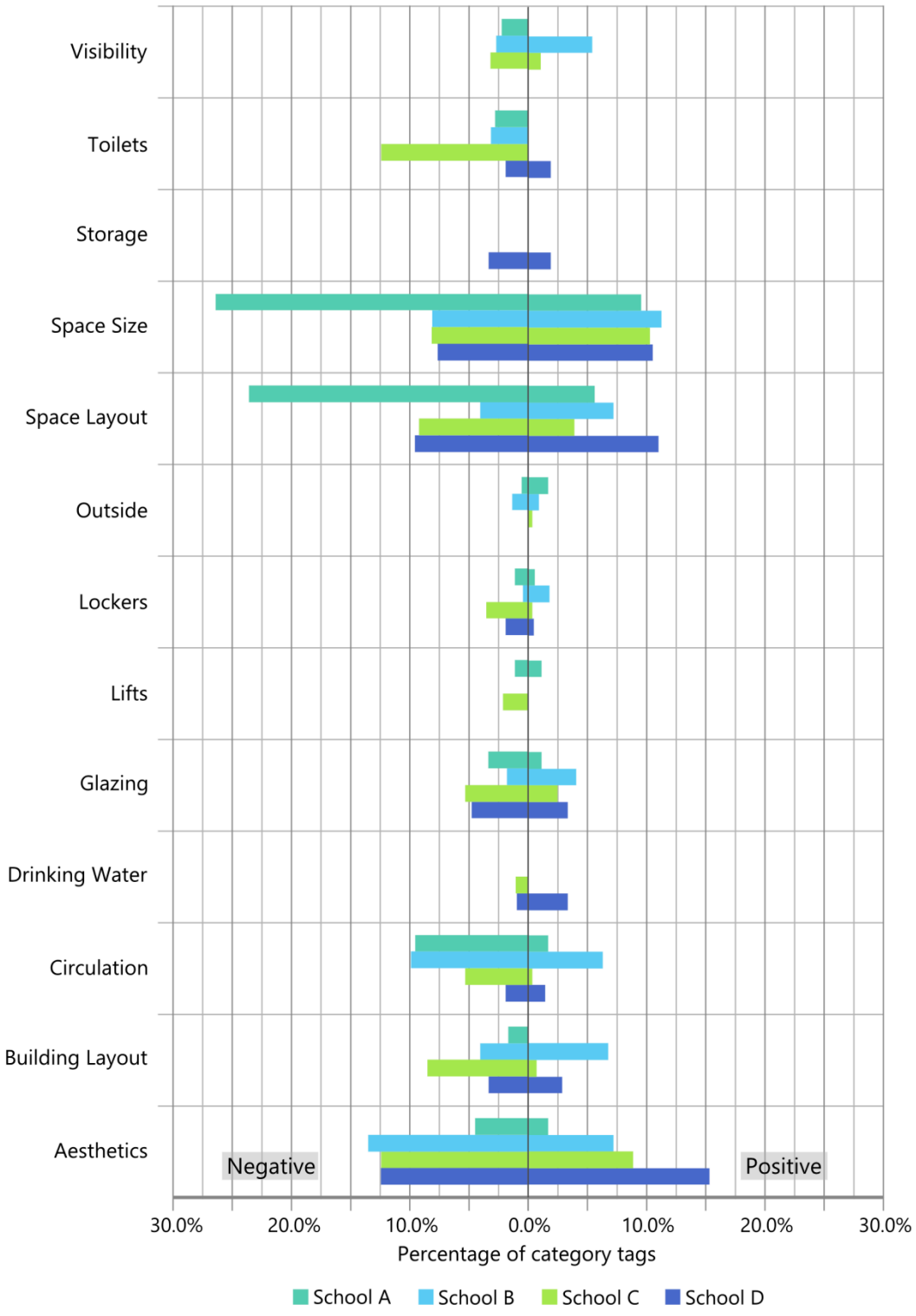

Figure 8: Polarity and percentage of properties recorded in tags from ISAT, for *School Design* dimension, shown as a percentage of total dimension occurrences in each school

Circulation was found to be a key property of the *school design* dimension, with School A and School B both rating it negatively. At School A, this is linked to the overcrowding between lessons "*Gets hard to move around along these pathways since students going to their lessons*" (Student at School A). Although at School B the comments are linked to the movement between lessons as well, they are more specifically about the one-way system the school has put in place: "One way system causes: packed doorways, accidental putting off of the alarm, possible health and safety violation, unnecessary corridor cards/lateness" (Student at School B). This need for a one-way system is likely to be a result of the complex and compact multi-level layout at school B. School A has a high student density (11.25 m^2/pupils) along with school B (13.05 m^2/pupils), but does not have stagger the lessons or breaks. School C, with the highest density (8.66 m^2/pupils) might be expected to feature here, but the large external courtyard significantly reduces the effective density during movement between lessons.

