Indoor Signposting and Wayfinding through an Adaptation of the Dutch Cyclist Junction Network System

Antigoni Makri *, Edward Verbree **

* MSc Geomatics, Faculty of Architecture and the Built Environment, Delft University of Technology, The Netherlands - A.Makri@student.tudelft.nl

** GIS Technology, Faculty of Architecture and the Built Environment, OTB Research Institute for the Built Environment, Delft University of Technology, The Netherlands - E.Verbree@tudelft.nl

Abstract. Finding's ones way in complex indoor settings can be a quite stressful and time-consuming task, especially for users unfamiliar with the environment. There have been developed several different approaches to provide wayfinding assistance in order to guide a person from a starting point to a destination but none of them has emerged to be efficient enough in order to act as a uniform solution. Moreover, referencing to landmarks is not widely employed by wayfinding assistance systems despite the fact that landmark-based navigation is the most natural way for people to navigate through unfamiliar environments. In this paper, a new wayfinding method for indoor environments is proposed, which makes use of the landmark concept. The method to achieve it is by translating the main principles of an already existing outdoor wayfinding system which applies successfully for the case of cyclists in The Netherlands. The first step is to define the locations, i.e. decision points, where wayfinding assistance is needed in indoor settings and secondly, to supply them with a special type of landmark which will be in the form of signpost, which provides all the necessary information. A graph based representation of the indoor setting is generated in order to extract the decision points and create the network of all possible routes in the environment.

Keywords. Indoor wayfinding, landmark, signpost, decision point, node network, route graph, Constrained Delaunay Triangulation

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1. Introduction

In recent years, navigation has become a very active research area with a wide range of application fields. One of the main constituents of navigation is wayfinding. Wayfinding refers to the requirement to know where to go and how to get there and forms the goal-directed and planning part of navigation (Montello & Sas 2006). Successful wayfinding requires that people are firstly capable of orienting themselves in space, namely to know where they are and in which direction they are facing. Then, planning a route and following the planned route while maintaining a real-time understanding and heading is necessary.

Wayfinding in indoor environments has emerged to be a significant field of interest as people spend most of their times indoors. Therefore, indoor spaces should be effectively navigable and people need to know how to find their way from their current location to their destination, which is not always an easy task. Wayfinding requires solving problems involving explicit decision-making, such as selecting routes to follow, orienting towards non-perceptible landmarks and scheduling trips (Montello & Sas 2006). Moreover, the sense of orientation in indoor spaces is affected by several parameters. Firstly, indoor space is characterized by the existence of the third dimension which is expressed though the different floor levels (Brunner-Friedrich & Radoczky 2006). Vertical movement can have a serious impact on the wayfinding performance. Finally, indoor environments are composed of fragmented areas, with a limited field of view and change of direction is imposed more often than outdoors.

Consequently, people encounter significant difficulties in the pursuit of their destination target when they are navigating in unfamiliar indoor environments. Especially in semi-public buildings, such as airports and train stations, hospitals, offices or university buildings, individuals often fail to find their way immediately or under time pressure without external information and would, therefore, benefit from a well-established system offering wayfinding assistance (Millonig & Schechtner 2007). Therefore, they depend on wayfinding directions, either providing by other people or given by maps or other wayfinding services. People use landmarks when they give route directions to anchor actions in space or to provide confirmation that the right track is still being followed (Michon & Denis 2001). However, while it is commonly accepted that directions provided by people are based on using landmarks as references, especially at decision points, the directions given by wayfinding services are generated based on the geometry of the space.

In the past decades, empirical research has established the importance of landmarks in our understanding of and communication about space (Lynch 1960, Michon & Denis 2001, Raubal & Winter 2002, Snowdon & Kray 2009). By using landmarks the wayfinding task can be significantly simplified (May et.al., 2003). The outcome of spatial-cognition studies reveal the importance of salient objects for orientation and navigation. Wayfinding process based on landmarks relies on the presence of landmarks at each point along a route where wayfinders might need assistance.

