Indoor Space Subdivision for Indoor Navigation

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ABSTRACT

There are a number of great attempts to develop an indoor navigation that provide the most optimal path and guidance. Finding a way in large buildings can be a challenging task. In order to represent the real situation to a maximum extent, a representation of the whole room as one single indivisible object is not enough as such representation is very abstract and this could make the navigation difficult and may result into inefficient route planning. In order to provide a smooth navigation path, the presence of humans within the indoor environment and the natural movement of individuals should be taken into consideration. In this paper a two-step indoor space subdivision for indoor navigation is described. Firstly, the indoor space is subdivided into navigable and non-navigable areas considering human perceptions of the environment and human behaviour. Secondly, the navigable space is subdivided applying a constrained Delaunay triangulation. Finally, the guidelines for generation of the navigation network and verification of the proposed model are presented.

Categories and Subject Descriptors
H.1.m **[Models and Principles]**: Miscellaneous

General Terms
Design, Theory

Keywords
Indoor navigation, space subdivision, navigation network, navigation path.

1. INTRODUCTION
Wayfinding is the process of orientation and navigation in order to reach a specific distant destination from the origin especially in complex and spacious environments indoors or outdoors [10]. The process of wayfinding is a fundamental human activity and part of everyday life: it is about knowing where the person and desired location are and how to get there [20]. Many people have problems finding their way in public buildings such as airports, hospitals, offices or museums. Indoor environments are complicated by the existence of multiple floors, relatively smaller spaces. Furniture, columns, podiums and other features might act as obstacles within indoor environment thus they need to be considered while orienting and navigating. Moreover, people have an option to move freely within rooms and corridors in contrast to road network defined by strict regulations [14]. The increase of indoor activities and complexity of indoor spaces demand context aware indoor navigation systems in order to determine the most optimal path from one location to another [1], [2], and [22]. People's behaviour depends among others on the spatial arrangement of the environment (spatial relationships between objects including proximity, separation, order and enclosure), thus human navigation systems require storing and retrieving different types of information for localization, path planning and guidance purposes [18]. As a result, the outcome of an indoor navigation system strongly depends on the building models. The dimensions of indoor environment are human-scaled, therefore indoor spaces require greater accuracy with higher level of details in order to deliver reasonable indoor localization and appropriate navigation services [11].

However, the majority of indoor navigation models lack details and can only provide coarse routes, without considering complex indoor structures. In most of the navigation systems, rooms are modelled as single indivisible elements and a detailed partitioning of a room into functional areas (waiting area, smoking area, check-in counters, coffee corner, etc.) is not implemented. In order to represent the real situation to maximum extent, a representation of the whole room as one single indivisible unit is not enough. Such representation is very abstract, could make the navigation difficult and may result into an inefficient route planning. The determination of separate functional areas within the rooms is especially important for the buildings that do not have a regular shape, contain large open spaces such as railway stations, airports or museums and are usually crowded with people who are unfamiliar with the environment. People gather around certain objects in space and so obstruct areas for walking. Therefore a semantic determination of particular spaces within a room or a hall would allow 1) more accurate localization within indoor space, 2) navigation of individuals to these separate areas and 3) would provide users with more precise guidelines.

Thus this paper explores how the elements of indoor environment can be identified and conceptualised for way finding purposes. The aim of the work is to subdivide space into navigable and non-navigable indoor subspaces and provide a more accurate navigation path. We present a conceptual model for automatic determination of functional areas within the indoor space by adopting principles of human behaviour and human perception of the environment as well a space subdivision for the generation of navigation network. In this study, abstract borders of spatial elements are of importance and the term functional area (sub-space) defines space where certain set of activities takes place. The functional area of a certain spatial element is described as an area around the object at a certain distance where people are served by this spatial element or are waiting for services provided

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by this spatial unit. An example is people are queueing at an airline information desk in airport. These people are waiting to be served by the information desk and the area occupied by the queue of people can be considered as the functional area of the airline information desk. As a result, this functional area (sub-space) becomes non-navigable for other individuals and should be identified and considered while deriving navigation path. Therefore a space decomposition into separate functional areas would enable more accurate localization and generation of more accurate navigation path while bypassing areas occupied by other individuals.

