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THESIS

Wayfinding in complex multilevel buildings

A case study of University Utrecht Langeveld building

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Wayfinding in complex multilevel buildings: A case study of University Utrecht Langeveld building

Abstract. This study is concerned with human wayfinding in complex public buildings. Wayfinding design primarily includes the two aspects of how to prevent problems from occurring and how to resolve problems after they occur. The former is directly related to architectural design, while the latter is related to signage. This study is mainly focused on the architectural design of the built environment. Spatial configuration as well as wayfinding behavior of users is investigated. An empirical study in a complex multi-level University building is performed, comparing wayfinding performance measures of first-time-visitors to a variety of locations. In addition, an architectural analysis of the building is performed, and possible causes for wayfinding problems are depicted. An attempt is made to link wayfinding performance of participants to the architectural analysis. A relation is found, and a floor plan analysis could therefore be used to predict human wayfinding behavior. From the converging results of both experiments, some design modifications to improve navigability in the Langeveld building are suggested.

1. Introduction

Wayfinding, we all have our stories of buildings in which we got hopelessly lost once, or even navigating through it after many visits still feels like moving through a maze. It has been noted by some corporations that the frustration caused by wayfinding difficulties not only provokes a negative appreciation of the physical setting but that it also affects the perception of the corporation itself and the services offered in that setting. Not surprisingly, facilitated wayfinding has recently become a public relations and a promotional feature for many instances (Passini, 1996).

Wayfinding is not just signage, it is many factors combined which together form an environment for us to navigate through. Gerald Weisman (1981) found that plan configuration was the most influential factor for wayfinding difficulty, followed by spatial landmarks, spatial differentiation, and finally signage and room numbers. Facilitating people's wayfinding needs is more than putting up signs, most of the time signs cannot overcome architectural failures (Peponis et al, 1990). How should we decide when and where it is useful to place signage?

Utrecht University is redesigning the Langeveld building (**figure 1)**. With a new floor plan, a new signage system is needed. Providing a new signage system is a complex problem, and focusing on floor plan configuration is estimated to be most fruitful (Weisman, 1981). In the present study an attempt is done to make progress towards linking architectural design and human spatial cognition research. An architectural analysis of the Langeveld building is performed, and results in the form of *navigability* scores and 'usability hotspots' are highlighted. Also, a wayfinding experiment with first-time-visitors is performed. The wayfinding performance results are related to the architectural analysis. From the converging results of both experiments, design modifications to improve navigability in the Langeveld building are suggested.

While conducting this research I encountered an important decision which has to be made when doing and architectural analysis of a multi-level building. I provided a description of the decision at hand, and the implications of deciding one way or the other. This knowledge could be of use to future architectural analysis.

2. Architecture and wayfinding

A key rule of environmental perception is that information is not perceived because it is there but because it is needed. The built environment is complex and contains much more information than a person can absorb at a given moment. The person, in order to cope with complexity, has to select. During wayfinding, people will select the information which is relevant to their task (Passini, 1996). Therefore, the challenge will be to only place a signs at relevant locations (i.e. decision points). Determining all decision points, and providing suitable signage is out of the scope of the study. What elements of the environment will be a fruitful focus of research in order to deal with wayfinding problems?

Much research has been done on signage, and in what form (colors, contrasts, fonts, pictograms) it should be provided (Rousek & Hallbeck, 2011 ; Arthur & Passini, 1992). There is also a growing body of literature about the way in which people explore, learn, and navigate through their environment. However, much less attention is given to the question: "what is there to be known about the environment (Peponis et al, 1990). Wayfinding problems can be unraveled by designing an environment which identifies logical traffic patterns that enable people to move easily from one spot to another without confusion.

McKean (1972) and Weisman (1981) argue that the ease by which one could form a cognitive map of an environment is related to the simplicity or good Gestalt of floor plan configurations. Symmetry, regularity, and continuity are among those qualities of good form (Canter, 1974). Symmetry can be helpful in interpreting vertical information of space, e.g., for spatial reasoning within multi-level buildings (Montello & Pick, 1993). On the other hand, symmetrical architectural settings are principally one of the foremost difficulties in spatial problem solving processes (Remolina & Kuipers, 2004). So, rules of thumb for designing a sound architectural setting cannot be the whole story. We should investigate a setting in more detail. An architectural analysis of the setting at hand using Visibility Graph Analysis (VGA) will provide us with useful extra information.

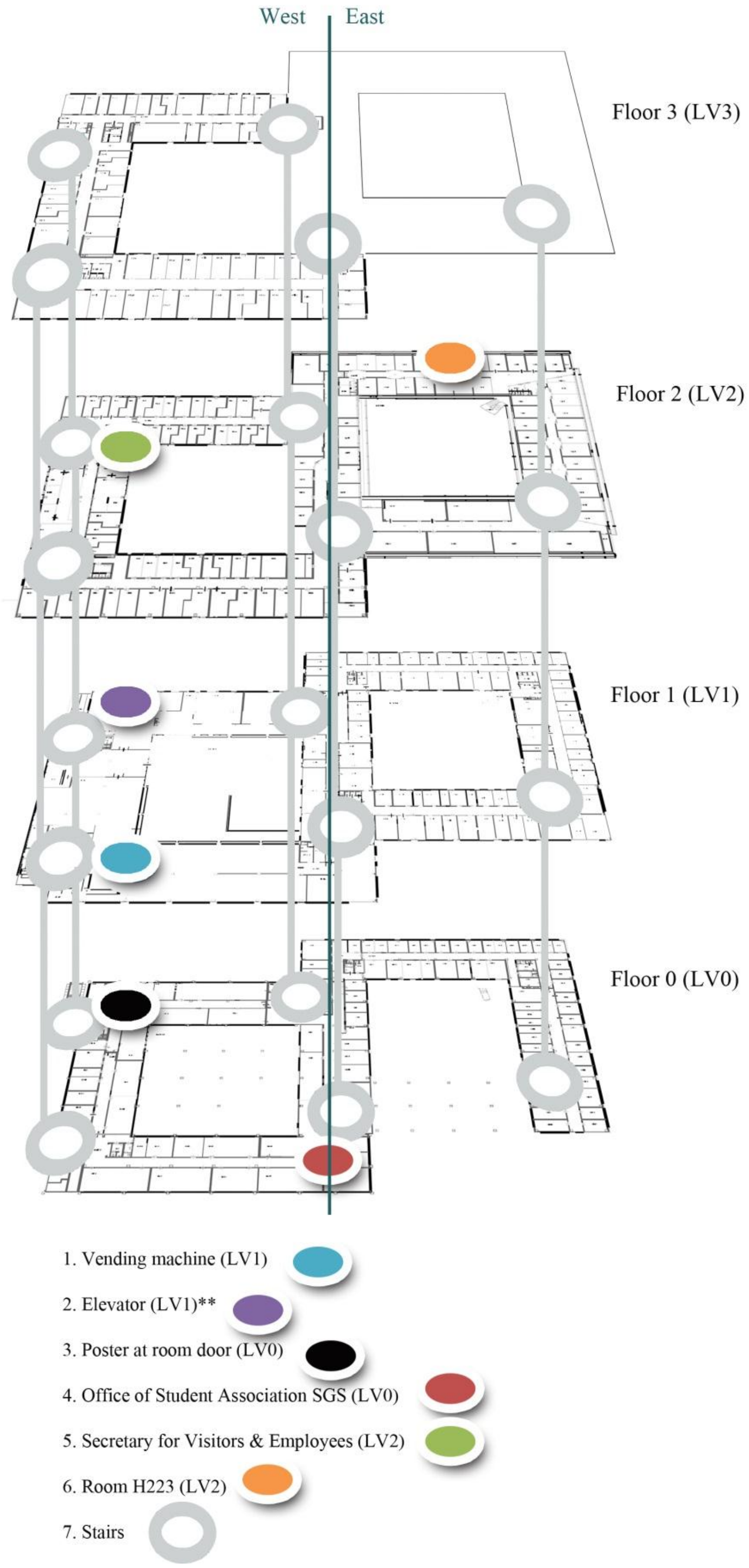

Figure 1: Floor plan of the Langeveld building. Destinations used in the wayfinding experiment are included. The building is divided into an Eastern and Western rectangle. Vertical connections are indicated by interconnecting lines between floors.