Thus, the aim of this work is to propose a wayfinding system for indoor environments in order to direct people to a pre-determined destination by following a set of special landmarks of the type of signposts, defined as landmark-signs, containing all the necessary information to guide the wayfinder in the space. Signposts can play a special role when they are used as landmarks. They have the potential of serving as distinctive, recognizable and salient landmarks while at the same time they can provide additional information (Fontaine & Denis 1999, Millonig & Schechtner 2007). This approach will be based on an already existing and recognized outdoor wayfinding system which applies successfully for the case of providing directional instructions to cyclists. The term landmark in this research is used to indicate prominent physical objects that can be used in order to indicate people's location in complex buildings and guide them to their destination. The emphasis is not only to the visual attributes of objects but mainly to the relevance of the location of their presence as fundamental parameter for the provision of direction instructions to facilitate the wayfinding task. A geometrical model is proposed in order to calculate the decision points, which are the points along a route, where people need wayfinding assistance. The landmark-signs are proposed to be installed at the decision points in order to provide location and directional information. Consequently, the main concept of the system is that a network of nodes is created through which any possible route is mapped out. Pedestrians follow a sequence of graphical-given instructions delivered at key points along a set of routes in order to reach a destination.

2. Background Research

2.1 Human Wayfinding

Human wayfinding research investigates the processes that take place when people orient themselves and navigate through space (Raubal and Egenhofer 1998). McKnight, Dillon and Richardson (1993) summarized the three primary ways that people employ in order to find their way:

landmark-navigation, in which people select easily identifiable points of reference in the environment and use them as a base, route-navigation, in which they put the landmarks in a sequence creating navigation paths and they navigate in the space by learning routes between locations, and map-navigation in which people create a general frame of reference (mental/cognitive map) containing the spatial relationships between objects and use it to navigate. People's perception of the real world develops gradually through these three levels by recording information about the environment. Accordingly, for successful wayfinding information about the environment - what is in the environment and where it is - are required.

Weisman (1981) distinguished the four classes of environmental variables which influence the wayfinding process. These four categories are: a. visual access to familiar cues or landmarks; b. the degree of architectural differentiation between different parts of a building; c. use of signs or room numbers; and d. plan configuration. The influence of each one of the abovementioned variables as well as of combinations of them on people's wayfinding performance has been examined in several studies (Weisman 1981, O' Neill 1991, Montello and Sas 2006, Hölscher & Brösamle 2007). From these studies it is revealed that when visual access is restricted, orientation becomes difficult and wayfinding performance is decreased. On the other hand, wayfinding performance is increased with the presence of signage. When the floor plan complexity is increased, people's understanding of the spatial layout is decreased and consequently wayfinding performance.

According to the degree of familiarity with the building the wayfinding strategy of the people can be changed. According to Hölscher et al. (2006), inexperienced users rely mostly on a central point strategy by sticking as much as possible to a central part of the building even if it entails more detours (Hölscher et al. 2006). On the other hand users familiar with the environment use mainly the direction strategy or the floor strategy in order to find their way. The first one corresponds to choosing routes that head and lead directly at the horizontal position of the destination target irrespective of level-changes, while the second one focus on firstly finding the floor of the destination and later on the horizontal position (Hölscher & Brösamle 2007).

2.2 Wayfinding Approaches

People perform wayfinding tasks in unfamiliar environments relying on common-sense knowledge of the geographic space and their previous obtained experience. Wayfinding is a natural skill that people develop throughout their lives (Raubal and Egenhofer 1998). However, external information can simplify the wayfinding task. Therefore, several systems have been developed in order to provide wayfinding assistance. The most common way of navigating in indoor spaces is by using the information systems of the building comprising by maps and signs.

Maps are fundamental tools in the wayfinding process. Traditional paper map is the oldest mean of supporting wayfinding. Nowadays, digital maps and route descriptions on a smartphone are becoming more and more popular with the wide-spreading of smartphones and Google Maps applications as well as GPS maps. Various presentation formats of spatial information have been developed, such as verbal navigational instructions, static and interactive maps, 3D visualizations and animations. However, this approach of supporting wayfinding is not very popular in indoor environments and creates difficulties and disorientation to the users. Additionally, digital maps in mobile devices can act as a wayfinding support tool only for users familiar with technological advancements who possess a wireless mobile device. These systems are not helpful for inexperienced users.