At School C there was a clear issue about the *building layout*, with a number of students noting the unusually placed columns: *"I walked into this pillar once because it's in a random place*" (Student at School C), and "*Seriously what's up with all these random pillars*" (Student at School C). These pillars are generally located close to the walls in the teaching wings, where the students queue before entering a lesson. This is not so apparent in the VGA, however students forced to stand next to the pillars will greatly reduce the effective width of circulation giving rise to the issues noted by the students.

School C also had a number of negative comments about the toilets, something that the other schools did not receive. From the comments it is clear to see that there is one set of toilets at the school that is dominating the feedback. These toilets were found to be unclean and closely related to disruptive behaviour, notably smoking: "*Toilets are always stinky and never get cleaned and always stinks of cigarettes*" Student at School C), "*The toilets are always used for smoking*" (Student at School C). Of all the four schools, only School C has traditional, closed style toilets, as opposed to the other three which have individual, closed cubicles of an open space. This is despite the toilets been located in a relatively well integrated location close to the dining hall (labelled in Figure 3). Local rather than global visibility is the driver behind control of spaces, with passive supervision impossible regardless of how often teaching staff pass the toilets. The lack of comments at the other three schools confirms the success of these layouts relative to the traditional closed toilets.

9. Conclusion

Using the space syntax tools and the newly developed ISAT has enabled four schools to be understood from a new perspective, bringing a qualitative commentary to the configurational properties. In doing so it has highlighted the potential that movement within a virtual version of a space can provide, moving beyond simplistic 3d-models (such as those used by Conroy-Dalton (2001)) to a rich representation of the environment. Movement within the ISAT has been shown to resemble patterns seen elsewhere (i.e.: configurational logic with attractors), validating the tool and enabling future research.

At this early stage, we have to yet to use the ISAT on a wide range of buildings, with three schools of similar morphology and one very different. Future work should extend this to examining a wider range of spatial morphologies and encompass other types of buildings. The limited number of morphologies tested within this work prevent immediate usage across all building layouts, and each one would require a similar validation exercise prior to interpretation. Ideally, further validation would include observation data for comparison, which was not feasible in this scope of work, anchoring the work in the real world. An obvious choice for exploration is to revisit the widely studied buildings, museums for example, leveraging the additional prior knowledge to improve understanding of the tool's qualities. To increase the understanding of the buildings tested, the intelligibility of the space should be explored (as used by Penn (2001)), building a better picture of the type of space the users are exploring and then how that relates to the findings of the ISAT.

Referecnes

Adams, M. et al., 2007. The 24-hour City: Residents' Sensorial Experiences. *The Senses and Society*, 2(2), pp.201–215.

Ben-Akiva, M.E. & Lerman, S.R., 1985. *Discrete Choice Analysis: Theory and Application to Travel Demand*, MIT Press.

Amaratunga, D. et al., 2002. Quantitative and qualitative research in the built environment: application of "mixed" research approach. *Work Study*, 51(1), pp.17–31.

Barrett, P. et al., 2013. A holistic, multi-level analysis identifying the impact of classroom design on pupils' learning. *Building and Environment*, 59, pp.678–689.

Beatty, P.C. & Willis, G.B., 2007. Research Synthesis: The Practice of Cognitive Interviewing. *Public Opinion Quarterly*, 71(2), pp.287–311.

Betoret, F.D. & Artiga, A.G., 2004. Trainee teachers' conceptions of teaching and learning, classroom layout and exam design. *Educational Studies*, 30, pp.355–372.

Burman, E. et al., 2012. Performance gap and thermal modelling: A comparison of simulation results and actual energy performance for an academy in North West England. Available at: http://www.bso12.org/-proceedings/papers/1B2.pdf [Accessed October 1, 2013].

CarbonBuzz, 2013. CarbonBuzz : RIBA CIBSE Platform. Available at: http://www.carbonbuzz.org/ [Accessed December 3, 2012].

Chatzidiakou, E. et al., 2014. Indoor air quality in London schools. Part 1: "performance in use." *Intelligent Buildings International*, 0(0), pp.1–29.

Chatzidiakou, L., Mumovic, D. & Summerfield, A.J., 2012. What do we know about indoor air quality in school classrooms? A critical review of the literature. *Intelligent Buildings International*, 4(4), pp.228–259.

Cohen, R. et al., 2001. Assessing building performance in use 1: the Probe process. *Building Research & Information*, 29(2), pp.85–102.

Conroy-Dalton, R., 2001. *Spatial navigation in immersive virtual environments*. University of London. Available at: http://discovery.ucl.ac.uk/1111/ [Accessed May 1, 2015].

Corbin, J.M. & Strauss, A., 1990. Grounded theory research: Procedures, canons, and evaluative criteria. *Qualitative sociology*, 13(1), pp.3–21.

