MULTI-LEVEL COMPLEXITY IN TERMS OF SPACE SYNTAX:
a case study

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Abstract

This paper is inspired by a wayfinding study by Hölscher et al. (2005), who find serious wayfinding difficulties in a complex multi-level building and identify architectural properties related to the difficulties. The present study re-analyzes the qualitative results in terms of Space Syntax measures and thus ties them down to formal properties of the architectural structure. The analysis carefully models the spatial interconnections between different floors, as stairs are considered to cause many of the usability issues. Axial maps of the separate floors were interconnected via additional staircase axes using the manual connection feature of Depthmap (Turner, 2004). With respect to Visibility Graph Analysis (VGA) staircases were represented by “widgets” – additional space with representative spatial properties. These were connected to the staircases in the floor plan by merging visibility graph nodes. Considering the building as a whole, the poor intelligibility score of 0.15 is remarkable. Analyzed as separate systems the floors' intelligibility ranges from .09 (second floor) to .71 (basement). With respect to usability issues, several techniques revealed valuable results. Along a typical trajectory through the entrance hall the primary isovist changes rapidly. At no point all relevant navigation choices are visible simultaneously. The lack of survey is best demonstrated by the distribution of integration and connectivity: E.g. the entrance hall neither contains the most connective nor the most integrated part of the system. For the analysis of dead ends in the basement we regarded them as blockages. The visual step depth from one side to the other quantifies the complexity of the detours to overcome the dead ends. (17 and 8 turns respectively). A similar technique was applied to measure the amount of turning occurring in the staircases. As all staircases are offset from the main axis one needs to travel along a minimum of 7 axial lines from the entrance hall to the corresponding main intersection in the basement. To validate our findings we constructed two layout re-designs. Eliminating the dead ends in the basement increases integration in a formerly segregated region. Also, the distribution of spatial measures becomes more similar between different floors. The second re-design removes visual clutter near the entrance where a local Integration maximum emerges together with the most connective area. Although the analyses are post-hoc at this stage the re-designs point at the potential of Space Syntax as a predictive tool for wayfinding design.

Introduction

Many people have problems finding their way around public buildings such as airports, hospitals, offices or university buildings. The problem may partially lie in their spatio-cognitive abilities, but also in an architecture that only rudimentarily accounts for human spatial cognition. Furthermore, most research in the field deals with fundamental cognitive processes but does not account for practical application in the field of usability.

Weisman (1981) identifies four general classes of environmental variables that shape wayfinding situations: visual access, the degree of architectural differentiation, the use of signs and room numbers, and floorplan configuration. Passini (1992) regards wayfinding as spatial problem solving and on this basis develops his “Wayfinding Design” framework. Evans and McCoy (1998) provide an excellent overview of cognitive and general psychological factors that can hamper the functioning of a building from a human-centered point of view. But only a few researchers have explicitly investigated usability issues of buildings with respect to navigation efficiency. Butler et al. (1993) present a usability study into the effects of graphical information, showing not only positive impacts of signage and floor maps but also providing guidelines for improving signage design. Werner and Long (2003) were able to show that a local mismatch in the alignment of parts of a building disrupt the mental representation formed by visitors of the setting. Such a mismatch could be tied to behavioural difficulties as well (Werner & Schindler, 2004).

A disadvantage of these lines of research is that spatial factors like floorplan complexity and configuration as well as visual access have been defined rather informally in the literature discussed above (e.g., by subjective ratings). The concept of isovists (Benedikt, 1979) provides a much more precise mathematical framework for capturing local properties of visible spaces, which correspond with psychological measurements of environmental perception (Stamps, 2002). Space syntax (Hillier & Hanson, 1984) has introduced formalized, graph-based accounts of layout configurations into architectural analysis. Calculations based on these representations express the connective structure of rooms and circulation areas in a building.

Our main question in the context of building usability issues and Space Syntax will be the following: Does Space Syntax provide the measures necessary to identify usability deficits of a complex, publicly-used multi-level building?

Point of departure

The present paper is inspired by an empirical investigation on wayfinding and usability by Hölscher et al. (2005, in press). In the experiment, participants’ task was to find six locations in a multi-level conference centre. Based on participants’ wayfinding behaviour and related architectural properties, Hölscher et al. identify several usability “hot spots” that appeared to hinder successful orientation and wayfinding. The architectural analysis was to considerable extent based on the intuitive evaluations of the architect in our team at the time.

In the present paper we re-analyze the qualitative results in terms of quantitative Space Syntax measures and thus tie them to formal properties of the architectural structure of the conference centre. Most of the navigation difficulties clearly stem from vertical travel and consequently many hotspots are related to vertical complexity. Therefore it appears extremely relevant to carefully model the vertical structure of the building. Based on the space syntax analyses, the usability hotspots of the building are re-assessed and options for an improved redesign of the basic layout are evaluated.