Signage is the most commonly employed physical means of enhancing wayfinding efficiency in indoor environments. Most building complexes posses wayfinding systems in the form of building and room names, directional signs or other graphical elements. Several studies (O' Neill 1991, Hölscher & Brösamle 2007) indicated the positive relationship between signage and wayfinding performance. However, it is also possible signs to create disorientation. People may have problems to understand the signs in case they are not clear or they have too much information or even confusion is generated when there are too many signs (Montello & Sas 2006). Difficulties with understanding and following the signs can be attributed to the fact that there is no common reference regarding the language and nomenclature used in the signs or the locations of providing assistance.

2.3 Landmarks

Presson and Montello defined landmarks as features that are relatively well-known and which define the location of other points. According to this definition anything that sticks out from the background can serve as a landmark (Presson and Montello 1988). Landmarks are stationary, distinct, and salient objects or places, which serve as cues for structuring and building a mental representation of the surrounding area (Millonig and Schechtner 2007).

Communication about an environment is facilitated by using landmark references. Landmark-based navigation is particularly important when people navigate through unfamiliar environments. Landmarks support clarity of a specific route. Route directions enriched with landmark references lead to less wayfinding errors. Therefore, incorporating landmarks along a route is a crucial task of navigation systems in order to provide more efficient and reliable guidance.

Most approaches to include landmarks in wayfinding instructions focus either on landmark identification (Nothegger, Winter and Raubal 2004, Elias 2003) by specifying the area in which landmarks has to be sought and then identifying the features that act as outliers in the area, or on the integration of landmarks into the generated instructions (Klippel, Richter and Hansen 2005, Caduff and Timpf 2005). However, today's navigation systems still give guiding assistance in terms of metric distances, based on the current position and the underlying digital map. The failure of incorporating landmarks in commercial applications can be attributed to the costs associated with the acquisition of the required data and the highly skewed distribution of landmark candidates in available spatial data (Richter 2013).

2.4 Route Directions in Wayfinding

Route directions are a primary means to guide someone in finding one's way. It can also refer to instructions on how to follow a route providing the actions to be carried out in order to reach the destination (Richter & Klippel 2005, Richter, Tomko & Winter 2008). To successfully navigate, wayfinders need to know which directions to turn to at the crucial spots along their way where they have to make a decision on how to move further, namely the decision points (Richter, Tomko & Winter 2008). A variety of details can be given when providing directions for wayfinding, such as landmarks, cardinal directions, street names, distances and turn descriptions (Hund & Padgitt 2010). In human route directions we almost never find numerical references to distances or turning angles, instead people use landmarks to anchor actions in space or to provide confirmation that the right track is still being followed (Michon and Denis 2001, Richter 2013).

The processing and representation of angular (direction) information is essential for wayfinding and route planning. Directional relations are used in several respects in route directions: they state the location of entities encountered along the route (like landmarks) with respect to the wayfinder or other entities; they announce a change of heading at decision points, i.e. represent turning actions; and they may relate these actions to an entity's location to better anchor them in space. In general, it can be stated that wayfinding can be characterized as following a route segment up to a decision point, making a directional choice, following the next route segment up to the next decision point, making a directional choice, and so on (Klippel et al. 2004).

3. The Proposed Wayfinding Approach

3.1 The Original 'Junction Network System'

The 'Junction Network System' (or originally 'knooppuntensysteem') is a special approach of providing direction instructions that help cyclists plan and follow a route. The system is widely used in the Netherlands and Belgium in order to enhance wayfinding for cyclists. This system is an innovative signposted network based on numbered junctions as it is illustrated in *Figure 1*. The main concept of the system is that users rely on a network of nodes, which is created by exploring the locations where the cycling paths intersect and placing a signpost containing a unique number and directional information to the next-encountered nodes/intersections. The number in the sign gives to the junction a unique identity and cyclists become aware of their relative location in the space. Additionally, by remembering a sequence of numbers a user-specified route is determined. The most important principle of the system is that assistance is provided to the users where they actually need to take a decision on how to go on. The signage system that dominated is a green sign with the node numbers in a white circle (*Figure 2*), which has emerged to be a special type of landmark along the cycling paths as it is easily identified by cyclists.