2.1 Architectural analysis

Making use of an architectural analysis, I intend to provide an answer to the following question: "*what are the main usability deficits of the Langeveld building, and how can we overcome these deficits?"* A number of architectural peculiarities of the university building will be determined, so called 'usability hotspots' (Hölscher et al, 2005) that appear to hinder successful orientation and wayfinding. That is, is there a systematic association between particular building features and way-finding difficulties? Usability hotspots are important features of a building which are designed or implemented in such a way they hinder successful wayfinding. A number of 'hotspots' are determined in a qualitative way by the researcher, and are backed by quantitative data from the experiments in the present study. I do not claim the list of indicated 'hotspots' to be an exhaustive list of usability deficits of the Langeveld building. This list provides a good insight in a number of features of the Langeveld building that hinder navigating through the building.

An analysis of visual access within the building is chosen to collect quantitative data of 'hotspots' in the building : if large parts of the building are immediately visible, people have to rely less on stored spatial knowledge and can rely on information directly available in their field of vision (Gibson, 1986). A way to analyze visual access is by means of the space syntax methodology (Hillier, 1984). This theory 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 and are strongly associated with route choices of hospital visitors both in unguided exploration and in directed search tasks wayfinding behavior (Peponis et al, 1990 ; Haq & Zimring, 2003). A theory called Visibility Graph Analysis (VGA) is influenced for a great part by space syntax and has proven to be an even more powerful way to represent the spatial structure of a building and its likely impact on wayfinding (Carlson et al, 2010). To provide an objective measure of the Langeveld building's 'good form', the *intelligibility* score of the building is determined. The *intelligibility* score can also be seen as the ease with which a person navigates through the building. Due to its providence, it was hypothesized that VGA would give a good indication of how people might interact with space either moving through it (Desyllas & Duxbury, 2001) or standing, discussing or generally occupying it (Doxa, 2001). Whether or not VGA actually succeeds in its aims is open to debate. Therefore, other methods for performing an architectural analysis could prove to be more promising in the future.

2.2 Visibility Graph Analysis theory

Visibility Graph Analysis is a space syntax method which developed from two strands of thought. One was isovist analysis (Benedikt, 1979), and the other space syntax (Hillier, B. 1984). Benedikt created maps of properties of the visual field at points within plans of buildings. He drew contours of equal visual area within the plan and called the resulting map an *`isovist field'*. He believed that these maps would give an insight into how people navigate the actual building. Since closely packed contours would indicate rapidly changing visual field he reasoned that these would indicate decision points within the building.

Independently, Hillier and Hanson developed the theory of *Space Syntax* (Hillier & Hanson, 1984). They created various representations for the components of space; they then drew maps of these components, and crucially, the relationships of the components with each other. Within the space syntax community, the representation that has become most used is the axial map. Hillier and Hanson created an interesting twist to established theory at the time. They created a graph using the axial lines themselves as nodes, so that each line was considered connected to others that it intersected. From this graph, they calculated how well `integrated' each line was with respect to all the others in the graph, that is they calculated a measure of the average number of steps it takes to get from one line to any other within the axial map. The *integration* of axial lines is of particular interest to researchers as it correlates well with the number of pedestrians found to be walking along the axial line (Hillier et al, 1993). Later, isovist fields and space syntax were combined to provide a measure of how well integrated isovists themselves are within a plan of an environment (Turner & Penn, 1999). The methodology was formalized as *Visibility Graph Analysis* (VGA) (Turner et al, 2001). In VGA, a grid of points is overlaid on the building's plan. A graph is then made of the points, where each point is connected to every other point in its line of sight . The *visual integration* of a point is based on the number of visual steps it takes to get from that point to any other point within the system.

2.3 Linking architectural analysis to wayfinding performance

Le Corbusier (1962, p.30) declared: "To experience architectural space truthfully it is necessary to perambulate and stride the building." To capture this experience, a wayfinding experiment is performed in which performance of first-time-visitors to reach destinations in an unfamiliar building is determined. Peponis (1990) performed an open-search wayfinding experiment and had a well formulated research question: "how do buildings lend themselves to exploration-how do they become available as search structures, bringing together the intelligibility of architectural form and the ability to reach particular destinations?" Evidence was found for a relation between *intelligibility* score and 'navigability' of a building (Peponis et al, 1990). Also, a correlation between VGA measures and the number of times locations are visited in an open search (gate counts) is found (Peponis et al, 1990). What interests me are *relations between VGA scores (integration, connectivity and step depth) and wayfinding performance to specific locations in a multi-level building*. If such relations exist, we should be able to predict wayfinding performance to specific locations. Some relations are found (e.g. (Hölscher et al, 2009)), but not much research is done on the relations of VGA measures and wayfinding performance in a multi-level building.

Wayfinding performance measures from the current experiment will be related to VGA measures collected in the architectural analysis. I expect to find some relations between measures, based on earlier findings (Peponis et al, 1990 ; Hölscher et al, 2009). A *navigability* score, *wayfinding performance* of first-time-visitors and an in depth architectural analysis will give us a good insight in the wayfinding problems University Utrecht Langeveld building floor plan, and can probably lead to minor adjustments in the buildings which will help us to better find the way inside.

2.3.1 UCL Depthmap

A number of programs to perform Visibility Graph Analysis are available for academic use, UCL Depthmap is chosen because it allows for all analysis required for the study at hand. Depthmap is a tool created by Turner (2001) to perform Visibility Graph Analysis. It actually performs "*dense grid Visibility Graph Analysis*" since it works with a dense grid of isovist locations to build a graph. Depthmap uses AutoCAD drawings as input. Drawings of the building were available, but had to be simplified rigorously. Also a lot of changes had to be made to the drawings to get the appropriate format for importing into Depthmap.

After constructing a Visibility graph with Depthmap a large number of measures become available. The most basic measure of Visibility Graph Analysis is *connectivity*. It reflects how many locations each node can see. Further, *step depth* from a specific location can be determined. The *step depth* may be viewed as the number of turns (plus one) that it takes to get from the current location to any other location within the plan. Everything directly visible from the starting location is at depth one, everything visible from that at depth two, and so on throughout the plan. Step depth is closely related to isovists.

An isovist, as determined by Benedikt (1979), is the polygon which contains all the visible area from a particular location. Depthmap does not calculate isovists. It is graph analysis software, not a geometric analysis tool. However, *step depth* from the current location is an approximation to an isovist. Every node one step away from the selected point is directly visible from that location, i.e., all those nodes are within the isovist of the point location. With a high density grid, this approximates to the isovist (Turner, 2004). *Step depth* from the entrance of the Langeveld building is of particular interest in the present study. In earlier studies, the *step depth* measure has been related to wayfinding performance (Hölscher et al, 2009).

The *visual integration(HH)* of a location is based on the number of visual steps it takes to get from that point to any other point within the system. It is defined in Hillier and Hanson (1984). Several other variants of determining *integration* are available. In the remainder of this article, when *integration* is used, it always refers to *visual integration(HH).* Intuitively *integration* reflects the centrality of a node with respect to the whole graph. The measure is important because it has been found to correlate well with route choices of wayfinders (Hillier et al, 1993).