Architectural Analysis

The Conference Centre

The Heinrich-Lübke Haus, a mixed-use conference centre, was built in 1970 in Günne, near Düsseldorf, Germany. The ground floor of the multi-functional building illustrates the general characteristics and spatial organization of the layout (see Fig. 1). The basic structure consists of various simple geometrical elements that are arranged in a complex and multi-faceted architectural setting. It is composed of a small ensemble of units and a large public circulation area. Each group of shapes implies different functions, e.g., the living quarters have a quadratic design style and the communication area a hexagonal design style. The layout of the hallways on every floor may appear to be locally one and the same for a casual user, but is actually different for each floor. For example, the configuration of the ground floor and the basement differs significantly. The consequences of this and related structural deficits of the building will be discussed as *usability hotspots* in detail below.

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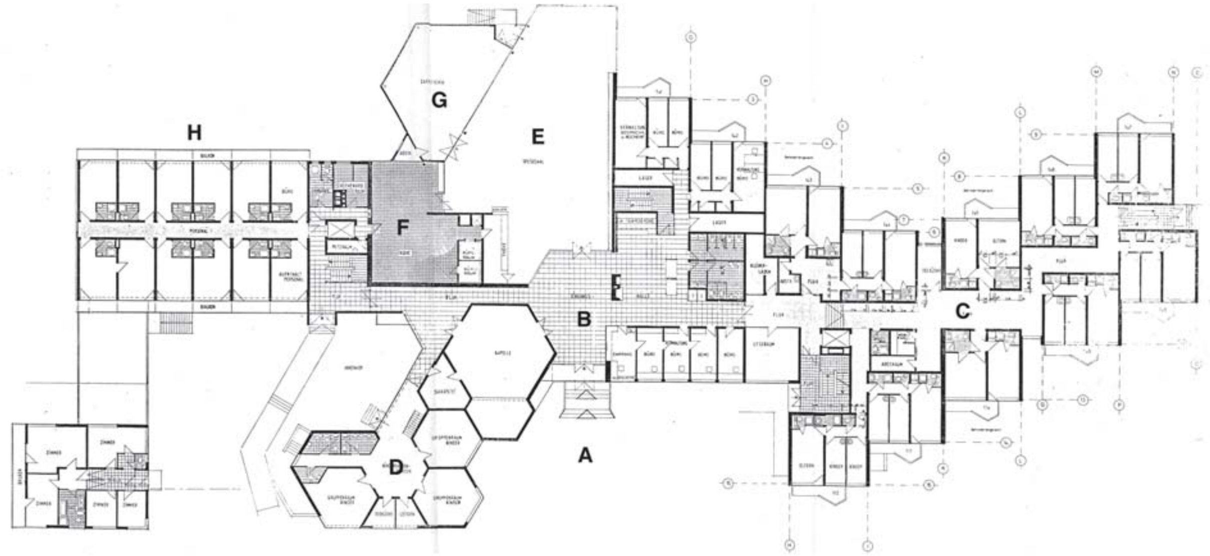


Figure 1:

Plan view of ground floor: (A) main public entrance (B) entrance hall (C) living quarters (D) commons - communication and conversation area (E) dining-room (F) kitchen (G) coffee bar (H) lecture rooms

The formal architectural analysis consists of two parts. The Axial Line Analysis (Hillier & Hanson, 1984) accounts for important aspects of the overall structure of the building. The more detailed Visibility Graph Analysis (Turner et al., 2001) is especially relevant for the analysis of the usability hotspots as well as the evaluation of two usability-oriented layout redesigns proposed by the authors.