2. BACKGROUND

2.1 Spatial Models for Indoor Navigation

The successful accomplishment of a navigation task involves: indoor localization of the start and destination points, route computation and guidance of the user [21]. Different digital models of buildings – geometric, semantic, topological or combination of them, can be used to support the indoor navigation. In geometric spatial models, space is considered as discrete or continuous. Semantic models reflect indoor environments using human-readable descriptions and topological-based structures illustrate connectivity and adjacency between spatial units [1], [3]. Semantic and topological models are commonly used to develop network based abstractions of the environment, where nodes roughly correspond to specific places and edges represent their spatial relations [12], [24].

An abstraction method presented by [2] supports different context of indoor environment. [2] propose a framework for semantic space subdivision, which allows the integration of conceptually separated indoor space models within a multi-layered representation. These layers represent separate decompositions of indoor space according to different criteria: topography, sensor coverage area, which is independent from building structure (for example, Wi-Fi signal, RFID tag system) or thematic criteria (accessibility, security zones, evacuation area). Using Dual graph these layers are linked and the spatial analysis for different navigation cases can be performed.

[27] follow ontology- and topology-based approach to identify spaces appropriate for human navigation, yet considering visibility regions and space syntax.

[12] presents a hierarchical graph structure. Different levels of abstraction are introduced meaning that a floor of the building might be represented as a graph at a certain level and at the same time this floor graph is just a node in a graph of a higher level – the whole building. The cell decomposition is performed depending on several criteria: size and concavity of a room and according to basic functional properties.

[5] develops navigation network which provides user adaptive and optimal length paths. The defined graph contains semantic information such as room labels or door accessibility constraints. Additionally, some separate areas within the room are represented as nodes and integrated into navigation network. The developed graph allows implementing hierarchical structure of the environment.

2.2 Human Navigation Behaviour

There is a strong relationship between the configuration of a space and the pattern of human movements in buildings and urban areas. Since people do not perceive the environment in absolute values; instead of exact calculations people apply qualitative method of spatial reasoning – recognition of landmarks [13], [19]. Therefore location descriptions can help individuals to locate themselves and can confirm that they are still on a right way. Additionally, these location descriptions can be used to enrich route directions as they are easier to understand compared to directions based only on geometry [16], [19]. For example, instead of saying *"turn right after 50 m"*, the directions could be formulated as *"turn right after the cathedral"*. Additionally, natural movement theory implies that people movements in space is mainly governed by spatial configuration. According to [8] people move along line of sight. [4] in his research proposes that people perceive the environment directly and uses *affordances* within it to guide themselves. Walkable surface provides *affordance* for further walkable surface. Or in other words, people move in a direction where further movement will be possible. [17] observed that people continue following the same direction if there are no significant changes in the environment. The route decisions are influenced by the available view of the environment: when a new view allows seeing more open space or more activity, people change their direction of movement. Furthermore, the presence of other people in the same space influences movement of individuals [6], [7]. A pedestrian normally feels increasingly uncomfortable the closer he/she gets to a strange person who may react in an aggressive way. This results in *repulsive* effects of other pedestrians. A pedestrian also keeps a certain distance from borders of buildings, walls, streets or other obstacles as the feeling of comfort decreases the closer to a border individual walks.

3. CONCEPTUAL FRAMEWORK

Typically, the arrangement of indoor environment differs with respect to the type of the building (airport, university, museum, station, exhibition pavilion, etc.) and the number of people entering the building. However, all indoor elements have common attributes regardless of their direct functions. For instance, a spatial element can be found attractive or not, moreover it might be highly important or not important at all for people inside the building. For this reason, properties that spatial elements have in common are selected as criteria for the indoor space subdivision. Concepts of this framework are illustrated using 2D ground floor plan of Rotterdam Central station, the Netherlands (see Figure 1).

