Location Techniques for the Design of a Walking Aid Network for Visual Impaired Students

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Abstract: Universities may have students with visual impairments that require support and facilities in order to ensure for help them adequate educational experience. Fortunately, many universities have already adopted particular solutions for those students by providing supportive services and advanced technologies. However, other campuses are still left behind and, thus, special solutions are still to be implemented. This position paper represents a preliminary study in this direction for a case-study university campus in Oman. It attempts to employ the location optimization techniques to design a walking aid network with rest lounges for students who are blind or suffer from a visual impairment. The walking network will connect the several classrooms, the administrative offices and the service structures that these students frequently visit during their academic day. The walking network will be equipped by tactile tiles and has, thus, budget and execution time restriction for its implementation. For this purpose, our approach will consist in selecting a subset of the available routes to be used for the tactile tiles installation purpose and also in developing the project management technique that allows to complete the project in the minimum span time. Preliminary results on the implementation of such techniques in the Omani University campus will be discussed.

1 INTRODUCTION

Visually impaired students are persons who are categorized as seeing very low and those who have total absence of sight and need support to achieve their daily tasks. The causes of visual impairment differ from one case to another such as diseases damage after birth that causes blindness or vision impairment which cannot be cured by surgery or medication. This paper deals with the orientation and movement problem that the visually impaired people are daily facing. It discusses how network location techniques can help the visual impaireds and how walking aid systems and appropriate infrastructure can positively affect their life. Designing special tracks can help the visually impaired people through directing them from a point to another inside the University Campus. Moreover, this study is useful to the society; visual impairment people will not use any further resources to help them in their mobility and can, thus, practice their life and be productive as normal citizens.

The walking aid system is a path made from tactile paving surfaces, used by the visually impaired students to help them in conveying the information, and in moving around the university facilities. Nowadays, it is frequent to observe how several visually impaired university students suffer while moving around the universities' buildings. This happens in different campuses, and specially in those established in developing countries, such as Oman. This fact often causes embarrassment for this category of students who are forced to ask for help or to reduce their movement.

Moreover, these students face often dangerous situation as highlighted by Legood et al. (2020) who reviewed several papers and reported that "people with visual impairment are 1.7 times more likely to have a drop and 1.9 times more likely to have multiple falls in everyday living activities as compared against the normally sighted persons. Moreover, the chances of getting a hip fracture are between 1.3 times and 1.9

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times more prominent for those with visual impairment."

This work attempts to have a positive ethical impact, by contributing in making the environment of the university suitable for all types and varieties of students. We will take Sultan Qaboos University (Oman) as a case study. In its vast campus, the colleges, facilities, roads, offices and car parking areas are distributed far away from each other and consequently the visually impaired students are facing many difficulties to move around the campus because of the total absence of any walking aid system. Moreover, the streets/corridors of the university are generally not suitable for blind and visually impaired students who are forced to face dangerous situations while moving from one building to another or crossing the streets. The walking aid system will, thus, reduce the difficulty of movement of visually impaired students, reduce the risk they are daily facing and speed up their movement around the campus buildings. The network to be designed will also include a number of rest lounges to be selected among a set of potential locations for the exclusive use of these students when moving from one building to another or just to have some relaxing time.

The contributions of this paper consist in using facility location techniques in order to design an optimized path to allow visually impaired students to freely move at any time without relying on other's help or exposing themselves to danger. We will use for this purpose the p-center location technique in order to design and optimize the walking paths and optimally locate the rest lounges. We will also apply the critical path method to schedule the activities related to its implementation. Facility location techniques have been intensively used in a wide range of applications, such as waste management (Ghiani et al., 2012), freight transportation (Triki, 2016), railway hubs planning (Mokhtarzadeh et al., 2020) and groundwater management (Triki et al., 2020). We are confident that they can be a valid tool even in the context of this application.

This paper is structured as follows. Section 2 will be devoted to the literature review. Section 3 will give a detailed description of the optimization models and approaches used to solve the problem under exam. Finally, Section 4 will conclude the paper.