Axial Analysis

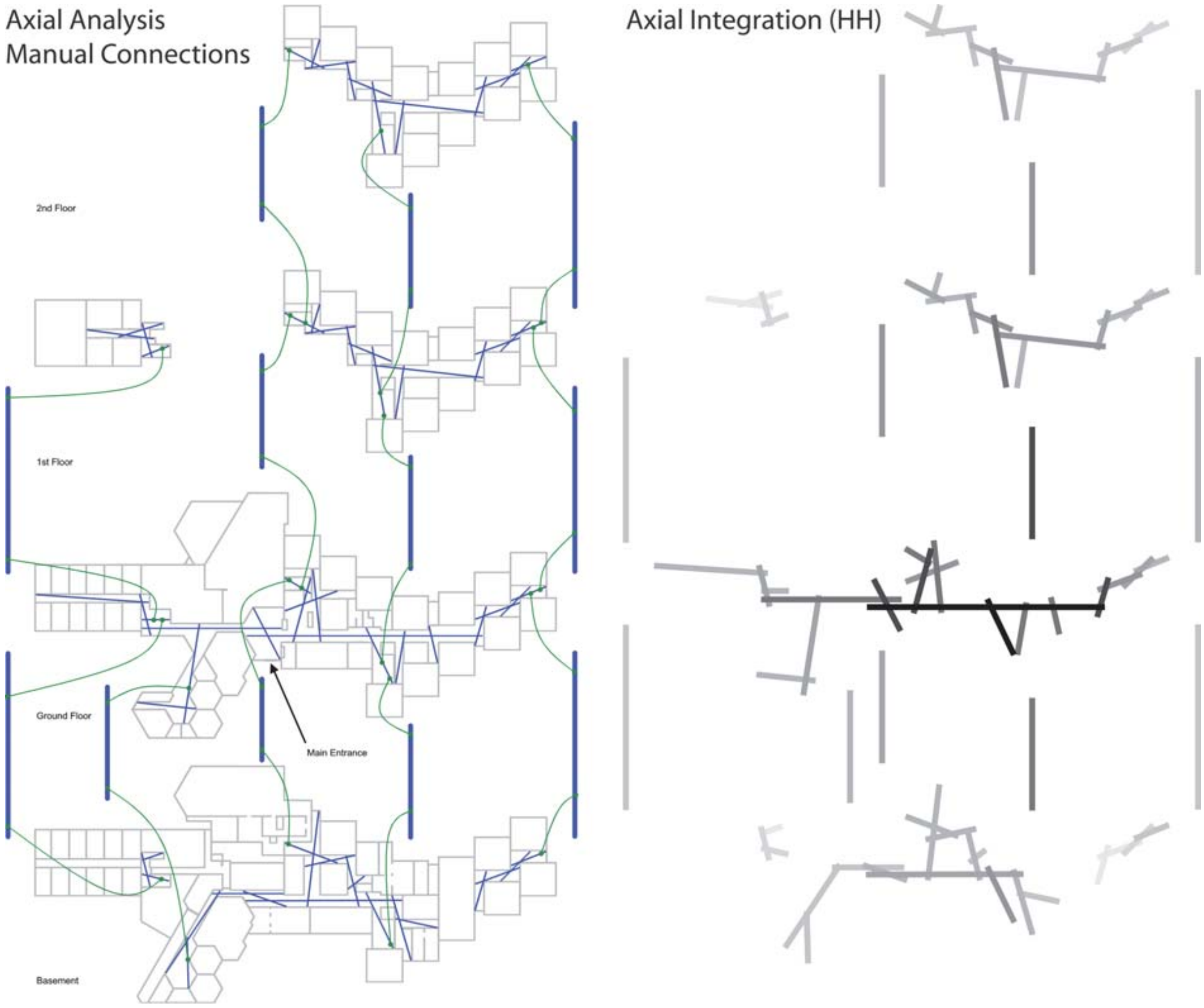
For the axial line analysis, the Space Syntax software *Depth Map* (Turner, 2004) was used. One of the key aspects of the analysis was to account for the building's multi level structure. Chang & Penn (1998) represented vertical interconnections by means of weighted links between floors. Our analysis uses an additional axial line for each connection between two floors. This additional axis is manually connected to the corresponding lines in the upper and the lower floor. Figure 2 (left) shows the floor plan of the building together with the axial map and the manual connections.

The axial map is intended to reflect the effective visibility structure when navigating the building, instead of being an ideal fewest and longest lines map. The most important consequence of this decision is to represent the main corridor (in the ground floor and in the basement) by two main axes although, in theory, one long line would be possible. In practice however, the main corridor is perceived as interrupted. Figure 2 (right) shows the axial line of the *navigation space* in the building.

A generally remarkable result with respect to wayfinding and usability issues is the poor *intelligibility* score (correlation of connectivity and integration) of the complete system, namely 0.15 (total no. of lines: 79). Analysing each floor separately, the ground floor and basement revealed substantially higher intelligibility scores (.53 & .71), unlike the first and second floor (.09 & .016). An axial map adding *all publicly accessible* rooms revealed an even poorer intelligibility of 0.12 (total no. of lines: 105). No major differences with respect to spatial variables between these two analyses were found. We will only refer to the analysis of *navigation space* below.

Figure 2:

044-04 *Analysis of navigation space*



Visibility Graph Analysis

Compared to the axial lines*, visibility graph analysis (VGA)* provides a more fine grained representation of architectural space. The visibility graph is based on a two dimensional grid of points which fills all open space to be considered. Two nodes are connected if and only if the corresponding locations in space are mutually visible. Again, Depth Map (Turner, 2004) was used for the VGA. The *step depth* between two locations *a* and *b* is defined as the number of edges on the shortest path between *a* and *b* in the visibility graph. This measure reflects the number of turns required to get from *a* to *b*. *Connectivity* or *degree* of a node *n* is a local measure which captures the amount of space directly visible from *n*. The global measure *integration* is a normalized version of the mean depth of a node *n* to all other nodes in the system. Intuitively integration reflects the centrality of a node with respect to the whole graph. For details on these measures please refer to Turner (2004; Turner et al., 2001).