Now, *connectivity* and *integration* have been determined we can put them to use. Intelligibility is the correlation between the latter two measures; it is an objective measure of a building's 'good form'. It is a correlation of the *local (connectivity)* and *global (integration)* properties of a building. Intelligibility can be seen as the ease with which a person navigates through the building, and is therefore a measure of *navigability*. Intelligibility is not only a physical attribute of the environment, but an aspect of spatial cognition as well (Kim, 2001). The inherent *intelligibility* of a spatial complex influences exploratory movement and the understanding of its configuration (Brösamle & Hölscher, 2007 ; Yun & Kim, 2007). Depthmap gives us the means of making scatterplots (**figure 2, 3).** Intelligibility can be determined by calculating the correlation coefficient between *connectivity* and *integration*.

3 Methods

3.1 Architectural analysis

Visibility Graph Analysis is used to perform an architectural analysis of the Langeveld building. Determining the intelligibility score of the University Utrecht building is the first step in the architectural analysis. With the intelligibility score, University Utrecht's buildings architecture can be compared with other buildings on navigability. Further, a number of 'usability hotspots' were chosen in a qualitative way by the researcher. Corresponding VGA measures are determined to provide a quantitative qualification of the usability deficits emerging at the 'hotspots'.

Procedure

The Langeveld building is a four level building. The form of the building is that of two partially overlaying rectangles. In the present article, the left rectangle will be referred to as the Western side of the building, and the right rectangle as the Eastern side. At some floors the rectangles are incomplete, causing floors to be incongruent (**figure 1).** Floors are connected by means of four stairwells and one elevator. Stairwells and elevators are the only visual connections between floors. The basement is not taken into account in the present study because it is no public space. AutoCAD drawings of the Langeveld building floor plans are simplified in such a way they can be imported by UCL Depthmap. AutoCAD LT 2012 is used to modify and simplify floor plans. Depthmap creates a Visibility graph of the imported floor plans. The Visibility graph was constructed with no restriction to visible distance, and for eye-height visibility.

Connecting floors

With the Depthmap software, when investigating a multi-level building, different floors have to be connected in a somewhat artificial way. Some extra points have to be created outside of the floor plan, a group of points together form a stairwell. Manual links have to be created, from points in the floor plan to points in the stairwell. Choosing points in the floor plan and using the same points consistently for every analysis has proven to be an important factor for attaining consistent results. Further, different ways of representing a stairwell are available. In the present study, a stairwell is used which connects different floors with one visual step, independent of how many floors you go up or down. Different ways of representing a stairwell are further discussed at the Discussion chapter.

Data analysis

First, the *intelligibility* scores of the current and changed floor plans were determined. The navigability of the current and changed floor plans, and navigability of independent floors are compared, as well as the Langeveld building scores to scores from buildings provided by other studies (e.g. (Hölscher et al, 2009)). The usefulness of the latter comparison is open to debate. In the discussion section of this paper, the issue of comparing navigability scores is further highlighted.

Second, several important features of the Langeveld building are determined. These 'hotspots' are evaluated using VGA measures. *Step depth* from the entrance to other locations was considered. *Connectivity* is calculated to indicate the level of overview a location provides. The global variable *visual integration(HH)* is determined to provide information of the *centrality* of locations in the building. From *connectivity* and *integration* scores, an *intelligibility* score for the Langeveld building was calculated. Intelligibility scores are determined for the building as a whole, as well as floors independently. At the six hotspots, the determined VGA measures provide a quantitative qualification of the usability deficits emerging at the 'hotspots'. Generally speaking, important features of a building should be well integrated and should provide some amount of overview.

3.2 Wayfinding experiment

A wayfinding experiment is performed in the Langeveld building to determine wayfinding performance to specific locations in the building. This experiment provides valuable additional information of the way people interact with architectural space. In the literature, wayfinding behavior and related cognitive competencies are analyzed in many different ways. Self-report can be used or the ability to recall and/or locate places on the plan of the premises (Evans et al, 1984). Direct observation of behavior is a more direct way of measuring wayfinding performance. Verbal reports were not used because they are restricted to consciously accessible aspects of cognitive processes, and therefore do not tell the whole story (Ericsson & Simon, 1980).

Participants

Eight male and 2 female University students were asked to participate in the experiment. Participants never visited the Langeveld building before, so all participants are first time visitors.

Procedure

A *directed* wayfinding experiment was carried out. Ten first time visitors performed *uninformed search* tasks (Wiener et al, 2009). The experiment is carried out in the evening hours when the building was minimally occupied by students or other users. People occasionally walked by, but never hindered a participant in any way. Participants each had to find 6 specific destinations throughout the building. The order in which destinations had to be found was randomly assigned to the participant. The starting point is the main entrance for every trial. Participants were filmed by the researcher, who followed at a distance of ± 5m. Starting at the main entrance, the participant had to find the given destination using only signage. When a task was completed the researcher and participant returned to the entrance.

Destinations (Floor)*

1. Vending machine (LV1)
2. Elevator (LV1)**
3. Poster at room door (LV0)
4. Office of Student Association SGS (LV0)
5. Secretary for Visitors & Employees (LV2)
6. Room H223 (LV2)

 * In the pilot study, all destinations were room numbers throughout the building. Because subjects could navigate to those destinations easily using the signage in the building, destinations were changed, save for destination 6 (see Discussion), to places which are not explicitly signposted.

 ** Some subjects went for the elevator at another floor.

Data analysis

Performance measures

Wayfinding Performance

The Wayfinding Performance measure is the same measure that is used in an experiment by Hölscher et al (Hölscher et al, 2005).

For each destination, the shortest route as well as a list of reasonable route alternatives was determined beforehand. Reasonable routes are defined as neither containing cycles nor dead ends or obvious detours. The following six variables were determined:

1. Time[s] Determined by the camera clock.

2. Stops[n] The number of times a participant stops to read signs or think about which way to go.
3. Getting lost[n] Every time a participant deviates from the shortest route, or reasonable route alternatives he is considered to be lost.
4. Distance[m]

   Stairs[n] an arbitrary distance of 22.5 meters was chosen for moving up or down the stairs. The number of stairs taken is counted in order to be able to change this arbitrary distance afterwards.

5. Distance / shortest way

6. Speed(Distance / Time)[m/s]

Intuitively *distance/shortest way* is the most informative performance measure. For every destination to be found, this variable expresses the proportion of superfluous way independent of distance covered. A score of 1.2 means 20% extra distance covered. The number of times a participant *stops*, or the average *speed* of a subject could give us useful information about how confident a wayfinder is about the task he is trying to complete. Also, the number of times getting *lost* is an interesting measure. When getting lost, consequently the distance covered will be greater. But taking a detour does not necessarily imply you are lost.

3.3 Linking VGA variables to performance measures

Procedure

Relations between wayfinding performance measures were calculated. If such relations exist, we should be able to predict wayfinding performance to specific locations in a multi-level building. Further, a variable WPerformance was constructed. Relations between WPerformance and VGA variables were determined.

Data analysis

Relations between wayfinding performance measures and VGA measures were tested with a Pearson correlation test. The VGA measure that has the highest correlation with performance measures can be classified as the best predictor for wayfinding difficulty.

4. Results

4.1 Building navigability

First, from the Visibility Graph Analysis 'navigability' scores of the investigated settings were determined. The current Langeveld configuration *intelligibility* score R^2 = (0.21 – 0.28) **(table 1)**. In other buildings *intelligibility* scores of R^2 = 0.29 (Hölscher et al, 2009) and R^2 = 0.47 (Beck & Turkienicz, 2009) are found. The Langeveld *intelligibility* score could is similar to the score of the building investigated in the Hölscher study (2009). The building in the Hölscher study was called a 'three-dimensional maze'. So, the poor navigability of the Langeveld building as a whole is similar to navigability of a three-dimensional maze.