2 LITERATURE REVIEW

According to the World Health Organization, visual impaired people are defined as people who face a limitation in their actions and functions because of the visual system. Also, they have a low vision which makes them unable to perform their daily routines properly. The causes of visual impairment are identified to be total darkness, glaucoma, and age-related macular degeneration. The National Eye Institute added more details by specifying that such visual deficiencies usually cannot be treated even through the use of glasses, contact lenses, medication or surgery. There are three types of visual deficiency depending on the vision level: (i) low visual acuity, (ii) blind and (iii) visual impairment.

Tactile was invented in 1967 by Mr. Seiichi Miyake. Yamauchi and Yamauchi (2003) claimed that the Tactile Tiles (called also Tactile Ground Indicators) were installed for visually impaired people the first time in the Japanese city of Okayama in March 1967. Their use started to expand quickly in Japan specially after 1985 when the Japan National Railways adopted them for the design of the stations platforms. Furthermore, the Japan Road Association (1985) gave insights on the different types of tactile tiles that were manufactured and installed in Japan. This latter document represented a guideline on the installation principles of tactile tiles and shows also the errors and mistakes that are usually made during the implementation process. Besides the Japanese experience, there are several countries that pioneered the installation of tactile tiles, such as Korea, Australia and New Zealand (see: https://www.nzta.govt.nz/assets/resources/road-traffic-standards/docs/rts-14.pdf). Another country that defined rigid standards for the design and use of tactile paving is United Kingdom. Indeed, in 1998 the "Guidance on the use of Tactile Paving Surfaces" (DETR, 1998) was published having the aim of efficiently installing tactile surfaces to help visually impaired pedestrians in finding their way and in gaining important information which related to the environment, danger, and location directions. The guideline defines a blister paving designed to warn the visually impaired pedestrians and give them a set of important information. Tactile paving is divided into two categories depending on the nature of its use: (i) warning surface that include blister indicators for pedestrian crossing points, corduroy hazard warning surface, platform edge off-street warning surface and on-street platform warning surface (Figure 1) and (ii) amenity surfaces which include guidance path and information surfaces (Figure 2).

There are many other recent attempts to propose feasible solutions to guide visual impaired persons that make use of modern technologies. For example, Crandall et al. (2001) suggested the "Talking Signs" system that uses infrared transmitters in order to generate audible signage to label key environment features. The spoken messages transmitted on a beam of infrared light will be received by an ad-hoc device hold by the blind or visual impaired person. The authors have shown that this system greatly helps in gaining in safety, and independence.

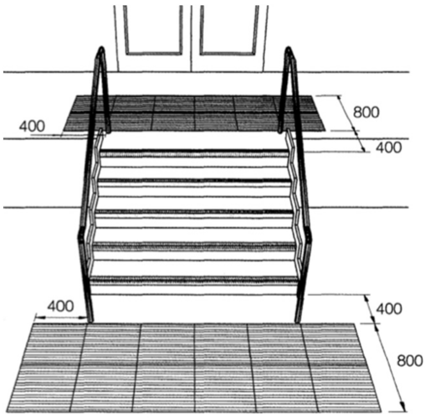

Figure 1: Example of corduroy hazard warning surface at the top and bottom of stairs (DETR, 1998).

Another example is related to the use of sensors embedded in a jacket that blind persons must wear in order to be guided accordingly (Sourab et al., 2015). Five sensors in total are installed with the aim of detecting potholes or stairs, obstacles near head, and barriers in front, right and left directions. Chai et al. (2020a) have reviewed 30 articles that have dealt with the identification of the recent studies on the smart technologies developed for supporting the visually impaired for their daily activities that involve both obstacle detection and ground plane hazards detection (see also Chai and Lau, 2020b).

Besides proposing the enabling technology for assisting visually impaired persons, there is nowadays a very intensive research work directed to the navigation aspect in order to help these pedestrians to plan their routes from an origin to a destination location (see for example Kammoun et al., 2010, Yusof et al., 2015 and the very recent review of Nawaz et al., 2020).