We have identified the vertical structure of the building as a crucial factor in understanding its behavioural consequences. Since Depth Map supports two-dimensional visibility graphs only, the analysis is based on separate floor plans for each building level. Vertical interconnections in the staircases were modelled with the help of *widgets* providing horizontal space with representative intervisibility structure. Visibility graph nodes in the floor plan were manually connected with those in the widget representing the staircase. With respect to the intervisibility in the widget space it was ensured that there is no direct connection between the lowest and the highest floor. E.g., the visual step depth between floors increases with the number of levels to traverse. When designing the staircase widgets it is important not to change the amount of space in the visibility graph. Basically, the widget duplicates the staircase area in the floor plan. To compensate for this, space in the staircase either

- has to be *merged* via manual connection (making it count only once in total) or
- has to be blocked in the widget or
- has to be blocked in the floor plan.

Figure 3 shows a schematic view of a staircase and how different areas are captured in the two-dimensional space of Depth Map for the VGA. Similarly, a set of steps (covering ca. 120 cm vertical height difference; within-level) in the main corridor towards living quarter was bridged with a corresponding widget area.

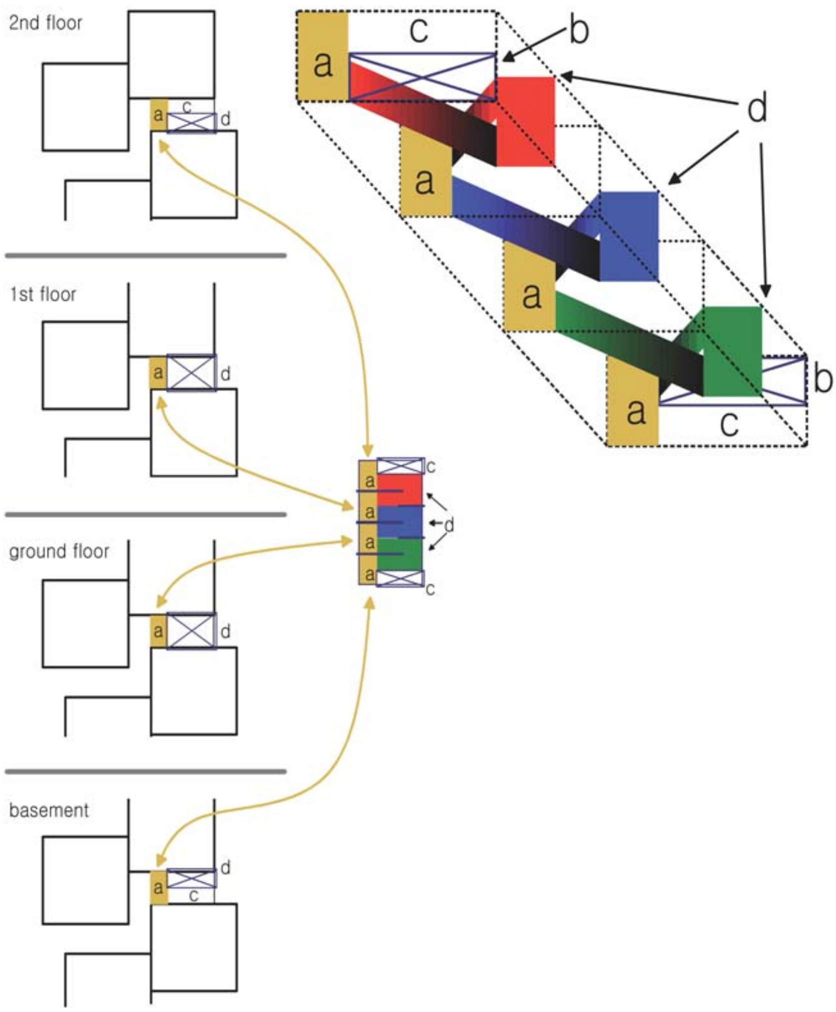


Figure 3:

Two-dimensional representation of the vertical interconnections via widgets and manual links. The floor plan of the staircase is shown as well as the widget representing the vertical interconnection between the stairs. Letters and grey tones help matching space in the schematic 3D view with the two dimensional representation. (a) Space merged between floor plan and widget space. (b) Space under the stairs in the basement and on top of the stairs in the upper floor is not represented. (c) Space represented in the floor plan but blocked in the widget. (d) Space represented in the widget but blocked in the floor plan.