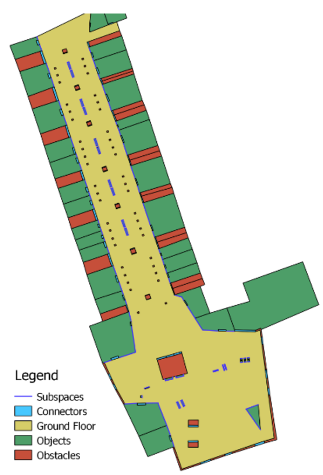


Figure 1. 2D floor plan of Rotterdam Central station.

The framework for determination of subspaces is based on characteristics of spatial elements and external factors. It should be noted that the smallest identifiable spatial element differs with respect to the use case and should be selected by a system designer with respect to specific user requirements. In addition, the functional areas of spatial elements have to be calculated in accordance with the total number of pedestrians inside the building. Therefore values of measured spatial element characteristics and external factors vary according to use case.

3.1 Criteria for Subdivision

We identify the following criteria that have impact on the subdivision of indoor spaces:

Attractiveness of spatial element (C1) is an important parameter that influences a people distribution within an indoor space. Research findings have shown that people are inclined to stay at places that offer an cosy structure or act as an attractive landmark [7], [20]. Shop windows or artworks in galleries are found to be attractive while workplaces or printing corners are not that attractive. Attractiveness of the object is coded with three values [1;2;3], where 1 indicates non-attractive elements (low attractiveness), 2 – object is attractive and 3 indicates highly attractive elements, i.e. an environment that have an inviting structure. However, attractiveness of an object depends on occurring events and other factors, thus it changes over time. For instance, shops, cafeterias or restaurants are usually closed at night so people are not going to stay at these places. Moreover, during lunch or dinner time the number of customers of restaurants and cafeterias increases and in this way the functional area of the restaurants and cafeterias might expand.

Necessity of spatial element (C2) is another important parameter to determine functional areas in indoor space. Necessity defines how essential is an object. The necessity describes if it is necessary to have this object in this specific environment, if it is an important feature of the environment. For instance, information desks are an essential part of train stations while shops and cafeterias are not that important and are not required to be in train stations. In this conceptual model importance of the object is coded with two values [0; 1], where 0 specifies objects that are unnecessary and 1 indicates necessary objects in the specific environment. Necessity of an object changes over time, as well. For instance, information screens in stations become more important during peak hours, therefore necessity values have to be adjusted with respect to some occurring events.

Object's closeness to central point of the environment (C3) also influences the people distribution within an indoor space. People incline to gather in central or near central locations in space [8], [17]. Exhibits in a museum that are located further away from entrances or are not clearly visible (e.g. they are placed in niches) attract less people. Furthermore, restaurants, cafeterias or shops in airports which are far away from gates attract fewer customers. People try to minimise physical efforts while navigating and pause at spots from where the least efforts are required to continue their trip [9]. Thus if an object is positioned far from central point of indoor environment it is populated by a lower number of people. Object's closeness is coded in the range of [0 – 1], where 0 corresponds to further away located objects and 1 describes objects that are located close to the central spots in space. Closeness of objects to central locations of the indoor environment is determined applying network analysis method. Closeness of object is determined as an inverse of cumulative distance required to reach from the object to all other locations along the shortest paths.

$$Closenesss^{r}\ [i] = \frac{1}{\sum_{j \in G-\{i\}, d[i,j] \leq r} (\mathrm{d[i,j]})}$$

Limited capacity (C4) is an optional parameter which describes if a spatial element has a limited number of seats or does not have sets at all. A part of the spatial elements can contain a limited number of people. For instance, a work station for a single employee is typically not occupied by other people. Additionally, the benches in waiting halls of airports also can be seated by a limited number of people. Limited capacity is coded using Boolean expression (*yes* or *no*) which indicates if object has limited capacity or does not have.