From the above literature analysis, it is clear that the research in this field has focused mainly on the pre-installation and post-installation aspects of the tactile tiles surfaces. To the best of our knowledge, no work has dealt with the phase in-between that consists in optimizing the design of the tactile tiles walking aid system and the underlying network in a big campus. Clearly, this problem arises when such a campus has not been designed since its construction to encompass tactile tiles and it will result, thus, extremely expensive to cover all the buildings at this stage. The focus is, thus, on identifying the building (classrooms, offices, departments, etc.) that visually impaired students frequently visit and connect them with an optimized path having tactile tiles and identifying suitable places for rest lounges.

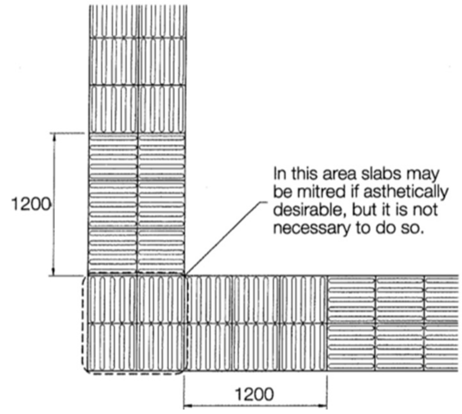

Figure 2: Example of layout of guidance path surface at a right angle turn (DETR, 1998).

3 NETWORK OPTIMIZATION APPROACH

According to Hoffman and Ralphs (2013) many practical optimization problems can be better modelled and analysed by means of the powerful tool of network optimization. This latter consists on a graph representation in which a set of nodes are connected with a set of links (that can be either directed arcs or simply undirected edges). Network optimization has been successfully used to solve several logistics problems such as designing highways, streets, integrated circuits and telecommunication networks (see Ahuja et al., 1993). In this study, we will make use of two specific network models, namely the p-center facility location and the critical path project scheduling models. Additional techniques, such as shortest route, may be needed at several stages of the design. The network to be designed is schematically represented in Figure 3, in which all the university buildings can be connected directly or through any of the rest lounges to be activated (among those potentially available).

Our general approach is based on the following steps:

- *Data Collection*: data are mainly collected through meeting visually impaired students in order to understand their needs and to identify the most important avenues they want the walking aid system should reach.

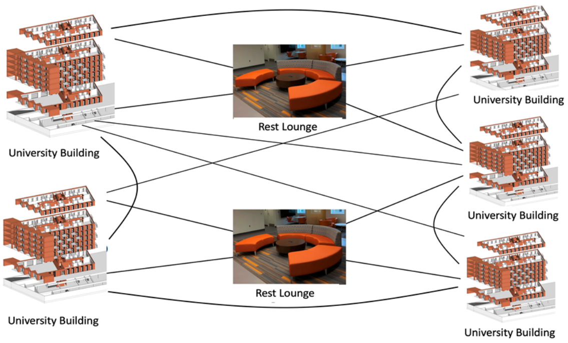

Figure 3: Network connecting the University buildings and the rest lounges through feasible links.

- *Network Analysis*: identify the main buildings inside the campus the visually impaired students frequently visit and try to meet their needs by considering them as nodes of our optimization network.
- *Network Algorithms*: make use of the facility location techniques in order to link all the network's nodes and to define, thus, the rest lounges locations and the walking aid system connecting all the buildings of interest at the minimum paving cost.
- *Project Management*: finally, the University administration needs to have insights on the time span required to complete implementing the walking aid network and the sequence of its execution. For this purpose, we will apply the critical path method to determine the project scheduling. The critical path method will allow to identify all the critical steps that will define the priorities among the activities and the duration of the project. The resulting outcome will be very helpful for the University managers to assess the best time to start executing the project and its implementation phases.

After executing the first step, the resulting outcome can be represented as shown in Figure 4, characterizing the University campus, with the main avenues frequently visited by the visually impaired students (identified in red color) to be considered as nodes of the network in the sequel. The resulting network is clearly a multi-graph since there exist several possible connections between many pairs of nodes. However, we represented for clarity the corresponding network (in Figure 5 in the Appendix) as a simplified graph showing only a subset of possible connections between nodes.