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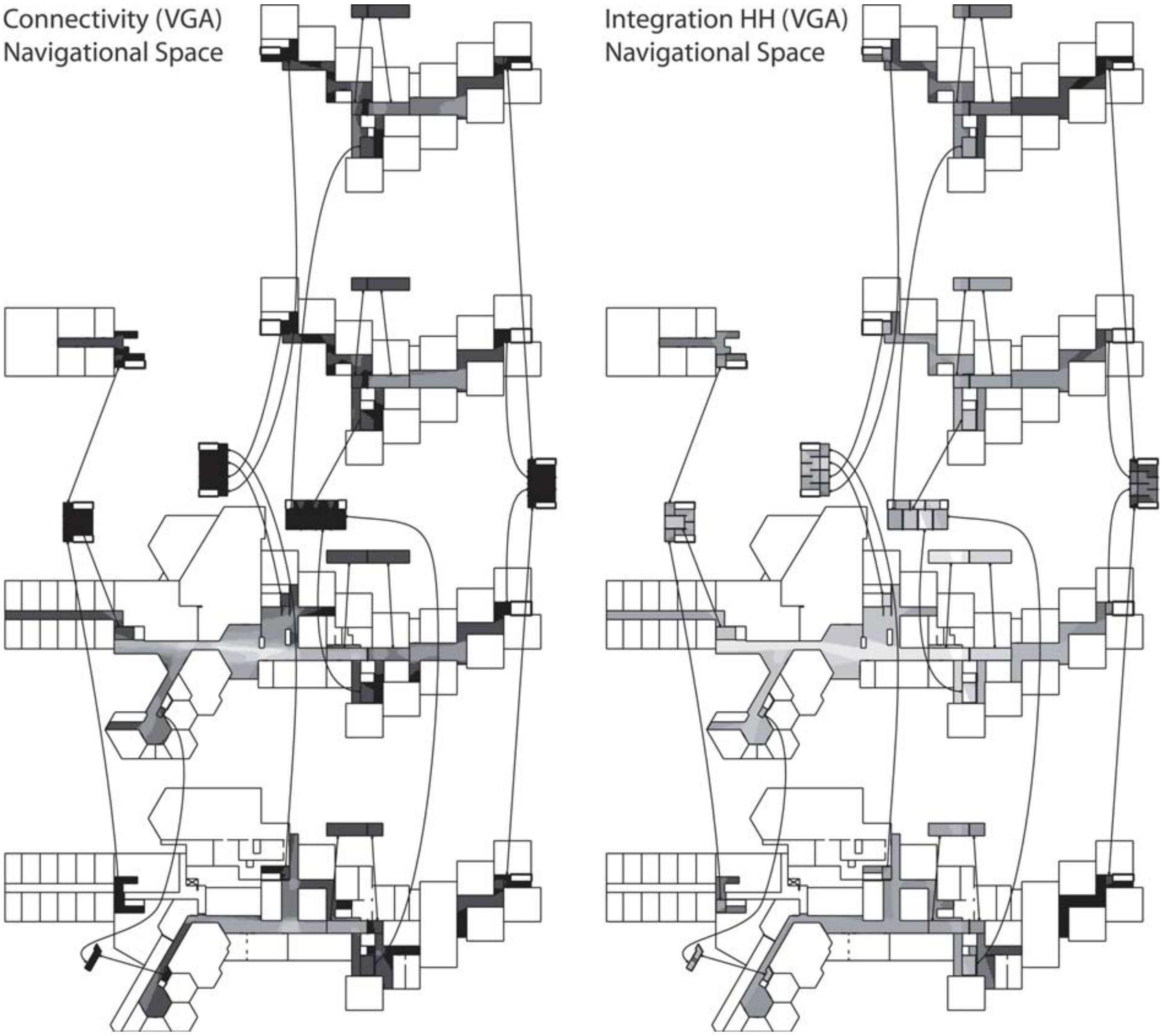


Figure 4:

Navigational space

Usability Hotspots and Layout Redesigns

Hotspots

The analysis of usability hotspots reported in Hölscher et al. (2005) was based on a qualitative expert evaluation of the building by the architect in the research team. To some extent the results were substantiated by relating behavioural measures like stops and detours to specific point and areas of the building. The current analysis uses the original qualitative analysis as input and tests how space syntax techniques can link these observations to concrete, objective measures of the building.

Overall, we believe the functional dilemma of this building for wayfinding is prominently caused by the problematic arrangement of complex decision points, their linking paths, the position and design of stairways, vertical incongruence of floors, incomprehensible signage, and too few possibilities for monitoring interior and exterior landmarks. Consequently, the building as a whole gives the impression of a three-dimensional maze. In the following, we focus on seven “hotspots” of the building and relate their disadvantages to formal analytic measures.

Hotspot 1: Entrance hall: The public entrance (Fig 1, A) as well as the large entrance hall (Fig. 1, B), are rather indiscernible, despite being centrally located in the general configuration of the building. An essential function of the entrance hall is to be readable as such and to cognitively structure the route network, especially for unfamiliar visitors, who tend to rely on central points for their navigation strategies.

The usability deficit of the entrance hall is maybe best illustrated by Figure 5, representing the direct visibility (step depth = 1) for several points in the entrance hall along a typical trajectory. For the user entering the entrance hall, the visual access changes very rapidly and at no point all relevant navigation choices are visible simultaneously. Especially the visual connection to the nearest staircase (next to the cafeteria area) is never properly made. The navigator has to leave the entrance hall to gain visual connection. More generally speaking, the entrance contains neither the most integrated nor the most connected areas of the navigation space in the building (see Fig. 4). Overall, the entrance hall doesn't make the navigation choices salient to the user; connections to all stairways are invisible from the entrance hall.