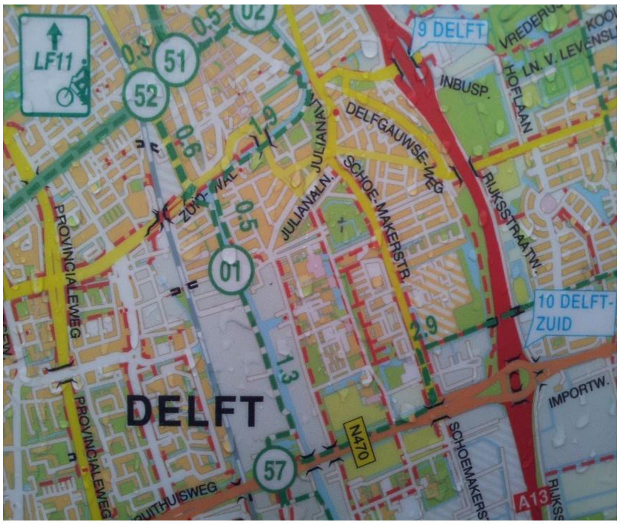

Figure 1. Numbered nodes to indicate a route

Figure 2. Signage system of Junction Network System

3.2 The 'Junction Network System for Indoor Settings' - Conceptual Model

The proposed system, 'Junction Network System for Indoor Settings', is registered as a first attempt of translating and applying the main principles of the original 'Junction Network System' in indoor space, having as a target group pedestrians of all age groups, with no physical impairment that prefer to be independent from a mobile navigation system. The whole concept and main principles of the proposed system derive from a direct mapping of the main principles of the Junction Network System to the case of indoor wayfinding. In terms of wayfinding communication, the system should be able to respond to three major questions: what information should be presented, where will the information be provided, and in what form.

More specifically, the proposed approach is based on the creation of a network of locations, equipped with a special type of signpost, the landmark-sign, containing a unique number for every location and directional information of the other numbered locations in the vicinity of it. In that way any possible route in an indoor setting is mapped out. The proposed landmark-signs will be placed in a prominent spot at these locations in order to be easily distinguished by people. Floor mounted signs will be used. One of the advantages of this choice is that they attract people's caution as they are visible from a distance. Moreover, there are no important limitations regarding their size, they do not interfere in the configuration of space and do not intervene in people's movement.

One of the main building blocks of the proposed system is the physical presence of the landmark-signs throughout the entire space. Landmark-signs, as depicted in *Figure 3*, signal the occurrence of the decision points, which are the crucial points where people need assistance in order to proceed further (junctions of the original system). Moreover, the location and directional information are revealed through the landmark-signs. By supplying every landmark-sign with a unique number the closest destination spaces to this sign are automatically registered to it. So, when the wayfinder is located at number 5 he can infer his relative location in the building. Additionally, directional assistance is provided by the signs that contain directional arrows indicating the closest numbered decision points or the arrival at a destination space in all possible directions of moving. The destination spaces are also marked with a unique number. The numbering of destination spaces starts after the numbering of the decision points. The location of the signs makes easier the conceptualization of turning instructions, enhancing the understanding of direction instructions.

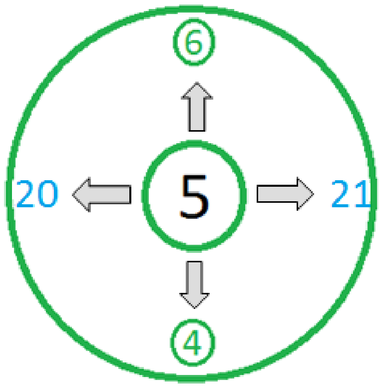

Figure 3: Landmark-sign

The connections between the landmark-signs and the destinations attached to each one of them create the whole network of nodes which provides all possible combinations of routes between starting points and destinations. This is the second important constituent of the system. The basic representation underlying the system is a sequence of decision points with their accompanying actions. Guidance is given by referring to numbers of signs and anchoring actions to them. The network of nodes has a twofold role: firstly, it acts as a routing system that enhances the successfully reach of destination while secondly, it plays the role of a referencing system which provides location information to the users.