However, if we look at floors independently we see that some floors score higher than others**.** Navigability of most floors is quite good (R^2 = 0.560 – 0.65), but the bottom floor (LV0) *intelligibility* score is only R^2 = 0.36. The drop in *intelligibility* scores when floors are connected (**table 1)** could be due to the placing of stairwells and elevators in the building. Also, inconsistently connecting floors in Depthmap could contribute to this decline of *navigability*. This is further discussed in the discussion section. The performed analysis puts a label of poor *navigability* on the Langeveld building, but will actual wayfinding in the building be as hard as could be expected on basis of this architectural analysis?

Table 1: Intelligibility scores of the Langeveld building

	LV 0	**LV 1**	**LV 2**	**LV 3**	**LV 0,1,2,3**
Intelligibility(current)	0.36	0.60	0.68	0.65	0.21 - 0.28

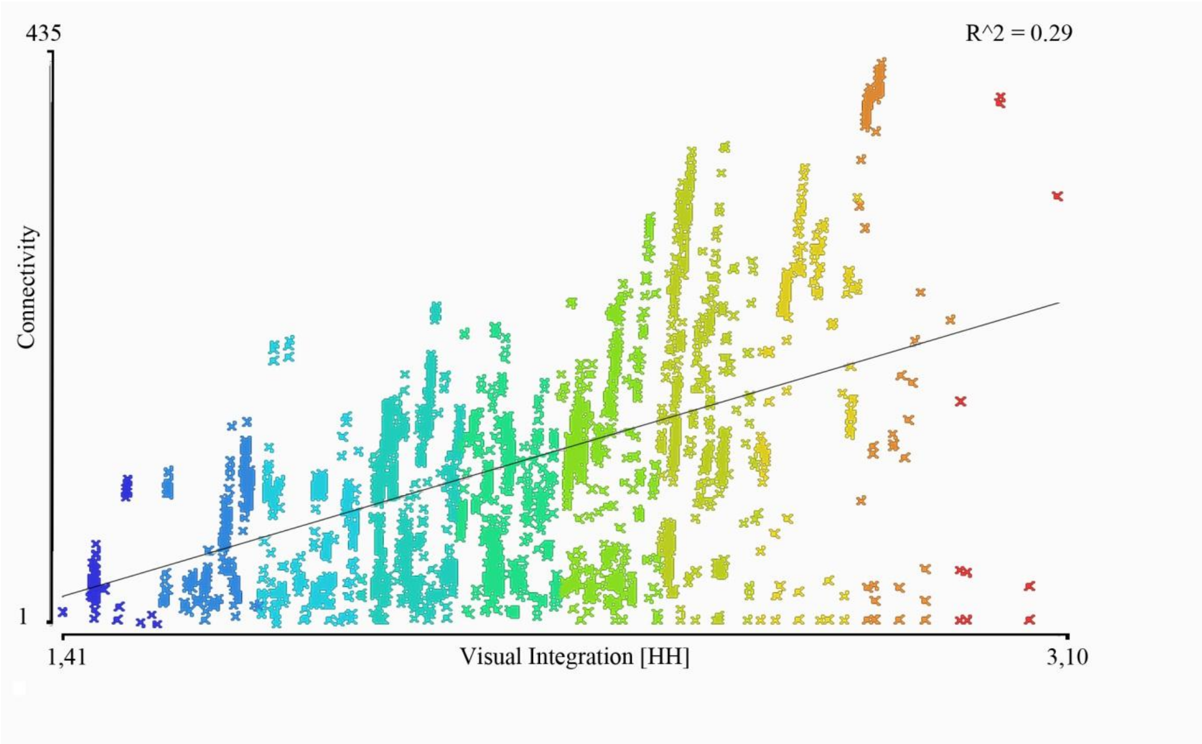

Figure 2: scatterplot of connectivity and integration scores for the Langeveld building. The correlation coefficient in this plot is called the 'intelligibility score', and is a measure of 'navigability'. Intelligibility: R^2 **= 0.29**

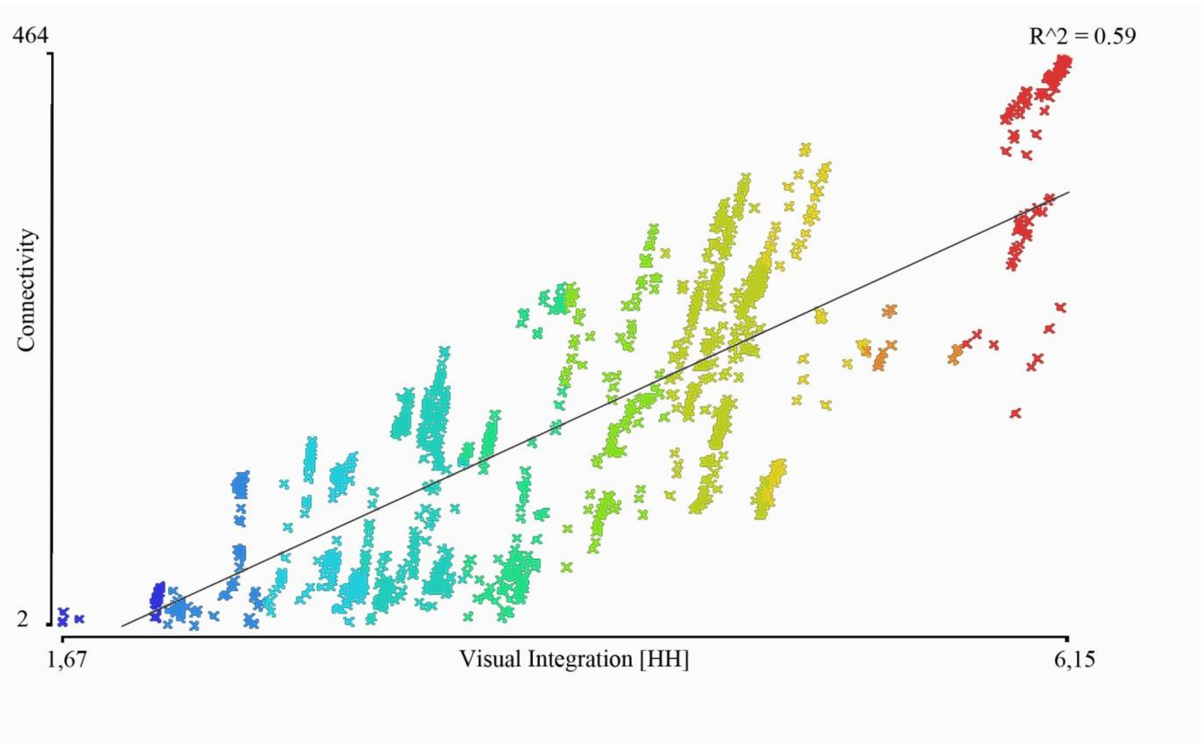

Figure 3: scatterplot of connectivity and integration scores for first floor (LV1) of the Langeveld building. The correlation coefficient in this plot is called the 'intelligibility score', and is a measure of 'navigability'. Intelligibility: R^2 **= 0.59**

Usability hotspots

The analysis of usability hotspots is based on a qualitative evaluation of the Langeveld building by the researcher. To some extent the results were substantiated by relating VGA variables and behavioral measures to specific points and areas of the building. The problems in wayfinding in this building are in part caused by vertical incongruence of floors, and dead ends or seemingly dead ends. In the following, I focus on six `hotspots' of the building and relate their disadvantages to architectural analytic measures. This list of six 'hotspots' is not an exhaustive list of usability deficits of the Langeveld building. Hotspots are determined on the basis of known usability literature, and the experience gained in the wayfinding experiment of this study.