Hotspot 2: Survey places: The building lacks survey places. While the entrance hall fails to visually connect to relevant decision points like stairs, lack of survey options is pronounced throughout the building. The only visual connections between floors are by staircases, the majority of which is separated from the corridor network by glass doors. There are no open connections like galleries, ramps or openly visible stairs. Lines of sight within floors are broken by (mostly 90°) zigzag turns and small corridor diameters. The lack of survey was identified to be particularly evident for the basement in the previous study, with more stops / hesitations observed in the basement compared to a matched area in the ground floor (near entrance hall) paralleled in size and alternatives. The visible area from any given point is captured by the VGA connectivity measure, representing the isovist area around it. As can be clearly seen in figure 4 (left), the navigation space in the basement as well as in the corridor networks of the higher floors provides almost no positions that can be characterized as providing overview.

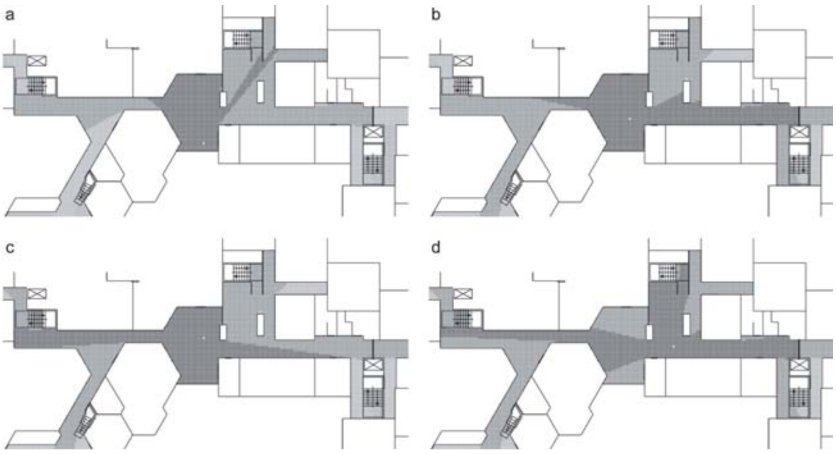


Figure 5:

Entrance hall: step depth from selected points (white dots) along a trajectory into the building, form the entrance (a) through the main hall towards the stairs (d)

Hotspot 3: Incongruent Floors: The floors in this building provide very incongruent layouts. For a person standing in the building, the floors of the conference centre *locally* give the impression of matching one another (especially in the living quarter area), but in fact the hallways are considerably different. From wayfinding research this is expected to prompt inadequate assumptions about the route network. While the incongruence of the floors is apparent without a formal building analysis, the stark differences between floors in the distribution of connectivity and integration (*see figure 4; VGA navigation space)* underscore the problem of confusing the user. A person who quite naturally assumes congruent floors (see Soeda et al., 1997), will form false expectations about the connectivity or integration properties of his surrounding in this setting.

Hotspot 4: Dead ends: Dead ends seriously complicate wayfinding, as they block the user's exploration activity and make it difficult to form a proper mental representation of the overall path structure. For the analysis, we differentiate two types of dead ends, *apparent dead ends* and *real* ones. The public area surrounded by the living quarters leads to a dark, uncomfortable corridor with zigzag turns, making it a good example of an *apparent dead end*. Users will not expect the stairways at the end of the corridor (Fig. 2, ground floor) and thus miss relevant route choices. Going down the corridor requires the users to navigate against a step decline in connectivity and integration (Fig. 4). In task 1 this corridor is the only option towards the goal, and most study participants were initially very reluctant to follow this path.

The behavioural consequences of real dead ends are more pronounced. We observed a total of 17 episodes of getting lost in our experiment. Five of these episodes (29%) were directly caused by the fact that the participant was stuck in one of the two dead ends in the basement (the far right and far left parts of the basement level in Fig. 2). In the VGA of the navigation space (Fig. 4) as well as the axial line analysis (Fig. 2), these dead ends are reflected in extremely low integration scores of these areas, especially for the dead end in the living quarter.

How difficult is it to overcome these dead ends? For our analysis we treat the dead ends as blockages in the path network and measure the step depth from one end of the blockage to the nearest navigable point on the other side. The step depth between both sides of blockage below the living quarter is 17, the step depth below the lecture rooms area is 8. This is an illustrative measure for the detour that a user of the building has to make if he erroneously runs into the blockage. A remedy for this substantial detour problem is presented in previous sections.

Hotspot 5: Interior building structure: Looking at the ground plan (see Fig. 1), the dissimilarity of geometrical shapes and architectural forms would appear to be helpful for the users to orientate themselves. But in fact, when actually navigating in the building, the different subsections (except for semantically rich areas like the entrance hall, the cafeteria or specific leisure facilities) are no longer readily recognizable for the inexperienced building user, leading to a lack of visual differentiation (Weisman, 1981). While this problem is likely related to *hotspot 2*, the lack of survey, we have yet to identify space syntax measures that would capture this problem adequately. On a more general level, the extremely low *intelligibility* score of (.15 in axial line analysis) can be seen as an indicator of a suboptimal path structure.