There are several aspects that can make the system a special approach and a useful tool for users in the wayfinding task. Firstly, it is based on an already existing and recognized system meaning that people can easily get used to it. It is applied successfully not only for cyclists but also for hiking and boat guidance purposes. The fact that it is successfully applied in different navigation modes makes it a promising solution for indoor wayfinding problem. Secondly, it provides an indication of the relative position of the user in the environment. It acts not only as a wayfinding/routing system but also as a referencing system. Thirdly, it is based on a physical object that acts as a unique identifier and plays several roles. This unique identifier is the landmark-sign, which expresses the critical points where people need to choose direction of moving and provides location and directional information. Finally, it is a solution that with minor modifications can be applied to different building cases.

3.3 Indoor Space Modelling

The proposed system aims at providing assistance for the simplest case of wayfinding, which is finding the way to a room when navigating in public buildings. This is though one of the most commonly repeated human activities. Therefore, the navigable space that is of our interest for the purposes of this research are the connecting spaces (connectors) between other entities which act as destinations and for which people are usually in search, e.g. rooms. People are using the corridors as the backbone of the building in order to reach their destinations. They correspond to main orientation of the building and they are the first parts of the building to be experienced. Consequently, for indoor space the areas that apply to this concept are the main ring (backbone of a building) or well-structured paths where movement occurs in big open spaces and which can arise from the observation of people's flow. The determination of all the connectors of an indoor setting provides the circulation routes in the space. The points where two or more of these spaces intersect or where an intermission of the continuity of the boundary of the connector occurs are the decision points for indoor space. The intermissions/gaps indicate the presence of an opening, which gives the opportunity of changing direction.

A graph model, as the one in *Figure 4*, is going to be used to represent the structure of the indoor environment. An approximation of Medial Axis Transformation generated by using Constrained Delaunay Triangulation is applied in the connecting spaces in order to extract their middle line, which is a good approximation of depicting the human movement in these spaces (Mortari et al. 2014). The Medial Axis Transformation extracts the topological skeleton of the polygons used to represent the geometry of the spaces. Connecting space polygons are mapped to nodes and edges of a graph, which is able to provide all possible routes. The other building spaces that act for this approach as destination spaces are represented by their central point, which are also components of the graph, and they are connected to the skeletons of the connecting spaces at the closest decision points node through the transition spaces (doors). These connections are implemented in order to illustrate the adjacency and connectivity relations between all the different parts of the indoor environment. In that way a network of nodes and edges is created which represents all the possible routes that humans can employ in a certain environment. The idea of a route skeleton corresponds to the central-point wayfinding strategy that people usually employ in unfamiliar environments.

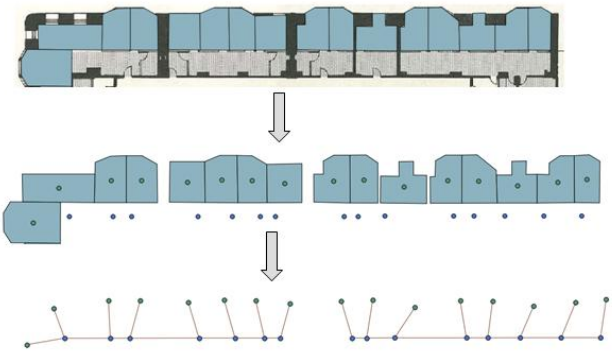

Figure 4. Graph Model of part of building

4. Implementation

GeoFort, which is an educational attraction in the field of cartography and navigation in The Netherlands, was selected as the most suitable place to implement and test the reliability of the system. The concepts of the proposed approach are illustrated using 2D floor plans of one of the buildings of the place (Figure 5).