1. **Integration Main Entrance**

   The integration score of the main entrance is very low (1.78) (**figure 5)** compared to the mean Integration of the building (MEAN = 2.11 SD = 0.30). This means the entrance is badly integrated in the building. This could also be seen as: the main entrance is not centrally located in the building. This results in big differences between locations in step depth from the entrance (**figure 6)**. The placing of the entrance cannot be changed, but at least the lack of centrality can help us to make choices in signposting the building.

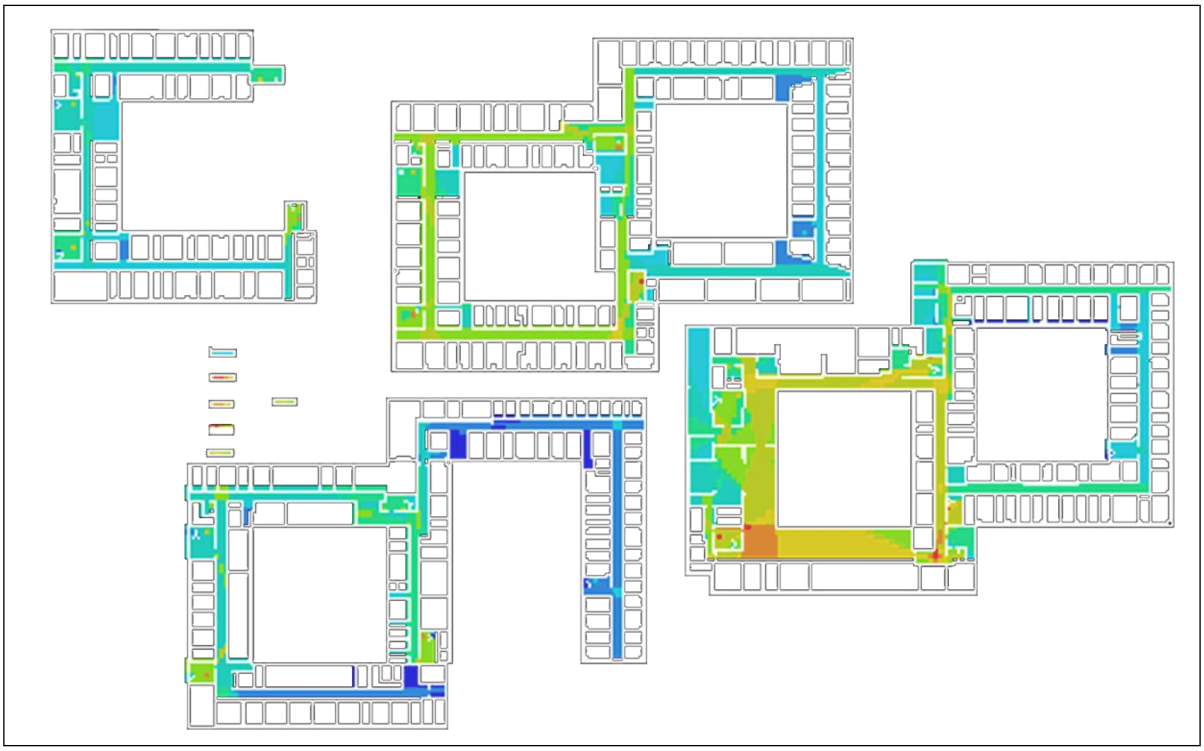

Figure 5: integration scores for the Langeveld building. The Integration score can intuitively be seen as a measure of centrality. A good score is represented by warmer colors (yellow/red), whereas a poor score is represented by cooler colors such as green and blue.

2. Incongruent floors

Floor 0 and floor 3 are different in form from floor 1 and 2. In a building, people expect floors to be the same all through the building (Passini, 1992). Floor incongruence will therefore make finding your way in the building harder (Soeda et al, 1997).

3. Eastern side of the building.

The eastern part of the building has *step depth* scores (**figure 6)** which are higher than the western part of the building, East (8.25) and West (5.56). Therefore, wayfinding performance will be worse to the eastern part of the building. *Integration* scores are lower for the eastern part of the building, East (1.86) and West (2.20). The 'centrality' of the eastern side of the building is therefore lower than the western side.

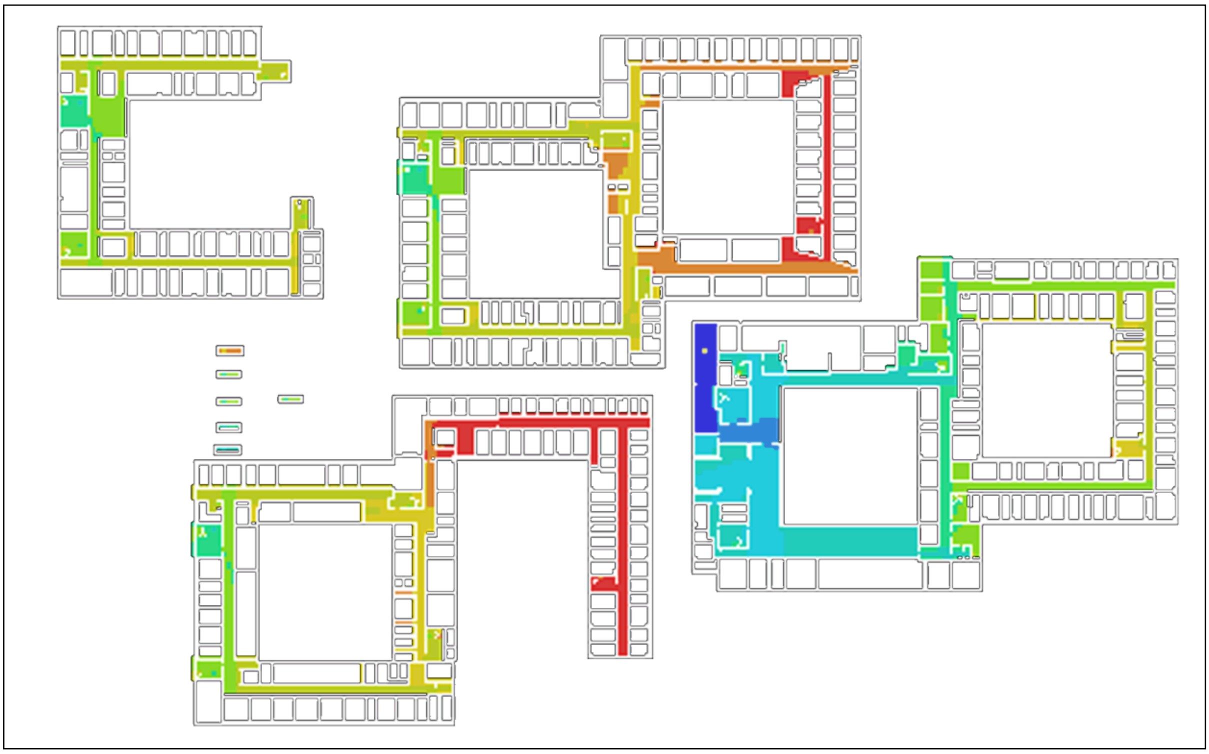

Figure 6: step depth from the main entrance. Higher step depth scores (a high number of visual steps or turns) are represented by warmer colors (yellow/red).