Hotspot 6: Public and private space: Further wayfinding problems are related to the differentiation of public and private space. Haq & Zimring (2003) have pointed to differences in space syntax properties of the public and non-public circulation networks of hospitals and possible consequences for building navigability. We have generally limited our investigation of this conference centre to those areas that the visitor of the building may enter. In fact, the personnel of conference facility have two additional corridors available. Ironically, these directly bridge the dead ends identified above. We interpret this as an indicator that the planning of public and non-private space was inadequate. By putting storage space and service corridors in positions where they essentially block public circulation, navigability was seriously hampered.

Hotspot 7: Stairways: In general, stairways should help integrating vertical information while exploring multilevel buildings and they should ease experiencing the layout spatially with respect to the building as a whole. When planning the design of staircases architects generally have to take into account two key design parameters. First the constructional and representational form of its appearance have to be highlighted with respect to the function of the building and second the position of the stairway has to be optimized in relation to the user' s activity within the layout. The positioning of the stairs in the building is critical. As we have seen with *hotspot 1*, the entrance hall, none of the five staircases is directly visible from that central area.

Behaviourally, the foremost stairway (near the entrance hall) was most problematic. This deficit is partly due to the complete lack of visual access to the outside, which would help to improve spatial updating. Additionally, the number of rotations within the stairway plays a great role for the user's stability of his cognitive map of the building (see Richardson, Montello & Hegarty, 1999, for further research into the consequences of rotations in vertical movement). This staircase is offset from the main axis requiring numerous turns when moving between the main corridors of two levels. Frequently, users reported being very disoriented after using this stairway. Six of the seventeen episodes of getting lost (35%) are identified as disorientation observed directly after leaving the stairway, sometimes even before reaching the proper destination level. The axial line analysis (Fig. 2) provides a numerical measure for this challenge: one needs to travel along a minimum of 7 (!) axial lines to move from the entrance hall to the corresponding main intersection in the basement.

Furthermore, there is no main stairway serving as the user's structural focus while exploring the building. In debriefing interviews users reported little sense of a *main stairway*. The VGA analysis of integration (performed separately by floors) provides a potential explanation: The integration values of the two most centrally located staircases fluctuate widely between floors: While the stairs closest to the entrance have higher integration values compared to the second-closest stairs (Fig. 1, lower right) on the ground floor and in the basement (6.7 vs. 5.9 and 6.9 vs. 5.8), the pattern switches around on the upper floors (2.8 vs. 5.2). Thus the stairs have different roles for the different levels of the building.

Structurally, the problem of choosing the proper staircase is increased by the fact that not all stairs connect to all floors or even all parts of individual floors (axial line analysis, Fig. 2). Taken together, the analyses revealed that - except for global building characteristics - the staircases are the single most clearly identified cause of wayfinding problems in our setting.

Layout Re-designs

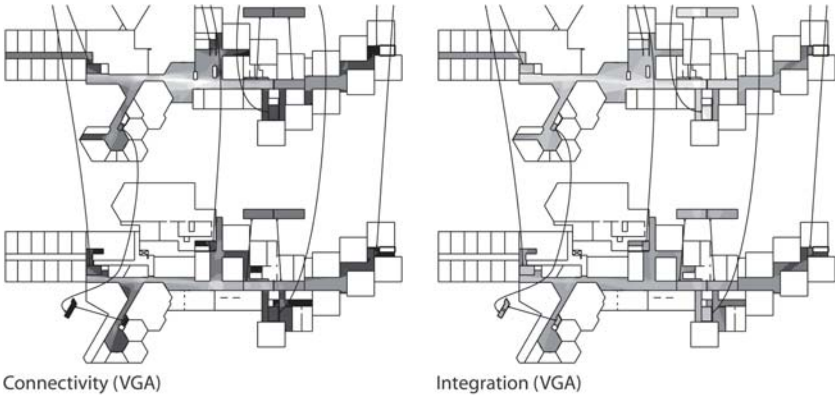
Based on the hotspot analysis, we have worked out two very simple variations of the layout. We do not claim any architectural soundness in these re-designs (e.g., aesthetics, structural engineering, or functionality), they are simply proofs-of-concept for addressing wayfinding problems. One of the variations is an attempt to overcome the dead ends in the basement by copying parts of the fully connected layout from the ground floor to the basement. The second variation addresses the problematic entrance hall by opening visual connections to the centrally located stairs.

Congruent Layout Variation

The congruent layout variation closes the dead ends (hotspot 4) and addresses the public-private space conflict (hotspot 6) as well as interior building structure (hotspot 5). Figure 6 depicts the resulting connectivity and integration distribution in this new layout. This intervention eliminates the segregation of the formerly dead-end areas, providing a much smoother gradient of connectivity and integration for the basement. The main corridor becomes much more legible and we find a clear focus of connectivity at the main T-intersection in the basement. In axial line analysis, the integration value of the originally least-integrated axis (at the dead end) of the basement improves from .36 to .72.