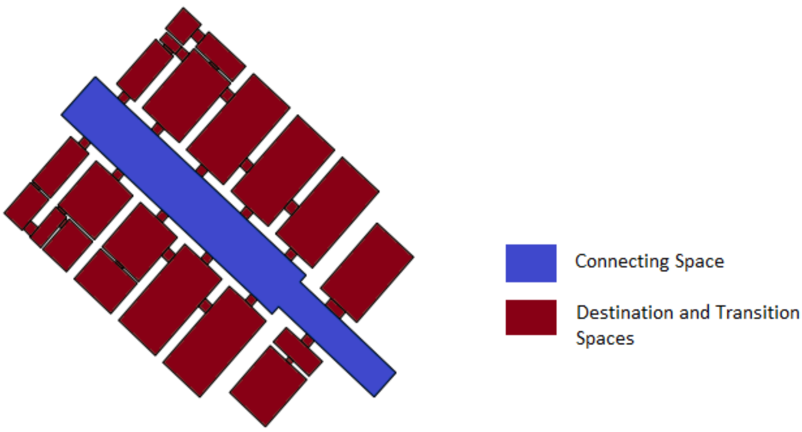

Figure 5. 2D floor plan of GeoFort building

The graph structure of the indoor environment is extracted in two levels. Firstly, in the more detailed level a Constrained Delaunay Triangulation is performed on the connecting spaces. This method subdivides the plane into a number of triangular-shaped non-overlapping facets, while it retains the boundary information. The space subdivision is shown in *Figure 6*. The main advantages of selecting this approach is the simplicity of the implementation and the precision in the resulting geometries. Constrained segments can be perceived as entities blocking the movement in the space, e.g. walls.

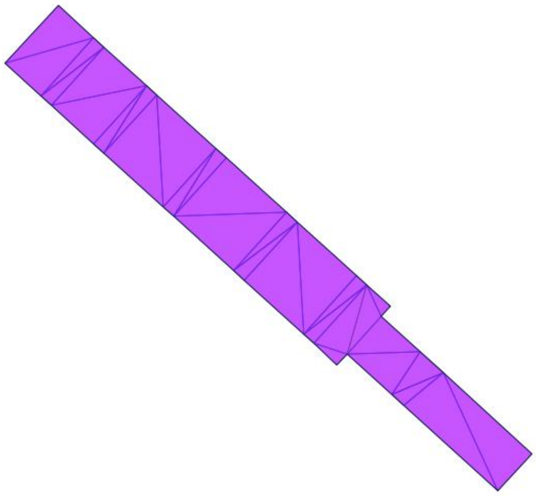

Figure 6. Constrained Delaunay Triangulation of connecting space

After applying the CDT two types of generated triangular facets can be distinguished: these that are built from edges that consist part of the user-specified constraints and others that are free of these constraints (*Figure 7*). The last type of triangles are adjacent to other generated triangles from all three sides. Thus, people standing at these sub-spaces are allowed to walk to three possible directions - there are no constraints to limit them to any direction. This type of generated sub-spaces corresponds in reality to areas that two or more navigable connecting spaces intersect. Consequently, in these sub-spaces decision points are located. By classifying the triangles the decision points are determined. The distinction between the two triangle types is performed based on their topological overlay relations with the originating polygon. Therefore, the topological spatial relations between the generated sub-spaces and the originating polygon are examined by using the Dimensionally Extended Nine-Intersections Model (DE-9IM) (Strobl 2008). If the result of the intersection of the boundaries of the two geometries is a point set then the triangle contains zero constrained edges.

Otherwise if it results in a line set the triangle has at least one constrained edge. In that way the triangles without constrained edges are selected.