Transition zone (Dtrans) is another optional parameter, which is applicable to a spatial element or not applicable at all. A part of the spatial element provides their functions in distance. For example, in order to see a painting or an information screen, people stand at a certain distance from these objects. In this study, the area between such type of objects and people is called transition zone and is considered to be a part of object's functional area and should be avoidable during planning of the navigation path. The transition zone is coded using numeric values and depends on the size of the object and the available space in the indoor environment.

Private space (Dprivate) has an impact on the size of the functional area of an object. [6], [7], indicate that the territorial effect plays an essential role while navigating inside buildings. Individuals feel uncomfortable when their private sphere is entered by a stranger as well the stranger avoids entering somebody's private sphere for the same reason. As a result, in this study personal spaces are considered to be non-navigable. The perception of personal space differs with respect to the type of a building and amount of space available in rooms. For instance, in offices co-workers keep smaller distances while passing their working colleagues. In contract, in railway stations, which are usually filled with people, distances between people waiting in a queue next to the information desk are smaller compared to the formal office environment. Distances between people can be interpreted as a buffer that determines safety. Private space is codied using numerical values.

3.2 Determination of Functional Areas

3.2.1 Determining size of sub-spaces

The proposed conceptual framework for indoor space subdivision points out three different computational methods for determination of special areas. The determined subspaces become non-navigable except in cases they are starting or target position of the user of navigation system.

1. In case no optional parameters are applicable to the special unit, the width (D) of functional area of object is determined by the weighted human body projection on a horizontal plane (AW) and the private space (Dprivate):

   $$D = AW + Dprivate$$

   The projection (A) determines the average space required for a single individual to avoid disturbance of others in a certain indoor environment. In this study, the required diameter of space for individuals, i.e.0,6m, is adopted considering the observations of [15].The weight (W) indicates the sum of several criteria values: *attractiveness (C1)*, *necessity (C2)* and *closeness to central objects (C3)*, which are adjusted taking into consideration occurring events in the environment (*T* – time impact):

   $$W = C1 * T + C2 * T + C3$$

Figure 2 and Figure 3 depicts functional areas of shop and ticket machine during peak and off-peak hours. Ticket machines are considered to be attractive and essential objects for the visitors of train stations. Additionally, during peak hour, *attractiveness* and *necessity* of ticket machines increases as the total number of people in the station increases. In contracts, *attractiveness* and *necessity* of shop decreases. *Private space* is illustrated in a different colour and acts as a buffer which determines safety. Typically people keep this distance to bypass other individuals.

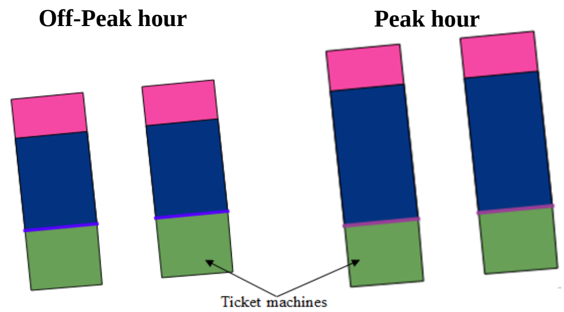


Figure 2. Functional areas (blue and pink) of ticket machines (green) during off-peak (2 meters) and peak (3 meters) hours. Pink colour represents areas determined by the private space criterion.

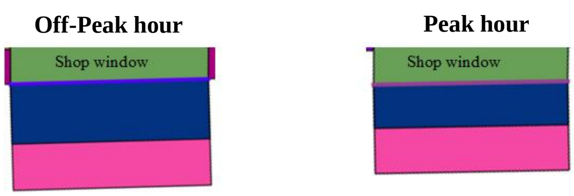


Figure 3. Functional area (blue and pink) of a shop (green) during off-peak (2 meters) and peak (1,5 meters) hours. Pink colour represents areas determined by the private space criterion.