Figure 6:

Congruent layout improvement



Visual Access Layout Variation

This variation opens the visual barriers in the top right corner of the entrance area (hotspot 1) and removes visual clutter in the adjacent area of the centrally-located staircase (hotspot 7). Similarly, we provide a large area of visual linkage between this staircase and the central pathway in the basement (hotspot 2). While in the original layout the stairs are separated by a glass cage, this is removed in the re-design. Figures 7 & 8 illustrate the resulting situation with respect to connectivity, integration and step depth from the entrance hall. A direct connection to the stairs is established (Fig. 8). The centre of connectivity moves to the entrance hall. While the highest integration level is still located further to the right, an area of high integration emerges in the entrance hall. Compared to the original layout, the correlation of connectivity and integration in VGA improves from .29 to .37. Local visibility now corresponds more closely with the global connections in the building.

Figure 7:

Visual access layout improvement

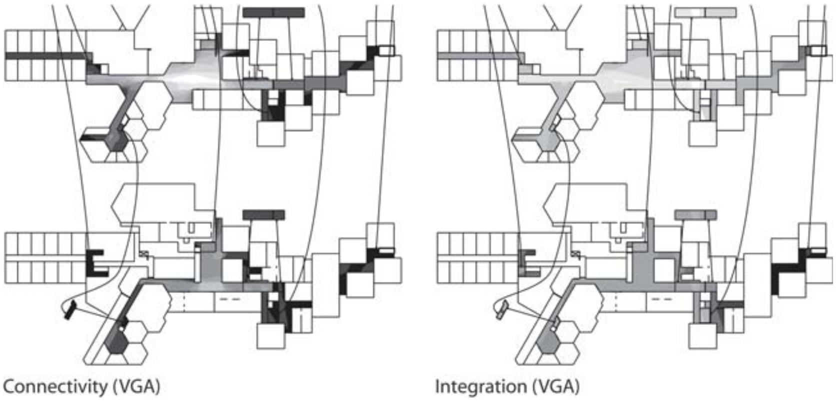
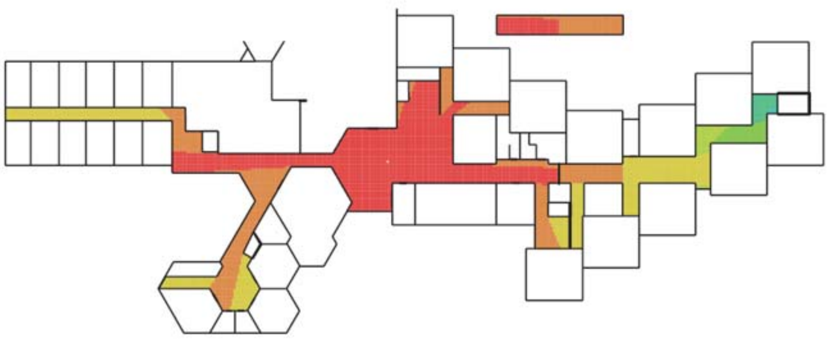


Figure 8:

Visual access layout improvement, step depth from entrance hall



Discussion

In our analysis we have successfully connected behavioural data from a wayfinding experiment to formal spatial analysis of the setting. The majority of the usability hotspots in the building could be clearly linked to space syntax measures of step depth, connectivity and integration. As expected, the step depth measure captured issues in local visibility of the entrance hall and staircases, while the integration measure was sensitive to more general structural deficits in the building, like dead ends and incongruent floor layouts. Compared to the original analysis in Hölscher et al. (2005, in press), we were not only able to put the conclusions on more formal grounds. We also identified structural causes for originally purely subjective impressions like the lack of a main stairway across floors. The layout variants proposed on the basis of the investigation show promising improvements in formal analysis. They provide initial support for the potential usefulness of layout improvements along these lines.

We are using space syntax as a /post-hoc analytic tool/ in this paper. Although the study presented here is based on a controlled experiment, it does not include a systematic variation of space syntax properties as independent variables. We believe that space syntax analyses have the potential to be a valuable tool not only for explaining deficits of a building in retrospect. In fact, to be truly helpful, practitioners would require predictive tools. We envision a combination of space syntax analyses and empirical user testing with Virtual Reality techniques as a viable approach to improve the navigability of future buildings and to foster a human-oriented perspective in the architectural design process.

A first step towards this goal will be the empirical confrontation of the improved layout designs: We intend to transfer these layouts to a virtual environment and run comparative experiments in the near future. But only the combination of such applied and case-based usability analysis on the one hand with the systematic variation of particular space syntax measures in controlled experimental settings on the other will give fundamental insight in the mechanisms of the relation of space syntax and human navigation.

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