4. **Secretary visitors & employees**

   The secretary for visitors should be really easily accessible, because a secretary is a typical destination for first-time visitors. When we look at wayfinding performance to this specific destination a mean *search time* of 456.1 seconds is measured, and the *WPerformance* score to the secretary is 2.35. This is the highest, and poorest, score of all investigated locations. Such long *search times* are undesirable, and therefore measures have to be taken. The secretary could be relocated, and if this is not an option or not desirable it should be really well signposted from the entrance.

5. **Survey places**

   The only visual connections between floors are by staircases and elevators. All of these connections can only be seen when you are close to it, and the elevator is even located at a dead end. The VGA *connectivity* measure provides us with a visible area from any given point. In (**figure 7**), poor *connectivity* scores indicate that almost no point in the building can be characterized as a survey place by providing an overview.

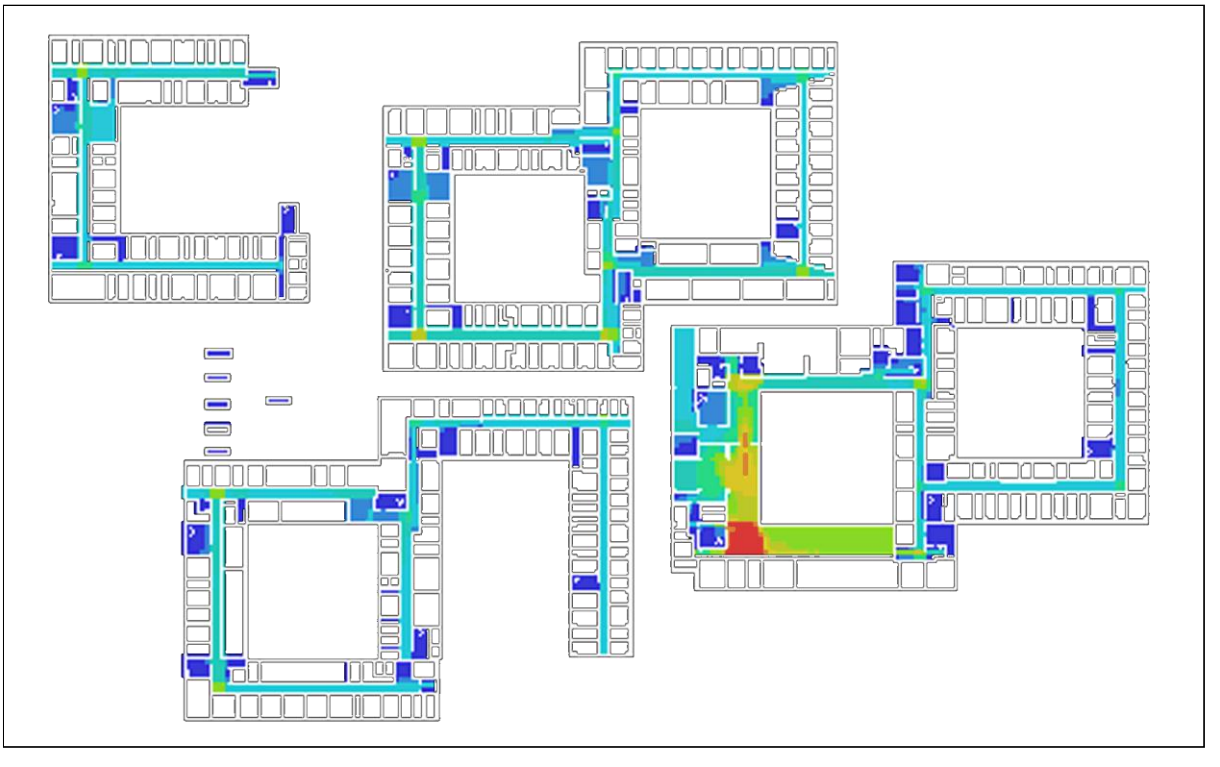

Figure 7: connectivity scores for the Langeveld building. Warm colors (yellow/red) represent a high connectivity (the number of places a node can see). This measure is a close approximation of the 'Isovist' measure.

6. Apparent 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 (Hölscher et al, 2009). Real dead ends do not exist in this building (apart from small corridors to toilets facilities). Apparent dead ends on the other hand are manifold (**figure 8)**. In LV0, the eastern wing corridors are apparent dead ends, because a stairwell at the end of the corridor will only be visible when reaching the end of the corridor. Therefore, when walking along the corridor it would feel like reaching a dead end until the very last moment. A list of apparent dead ends, and some possible actions to overcome these dead ends are provided.

A. <u>LV0 bottom:</u>

A non-transparent door is located at the end of the hallway. The door is never opened by any of the participants in the wayfinding experiment. This door creates two unnecessary dead ends, and can easily be overcome by placing a transparent door.

B. <u>LV0 Eastern wing:</u>

The Eastern wing forms in LV1 and LV2 a full rectangle, but in LV0 the rectangle is incomplete. This seems to create a dead end (verbal reports and declining speed).

C. <u>LV3 both stairways:</u>

The stairwells are located at the end of an apparent dead end. Only when almost at the end of the corridor, the stairwell can be seen.

D. <u>Elevator:</u>

The elevator is located at a small blind corridor. The corridor appears to be a dead end, only when it is entered the elevator can be seen.

Floor 0 (LV0)

Floor 3 (LV3)

Figure 8: Apparent dead ends in the Langeveld building. Numbers correspond with the reference numbers in the list of apparent dead ends above.

Analysis of redesigns

With the architectural analysis, modified floors plans of the Langeveld building can be investigated. This gives us the means to explore redesigns in the building, determining *intelligibility* scores before and after a re-design, and provide recommendations whether or not to implement this modification in Langeveld building. Functional redesigns for the Langeveld building that do not require a radical rebuilding are limited. Two possible redesigns are investigated: placing a transparent door at the apparent dead end of the bottom of LV0 and making floors congruent by completing the Eastern rectangle of LV0 and LV3.With the first redesign, *intelligibility* of LV0 improves from 0.36 to 0.57. An increase of navigability for LV0 is achieved. What is interesting is that for the complete building, *intelligibility* has dropped from (0.21 – 0.28) to 0.18. With the second redesign, creating congruent floors, *intelligibility* of LV0 improves from 0.36 to 0.85 and LV3 from 0.65 to 0.80. An increase of navigability on both floors is achieved. The global *intelligibility* however, drops from (0.21 – 0.28) to 0.16. Part of the global *intelligibility* drops may be due to inconsistently connecting floors in Depthmap, but the improvement of *intelligibility* on a single floor leading to a downfall in global *intelligibility* is interesting, and could be further investigated with additional redesigns (see Future Research section).

Table 2: intelligibility scores of separate floors of the Langeveld building, and all of the floors connected(LV 0,1,2,3) before, and after a described redesign is implemented.

	LV 0	**LV 1**	**LV 2**	**LV 3**	**LV 0,1,2,3**
Intelligibility (current)	0.36	0.60	0.68	0.65	0.21 - 0.28
Intelligibility (redesign)	0.57	-	-	-	0.18
Intelligibility (congruent)	0.85	0.60	0.68	0.80	0.16
Difference	+ 0.19	-	-	-	- 0.10

4.2 Wayfinding behavior

Finding ones way from the entrance to a specific location was the task of ten participants taking part in the wayfinding experiment. Performance was measured using several variables. The first four variables in (**table 3)** are directly collected from the wayfinding experiment. From this data, other variables like *speed*, *distance* and *WPerformance* (**equation 1)**, are computed.

Wayfinding performance

From the data collected, a variable *WPerformance:* was constructed (**equation 1)**. This variable assumes variables *speed*, *stops, getting lost and degree of detour* (DistShort) to equally contribute to wayfinding performance because each measure is weighted in such a way that all measures cover the same interval for the data collected in the wayfinding experiment.