2. In case the *Transition zone (Dtrans)* parameter is applicable to a spatial unit, the functional area of the object is calculated by adding transition distance to weighted human body projection on a horizontal plane and private space. Figure 4 illustrates the functional area of an information screen, which has a transition area.

$$D = Dtrans + AW + Dprivate$$

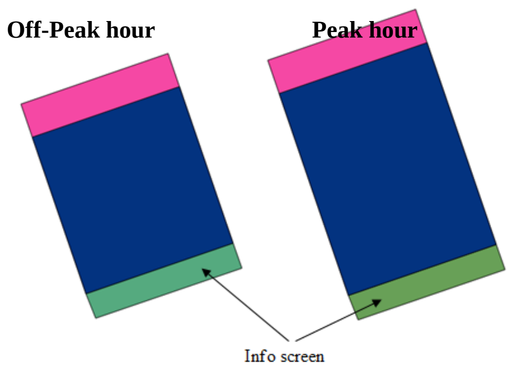


Figure 4. Functional areas (blue and pink) of an information screen (green) during off-peak (5 meters) and peak (6,5 meters) hours. Pink colour alone represents areas determined by the private space criterion.

3. In case the optional parameter *Limited capacity* is applicable to a spatial unit, the functional area is calculated applying only private space concept. Spatial elements that have a limited number of seats cannot expand or shrink. For this reason the functional area of spatial elements with limited capacity is defined applying only one measure – private space. Figure 5 shows the functional area of a bench with a limited number of seats in the railway station.

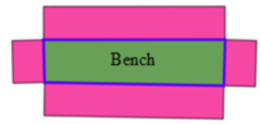


Figure 5. Functional area (pink) of a bench (green) in Rotterdam Central station (0,9 meter).

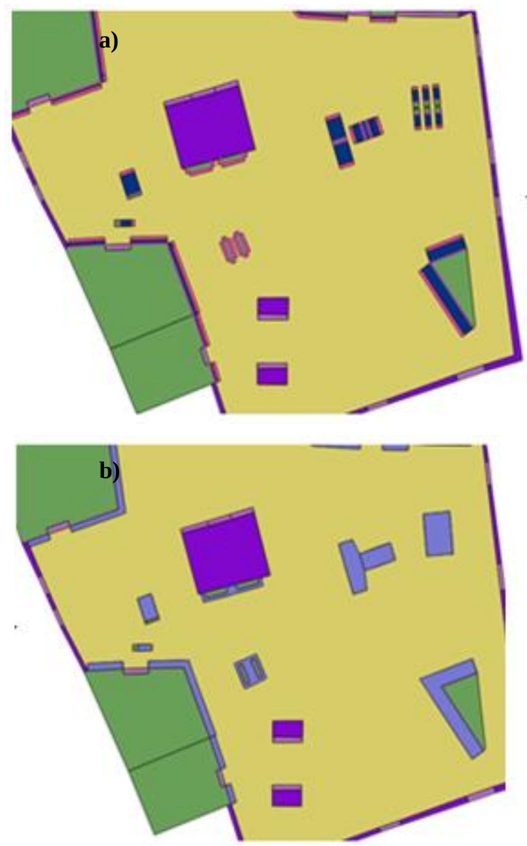


Figure 6. a) Computed fictional areas for Rotterdam central station. b) Overlaps between subspaces are eliminated and functional areas are aggregated.

3.2.2 Special cases

In case the estimated functional areas overlap, a set of rules is applied in order to remove the overlap and ensure a planar partition:

- If overlapping areas have the same semantics (name), they are united.
- In case the overlapping sub-spaces contain different semantics (names) and have different weight values, the priority is given to the object with larger weight and the

intersecting area is cut from the object with the lower weight.

- If the overlapping sub-spaces have different semantics (names) but the same values, the overlap is cut from the sub-spaces with the larger area.

Finally, determined sub-spaces that are away from each other at a distance smaller than 1 meter are aggregated so that narrow passages for navigation would not be generated (see Figure 6).