Durán-Narucki, V., 2008. School building condition, school attendance, and academic achievement in New York City public schools: A mediation model. *Journal of Environmental Psychology*, 28(3), pp.278–286.

Eisenhardt, K.M., 1989. Building Theories from Case Study Research. *The Academy of Management Review*, 14(4), pp.532–550.

Heschong, L. et al., 2002. Daylighting impacts on human performance in school. *Journal of the Illuminating Engineering Society*, 31(2), pp.101–111.

Higgins, S. et al., 2005. The impact of school environments: A literature review. *The Centre for Learning and Teaching, School of Education, Communication and Language Science, University of Newcastle. Accessed online on*, 10, pp.04–08.

Hillier, B. et al., 1993. Natural movement: or, configuration and attraction in urban pedestrian movement. *Environment and Planning B: Planning and Design*, 20, pp.29–66.

Hillier, B. & Hanson, J., 1984. *The social logic of space*, Cambridge university press Cambridge. Available at: http://www.academia.edu/download/30374693/Hiller___Hansen.pdf [Accessed October 27, 2014].

Hillier, B. & Penn, A., 1991. Visible Colleges: Structure and Randomness in the Place of Discovery. *Science in Context*, 4(01), pp.23–50.

Leaman, A. & Bordass, B., 2001. Assessing building performance in use 4: the Probe occupant surveys and their implications. *Building Research & Information*, 29(2), pp.129–143.

Martin, S.H., 2002. The classroom environmnet and its effects on the practice of teachers. *Journal of Environmental Psychology*, 22(1–2), pp.139–156.

Moore, G. et al., 2008. The photo-survey research method: capturing life in the city. *Visual Studies*, 23(1), pp.50–62.

Pasalar, Ç., 2007. Spaces for Learning Through Better Social Interaction. In E. Knapp, K. Noschis, & Ç. Pasalar, eds. *School Building Design and Learning Performance*. Lausanne: Comportements, p. 51.

Pasalar, Ç., 2004. The Effects of Spatial Layouts on Students' Interactions in Middle Schools: Multiple Case Analysis.

Penn, A., 2001. Space Syntax and Spatial Cognition: Or, why the axial line? In *3rd International Space Syntax Symposium*. Atlanta. Available at: http://eprints.ucl.ac.uk/3419/1/3419.pdf.

Peponis, J. et al., 2004. Measuring the effects of layout upon visitors' spatial behaviors in open plan exhibition settings. *Environment and Planning B: Planning and design*, 31, pp.453–473.

Peretti, C. & Schiavon, S., 2011. Indoor environmental quality surveys. A brief literature review. *Center for the Built Environment*. Available at: http://escholarship.org/uc/item/0wb1v0ss [Accessed January 31, 2015].

Powell, K., 2010. Making Sense of Place: Mapping as a Multisensory Research Method. *Qualitative Inquiry*, 16(7), pp.539–555.

Sailer, K., 2007. Movement in workplace environments–configurational or programmed? In 6th International Space Syntax Symposium.

Sailer, K., 2010. *The space-organisation relationship : on the shape of the relationship between spatial configuration and collective organisational behaviours / Kerstin Sailer*. Online-Ressource. Technische Universität Dresden.

Sailer, K., 2015. The Spatial and Social Organisation of Teaching and Learning – The Case of Hogwarts School of Witchcraft and Wizardry. In *10th International Space Syntax Symposium*. UCL, London, pp. XX–XX.

Shield, B. & Dockrell, J., 2003. The Effects of Noise on Children at School: A Review. *Building Acoustics*, 10(2), pp.97–116.

Stern, P.N., 1980. Grounded Theory Methodology: Its Uses and Processes. *Image*, 12(1), pp.20–23.

Turner, A. et al., 2001. From isovists to visibility graphs: a methodology for the analysis of architectural space. *ENVIRON PLANN B*, 28(1), pp.103–121.

Tzortzi, K., 2004. Building and exhibition layout: Sainsbury Wing compared with Castelvecchio. *arq: Architectural Research Quarterly*, 8(02), pp.128–140.

Varoudis, T., 2012. *DepthmapX Multi-Platform Spatial Network Analysis Software*, Available at: http://varoudis.github.io/depthmapX/.

Willis, G.B., 2004. *Cognitive interviewing: A tool for improving questionnaire design*, Sage Publications.

Wollin, D.D. & Montague, M., 1981. College Classroom Environment: Effects of Sterility Versus Amiability on Student and Teacher Performance. *Environment and Planning B*, 13(6), pp.707–716.

Zagreus, L. et al., 2004. Listening to the occupants: a web-based indoor environmental quality survey. *Center for the Built Environment*. Available at: http://escholarship.org/uc/item/8cf6c6dr [Accessed April 27, 2015].