Equation 1

$$WPerform. = ((\log_{10} Distshort) + 1) - \frac{Speed - 0.52}{2} + ((\log_{10} Stops) + 1) + \frac{(\log_{10} Lost) + 1}{2}$$

The *WPerformance* measure gives us the means to compare performance between destinations very easily. Destination 4 and 5 are hardest to reach, *WPerformance* 2.22 and 2.35.

Destination 6 (Room h223) has proven to be somewhat different from the rest of the destinations. It is explicitly signposted, and participants could very easily figure out this destinations should be located on the second floor. Therefore I decided to run most of the analysis with, and without, destination 6. Trial 28 (participant 5, destination 4) has been excluded from the results because the exact location of the destination was known after looking at a poster. After this incident, participants were instructed not to read text on posters extensively.

Table 3: wayfinding performance measures for each destination, the average performance and the standard deviation across all wayfinding tasks.

	Dest. 1 N=10	Dest. 2 N=10	Dest. 3 N=10	Dest. 4 N = 9	Dest. 5 N=10	Dest. 6 N=10	Mean	SD
Time(s)	30.9	94.1	241.2	670.3	456.1	163.6	269.36	317.16
Distance(m)	34.0	93.1	241.6	608.5	367.8	162.6	245.20	292.38
Stops(n)	0.0	1.0	1.9	7.3	4.7	0.7	2.53	3.63
Lost(n)	0.0	0.7	0.8	4.1	2.1	0.3	1.29	2.02
Speed(m/s)	1.13	1.03	1.03	0.89	0.78	0.98	0.98	0.20
DistShort	1.0	3.1	6.0	6.5	10.8	1.7	4.8	5.61
WPerformance	0.69	1.23	1.64	2.22	2.35	1.07	1.52	0.79

4.3 Linking architectural analysis to wayfinding performance

In this section, VGA variables from the architectural analysis and performance measures are linked to uncover correlations between VGA variables and wayfinding performance measures. Integration, connectivity and step depth are considered (**table 4)**. Both Pearson correlation analysis including, and not including *Destination 6* is performed. Dropping location 6 leads to a better correlation score every time. This effect is strongest when looking at *step depth.* Correlation of *step depth* and *WPerformance* improves from (0.17) to (0.69) when leaving out location 6. Correlations of *integration* with wayfinding performance measures vary from -0.25 to -0.56. Correlation with wayfinding performance measures vary from (-)0.21 to (-)0.39 for *connectivity*. For *step depth,* the correlations vary from 0.42 to 0.69. The difficulty of the wayfinding task is clearly described best with the *step depth* measure. So, wayfinding performance to specific locations could best be predicted by the *step depth* measure. The WPerformance measure relates stronger to the *step depth* measure (0.69) than any other performance measures (0.42 – 0.63) and could therefore be a good candidate for being a wayfinding performance measure.

Table 4: Integration, connectivity, and step depth of each destination, and the corresponding wayfinding performance for scores for that destination. The thee rightmost columns indicate the Pearson correlation of respectively integration, connectivity and step depth scores with the corresponding performance measure. Pearson correlates are determined including (+6) and excluding (-6) destination six.

	D 1 N=10	D 2 N=10	D 3 N=10	D 4 N=9	D 5 N=10	D 6 N=10	Corr Int +6 / -6	Corr Con +6 / -6	Corr StD +6 / -6
Integration	**2.80**	**2.14**	**2.28**	**1.73**	**2.29**	**1.95**	**-**	**-**	**-**
Connectivity	**415**	**31**	**250**	**112**	**164**	**105**	**-**	**-**	**-**
Step Depth	**3**	**4**	**5**	**6**	**5**	**8**	**-**	**-**	**-**
Time(s)	30.9	94.1	241.2	670.3	456.1	163.6	**- 0.43** / - 0.52****	**-0.22 / -0.28**	**0.24 / 0.63****
Distance(m)	34.0	93.1	241.6	608.5	367.8	162.6	**- 0.43** / - 0.51****	**-0.21 / -0.26**	**0.24 / 0.60****
Stops(n)	0.0	1.0	1.9	7.3	4.7	0.7	**- 0.41** / - 0.54****	**-0.23 / -0.31***	**0.16 / 0.62****
Lost(n)	0.0	0.7	0.8	4.1	2.1	0.3	**- 0.43** / - 0.56****	**-0.24 / -0.33***	**0.15 / 0.58****
Speed(m/s)	1.13	1.03	1.03	0.89	0.78	0.98	**0.29* / 0.33***	**0.27* / 0.29***	**-0.23 / - 0.43****
DistShort	1.0	3.1	6.0	6.5	10.8	1.7	**- 0.14 / - 0.25**	**-0.13 / -0.21**	**0.03 / 0.42****
WPerform.	0.69	1.23	1.64	2.22	2.35	1.07	**- 0.38** / - 0.53****	**-0.29* / -0.39****	**0.17 / 0.69****

*correlation is significant at the 0.05 level (2-tailed)

** correlation is significant at the 0.01 level (2-tailed)

Conclusion/discussion

What proved to be hard was to find proper destinations for the wayfinding experiment. According to the space syntax theory, VGA measures like *integration* are correlated with human behavior in an open search task (Peponis et al, 1990). But creating the circumstances for an open search to a specific location is not at all trivial. The effect of poorly chosen locations is clearly visible when we look at the wayfinding performance to *step depth* relation (**table 4)**. The *step depth* correlation is significantly (0.17 → 10.69) affected by leaving location 6 out of the analysis. This shows us that location choices are crucial for the outcome of linking architectural analysis to wayfinding performance. The task affordance hypothesis could help us understand this effect. According to this hypothesis, people will be more likely to use a specific strategy as tasks more readily afford its use. So, for instance a search for the *vending machine* will invoke the strategy of looking for the canteen. And a search for the *secretary* will start with people looking near the entrance (Raubal & Worboys, 1999). A location like a *poster on a door* does afford the least possible amount of strategy. Participants will start looking for it with little to no prior knowledge or beliefs about its location. Let us call such a location a *minimal-affording* location. Carrying out an experiment with a set of *minimal-affording* locations will be an interesting subject for further research.

The wayfinding experiment gives rise to a number of other challenges. For example, the starting point of every trial is the main entrance. This enables randomization of destinations, and the task of moving to specific locations of a first-time visitor is investigated. Because after each trial the participant has to walk back to the entrance, some extra knowledge of the building is gained. To keep the extra knowledge to a minimum the researcher talked with the participant on its way back. In other studies (i.e. (Hölscher et al, 2009)), participants have to move from location to location, and the task of moving from location to location is investigated. The researcher followed the participant during the experiment, this allowed for reliable video material and test data. Participants said not to have been hindered by the researcher. It was an unforeseen setback that the third floor could not be investigated in respect to wayfinding performance because restructuring work was being done. Poor VGA measure scores for the third floor imply poor wayfinding performance. Furthermore, third floor's form is incongruent with other floors, and stairs lay at dead ends, my expectation would be that wayfinding performance to locations at the third floor will be quite poor.

The architectural analysis also came with its difficulties. The process of connecting floors with the architectural analysis software has proven to be an important factor in the analysis of the Langeveld building. The drop in *intelligibility* scores when floors are connected (**table 1)** could be due to the placing of stairwells and elevators in the building. Also, the procedure of connecting floors could contribute to this decline of *navigability*. The degree in which either causes contribute to this effect remains unclear and could be a subject of further research. Further, when performing the Visibility Graph Analysis in Depthmap, an important choice has to be made. In a multi-level building, different floors have to be connected in a somewhat artificial way. Some extra points have to be created outside of the floor plan, and those points together form the stairwell. Now we can make the following choices:

1. Connect floors with one visual step. So moving from floor 1 to floor 2 is the same, in visibility terms, as moving from floor 1 to floor 3 (Turner, 2004).
2. Connect floors with one visual step per floor up or down. So the cost for moving from floor 1 to floor 2 is one visual step, and moving from floor 1 to floor 3 will cost two visual steps (Hölscher et al, 2009).