4. NAVIGATION MODEL

The navigable space is determined by subtracting aggregated functional areas (non-navigable areas) from the initial floor plan and the generated navigable space is further subdivided in order to derive navigation network. In this research, the Constrained Delaunay Triangulation is used for space subdivision as it is a fast and well-know method. The navigation network was constructed by calculating centroids of triangles and establishing links between centroids of neighbouring triangles. Central points of polygons representing connectors (such as doors) were calculated and linked to the centroids of the adjacent triangles (Figure 7). The central point of the area determined by the private space criterion was extracted so that people could be navigated to the border area and not to the centre of the functional area which can be occupied by people (Figure 8). Centroids of functional areas are linked to the closest node in the network and might have maximum one link ("dead-end nodes"). Nodes of functional areas have only one link so that they would be only start or end point in navigation path and would be avoided in other cases.

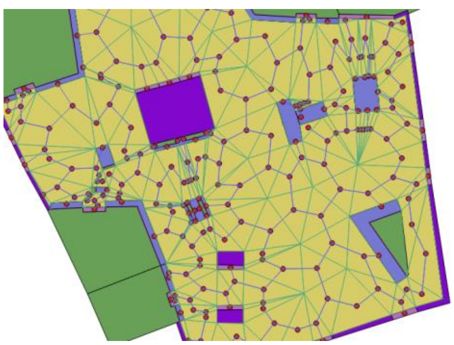


Figure 7. Navigation network.

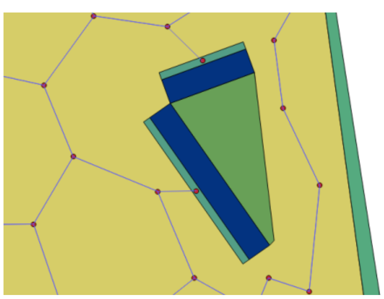
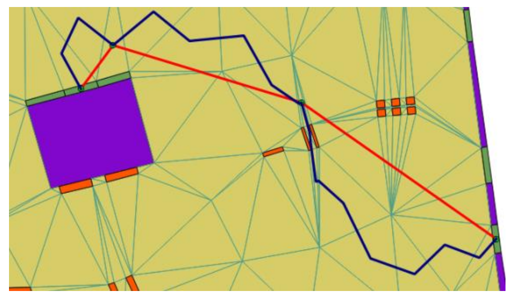


Figure 8. Representation of functional areas in navigation network.

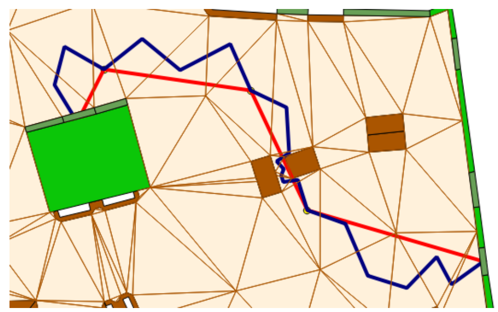
This network can be generated quickly on the fly considering the time of the day and the number of people available in the indoor environment. However the generated paths does not represent the actual human movement (Figure 9). Therefore, a simplification algorithm was implemented that generates straight segments. The path simplification algorithm is based on the following principle: if there is line of sight from node i in the navigation network to the node i+2, the node between them i+1 is removed. The same action is repeated until there is no line of sight between adjacent points in the path.