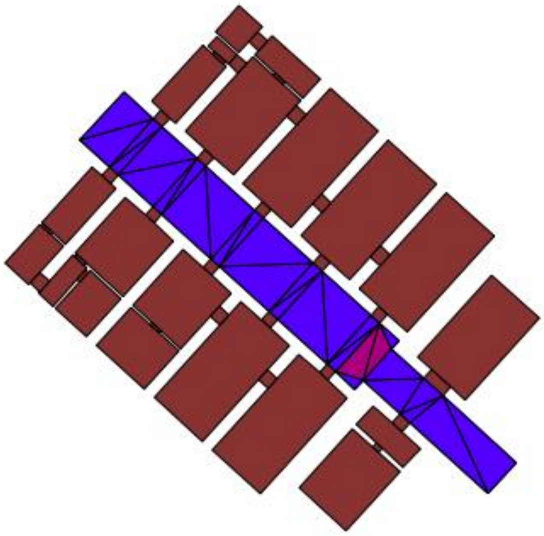

Figure 7. Triangles with (blue) and without (purple) constrained edges

However, the CDT takes into account the positions of the openings of the connector polygon. If both starting and ending points of a door are mapped, the generated output will entail a facet whose constrained edge is spanning over the whole length of the door frame. However, in reality this is not a real constraint. Therefore, the semantics of objects indicating openings should be considered in the process of discriminating between triangle types. Thus, a classification of the segments used as an input for the triangulation is performed and the set of triangles without constrained edges is extended by these triangular sub-spaces that are adjacent to transition spaces, i.e. openings (*Figure 8*). The arrival at a destination space can be signified through the landmark-signs located at these decision points.

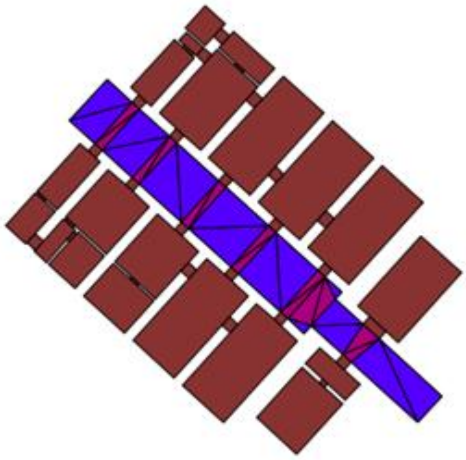

Figure 8. Final triangles with (blue) and without (purple) constrained edges

Finally, the centroids of all the triangles that contain zero constrained edges are calculated as they are the most representative points in order to act as decision points. However, in some cases some of them are very close to each other. The problems arising from this situation is that firstly, two or more signs can be installed very close to each other or even partially overlap depending on the sizes of the selected signs and secondly, this entails the risk of creating confusion or misinterpretation of the assistance. In order to deal with the redundancy, adjacent triangles are merged into one polygon and its central point represents the final decision point (*Figure 9*) by replacing the previous generated centroids.

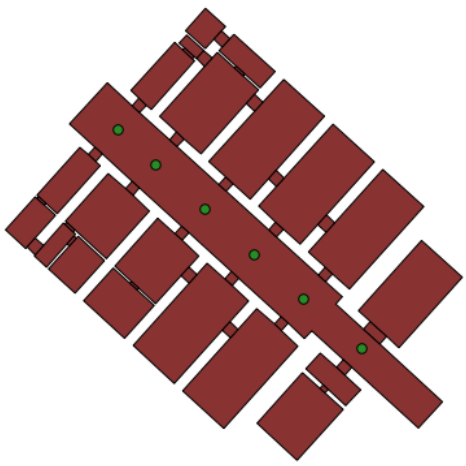

Figure 9. Decision Points

5. Next Steps

In order to finalize the graph representation of the connecting spaces, the middle points of the edges of triangles with at least one constrained edge are going to be calculated and all the nodes (decision points and middle points) are going to be linked based on their adjacency relationship. Finally, for the generation of a network of the entire building the central points of polygons representing destination spaces and transition spaces are going to be calculated and linked to the closest decision point node. In that way all the possible routes of the building are represented and distances between the nodes can be estimated as the graph reflects not only the topological relationships between spaces but also the geometry of the building.

The proposed approach is going to be verified by determining the decision points at the entire GeoFort area and installing the proposed landmark-signs. A human-based survey is going to be carried out. People will be asked to follow the numbered signs in order to reach various destinations and their movement is going to be observed in order to test the usability of the system. The time to reach the destination and the number of detours are the main measures to be estimated in order to infer about the reliability of the approach as an indoor wayfinding aid.

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