While at first sight this difference looks superficial, it could affect results of a Visibility Graph Analysis radically. Because Integration(HH) is directly linked to step depth, this variable will be affected also. When switching from the first to the second option, all Integration(HH) scores will go down (which represents a worse score) because moving from floor to floor has become more costly. As you can imagine, when the building being investigated has many floors the Integration(HH) scores will drop to a very low level. We should ask ourselves whether the intuitive interpretation of the Integration(HH) score as a measure of *centrality* is applicable to a multi-level building. So, Integration(HH) will change with the method choice of connecting floors. Also, the change will be dependent of the number of floors investigated. And even more important, the correlation between connectivity and Integration(HH) scores will be affected. This correlation, the so called 'intelligibility' or 'navigability' of a building is used to compare different buildings on navigability.

The connectivity score is not much affected by the number of floors in a building. The Integration(HH) score is affected, but in a predictable way(can be calculated with #floors and #locations on each floor).So, if the second option of connecting floors is chosen, at least we can adapt our Integration(HH) scores in such a way that Intelligibility can be determined in a meaningful (I do not state it is the right way, but at least we're looking at the same correlation as if we were using method 1) way. My claim is that if we do not consistently choose one or the other options of connecting floors, comparing Navigability scores will be of not much use. So, for now it might be wise to use both methods and report results of both analyses. At least the method chosen should be mentioned and substantiated. Maybe in the future a new method will be developed which will allow us to perform our analyses in a more consistent way.

In spite of al difficulties and challenges, a number of usability deficits of the Langeveld building have been determined, using the data collected in the wayfinding experiment, and the performed architectural analysis. The list of deficits is not an exhaustive list, but provides a good insight in a number of features of the Langeveld building that hinder navigating through the building. The overall navigability of the Langeveld building is not very good, and even decreases when an expected improvement, placing a transparent door, is implemented. So, a number of usability deficits have been identified. Getting rid of our usability hotspots and hard to reach locations is another matter. The proposed redesign proved not to easen up wayfinding, according to the architectural analysis. A list of design adjustments to improve navigability in the Langeveld building cannot be concluded from this research. Further research could produce navigability enhancing redesigns. Providing extra signage for hard to reach locations like a secretary could also easen up wayfinding. But placing extra signage will not always overcome bad building design.

Relations between performance measures of the wayfinding experiment and architectural analysis have been tested. Results show us that wayfinding performance to specific locations could best be predicted by the *step depth* measure. This finding is in line with earlier findings (Peponis et al, 1990 ; Hölscher et al, 2009). A wayfinding performance measure was constructed (*WPerformance*) which relates stronger to the *step depth* measure than any other performance measures and could therefore be a good candidate for being a new wayfinding performance measure. Therefore, we should be able to predict wayfinding performance to specific locations using the *step depth* or *WPerformance* measures. The acquired *navigability* score, *wayfinding performance* of first-time-visitors and in depth architectural analysis, gives us a good insight in the wayfinding problems of the University Utrecht Langeveld building, and can probably lead to minor adjustments in the building which will help us to better find the way inside.

Future research

In the future, the architecture of other university buildings could be analyzed, and navigability results can be compared. This will provide us with a 'navigability ranking' of several buildings, and will hopefully be of use to future architects and designers. Also, a wayfinding experiment in the Langeveld building could be repeated, using only *non-affording* destinations. An experiment with several changes made in the building could also produce useful results. Think of creating less visibility by changing transparent doors or windows to opaque, and creating extra visibility by changing opaque doors to transparent or creating an atrium at the entrance. Scores of different designs can be compared, and the best design can be pointed out.

Further, a number of architectural analysis of a floor plan could be performed with first, minor adjustments made in the procedure of connecting floors (i.e. attaching custom links in the visibility graph to surrounding nodes of the originally used node) , and determining the contribution of changes to the *intelligibility* score. Second, a number of floors plans with adjustments in vertical connections (i.e. stairs, elevators and visual sightlines floors) should be investigated. Insight in the amount of contribution to *intelligibility* scores of either manipulation will be provided with such an experiment.

What I also hope to achieve is a discussion of using Visibility Graph Analysis for multi-level buildings. The question whether *integration* is to be interpreted as a centrality score in a multi-level building is up for discussion. We should also attempt to develop a consistent technique of connecting floors in our analysis to create a model which corresponds to behavioral data like movement patterns and can maybe even correspond to wayfinding performance.

As the practical goal for the present study was to provide guidelines for a new signage system in the restructured Langeveld building, a same strategy could be used if the same questions arise for future buildings which are in need of new signage after restructuring. With the provided analysis, wayfinding difficulty to specific locations can be predicted well, and measures can be taken to pay extra attention to locations which have proven to be hard to reach. These measures could be providing extra signage, but a lot of other interventions could be applied. Based on the present study I hope to intensify the cooperation of cognitive scientists and architectural designers. It will be worthwhile to develop more detailed methods to support usability from the early planning stages on, in order to avoid costly design mistakes. With the techniques presented here, before a building is built, a visibility analysis can be performed to identify usability deficits.

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Reflectie

Wat ik heb geleerd is dat het bepalen van een duidelijke richting en onderzoeksvraag het eerste zou moeten zijn waar je in een onderzoek aan moet werken. Het ontbreken van een duidelijke richting in het begin van mijn onderzoek heeft ertoe geleid dat ik veel literatuur heb gelezen die slechts zijdelings gerelateerd is aan het onderwerp van mijn uiteindelijke onderzoek. Het bewegwijzeringsproject van twee universiteitsgebouwen, waarbinnen dit onderzoek valt is dusdanig breed dat er vele onderzoeksvragen mogelijk zijn. Een adviesrapport was reeds voorhanden, en vele antwoorden op mogelijke vragen worden daarin beantwoord. Ook is veel van het nieuwe ontwerp van de gebouwen al vastgelegd, en is de insteek: nu alleen nog even bewegwijzering plaatsen.

Omdat deze aanpak de mogelijke manipulaties in de gebouwen, en daarmee de onderzoeksvragen zeer beperkt was het lastig een geschikte onderzoeksvraag te formuleren. Uiteindelijk heb ik de architectuur als meest interessante en uitdagende insteek gezien, en heb me gefocust op de vraag: hoe moeilijk is het om de weg vinden in de gebouwen, puur gebaseerd op het ontwerp van een gebouw.

Wat ik heb geleerd is dat een onderzoek kan vallen of staan op de toepasbaarheid van een onderzoeksmethode. Om mijn gebruikte methode te kunnen toepassen heb ik vele hindernissen moeten nemen en ook regelmatig moeten afwijken van de ideale situatie. Het volledig begrijpen, en correct kunnen uitvoeren van een nieuwe methode, in dit geval VGA, heeft veel tijd gekost. Het leuke hieraan is dat ik echt het idee heb gekregen een expert te zijn geworden op het gebied van VGA Via een online community (http://www.jiscmail.ac.uk/depthmap) heb ik met verschillende onderzoekers meegedacht over problemen waar ze tegenaan lopen, en vaak ook een nuttige bijdrage kunnen leveren. Het feit dat je als onderzoeker erg snel een expert wordt op het betreffende onderzoeksgebied heb ik erg positief ervaren. Na dit onderzoek heb ik het idee een zinnige bijdrage te kunnen leveren aan het onderzoeksgebied van wayfinding.

Bijlagen

1. Wayfinding Performance data