Three different navigation networks were built: a navigation network without an indication for functional areas, a navigation network with functional areas during off-peak hour and a navigation network with functional areas during peak hour in Rotterdam central station. Navigation paths from the same start point to the same target were generated using these navigation networks in order to compare the results. The generated paths show that the determination of functional areas provides more realistic routes as narrow passages between objects are avoided (Figure 9). Determination of functional areas and their indication in navigation network, additionally, use of path simplification algorithm provide more realistic abstraction of the environment and more accurate navigation path which adopts principles of human natural movement [9], [20].

a)



b)



c)

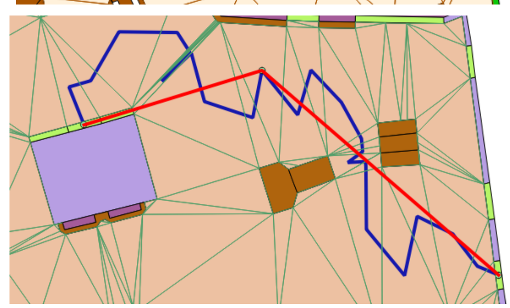


Figure 9. The initial (blue) and the simplified (red) paths in a navigation network a) without functional areas. b) with functional areas during off-peak hours and c) with functional areas during peak hours.

5. VALIDATION

The proposed conceptual framework was verified using 126 photographs taken during peak and off-peak hours at Rotterdam Central station. The images were processed using picture analysis software. The occupancy of objects and distances that people keep between each other and objects were determined (Figure 10). The performed image analysis confirmed that properties of indoor objects and territorial effect influence people distribution inside buildings. Image analysis showed that model based estimations to determine functional areas of objects during off-peak hour were supported. In addition, image analysis confirmed that private space property is an appropriate measure to delineate functional areas of objects with limited capacity.

Figure 10. Example of images and performed measurements.

This research has also showed that the criteria need further investigations. An attention has to be paid to the attractiveness and necessity values of an object over time. In some cases, the results of the model representing functional areas during peak hours were not supported by results of image analysis. For instance, functional areas of ticket machines are larger during off-peak hours and did not support calculations of functional area during peak hour as suggested by the proposed subdivision framework. The main argument for the larger distances during off-peak hours could be that during rush hours the majority of passengers are employees or students who use public transportation daily. They most probably possess travel cards or other means to pay for the services, and therefore avoid buying ticket at the station. Whereas occasional travellers, who tend to travel in off-peak hours, buy ticket using ticket machines. Generally this study has to be further extended with analysis of more factors: total number of visitors, habits of visitors of the environment, while assigning values to criteria.

6. CONCLUSIONS AND FUTURE WORK

In this paper a conceptual framework for determination of functional areas within indoor space based on human perception of indoor environment and human social behaviour was presented. The performed research confirms that *attractiveness*, *necessity*, possession of *transition zone*, possession of *limited capacity* of object, *object's closeness* to a central point of the environment and *private space* concept have effect on the formation of groups of people and people distribution within indoor environment. Therefore, these properties of spatial elements can be used as measures to determine functional areas within indoor space. The human body projection on a horizontal plane, weighted with the values of characteristics of spatial object, provides reliable results to determine abstract borders of functional areas within indoor space. Furthermore, it has been demonstrated that the determination of separate functional areas within indoor environments and the incorporation of separate functional areas in navigation networks as nodes can provide users with descriptive information of the location. Additionally, such fine granularity indoor space subdivision and its incorporation in the navigation model enables the navigation of users to separate functional areas and allows bypassing spaces that are occupied by other people. Moreover, the aggregation of areas that form narrow passages and use of developed path simplification algorithm enable generation of clear navigation path which adopts principles of human natural movement.

The proposed framework for determination of functional areas can provide quite accurate results, however the following aspects can be improved in the future. The ranges of criteria should be further investigated in order to derive better results. Different ranges should be set for criteria and tested in the same environment. An attention should be given to the improvement of closeness analysis. Currently, the closeness parameter is calculated using the central point in the network as a reference point. A closeness measurement to the main entrance or closeness to a specific room could be introduced in order to derive more reliable results, which are suitable for different cases. Furthermore, additional tests could be performed to examine the people distribution in certain areas during a longer period of time. Additionally, video records could be made to extract accurate people movement trajectories. Video coordinates could be converted to reference coordinate system and displayed together with the generated navigation paths for comparison. More experiments could be performed with different networks as well, e.g. visibility graph [25] or grid-based approaches [26].

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