3.1 The p-center Location Model

The *p*-center model is applied to the decisions related to the location of service centers (typical examples are fire brigade stations and first aid centers) in the event that it is necessary to ensure equity of treatment to a set of nodes spread over a large area (the university campus in our case). The goal is to locate *p* logistic nodes (rest lounges here) in the area with the aim of minimizing the maximum transfer time between a node and the lounge closest to it.

The problem can be formally represented on an undirected bipartite graph G (V, N, E) in which V is the set where the lounges can be positioned, while E is the set of edges identify all possible links between the various nodes. Moreover, N indicates the set of the destination buildings that are of interest to the visually impaired students. Often, in these kind of applications, sets V and N can coincide which means that any destination building can be the location of a potential lounge node as well. However, in the sequel we will consider them different for the sake of generality and to allow flexibility in adding or removing any node to be (or not to be) considered as a possible lounge location. To each edge $(i,j) \in E$ is associated a cost d_{ij} representing the length of edge (i,j), i.e. the distance from node i to node j. In the particular case of a given building will be also selected as a lounge location, then the building-lounge distance will be equal to zero. The problem will consists in minimizing the maximum distance between any of the destination buildings and the closest lounge to it. In this way, we are minimizing the uncomfortableness of the visually impaired students to reach a lounge from any of the buildings of interest for them. The model's decision variables are as follows (see Daskin, 2013):

- x_{ij} $(\forall i \in V, \forall j \in N)$ is 1 if destination building j can be served by the lounge placed in node i. Otherwise $x_{ij} = 0$;
- y_i $(\forall i \in V)$ is 1 if a lounge is to be located at node i, and zero otherwise.

Thus, the lounge location problem formulated as a p-center model can be expressed mathematically as:

$$\text{Min } v \tag{1}$$

$$\text{S.t.} \sum_{i \in V} x_{ij} \geq 1 \qquad \forall j \in N \tag{2}$$

$$\sum_{i \in V} d_{ji} x_{ij} \leq v \qquad \forall j \in N \tag{3}$$

$$\sum_{i \in V} y_i \leq p \tag{4}$$

$$x_{ij} \leq y_i \qquad \forall i \in V, \forall j \in N \tag{5}$$

$$x_{ij} \in \{0,1\} \qquad \forall i \in V, \forall j \in N \tag{6}$$

$$y_i \qquad \forall i \in V \tag{7}$$

The objective function (1) minimizes the variables v which represents the maximum distance between any destination building and its assigned lounge. Such unrestricted variable v is defined through constraints (3) as the highest distance of any building-lounge assignment. Constraints (2) ensure that every destination building is assigned to at least one lounge. Constraint (4) will limit the number of lounges to be opened to an upper bound value p. Such parameter p is defined by the decision maker (the University in this case). Set of Constraints (5) will ensure that no destination building j will be assigned to any node i if no lounge will be activated in that node. Finally, Constraints (6) and (7) define the binary nature of the decision variables.

The defined model (1)—(7) results to be a mixed integer linear optimization program whose size increases with size of the underlying graph. The complexity of such the model depends to a big extend on the value of the parameter p, as will be discussed in the next subsection.

3.2 Solution Approaches for the p-center Model

The specific case of 1-center location problem (i.e. in which one single lounge must be located in the network) the problem can be easily and efficiently solved through the well-known algorithm of Hakimi (Hakimi et al., 1978). However, for the general case of $p \geq 2$, the p-center model is known to be an NP-hard problem (Ghiani et al., 2013). Therefore, the solution of moderate sized instances can be performed by solving the p-center optimization model (1)—(7) by using exact solution methods such as those implemented within the general purpose commercial solvers Cplex, Gorubi or Lingo. Alternatively, specialized exact algorithms, such as that developed by Daskin (2013), can be adopted and applied. For example, the specific case of the network shown in figure 5, having a limited number of nodes, can be solved without difficulties with exact solvers (a solution for $p=2$ is shown in Figure 6). However, when the size of the problem (i.e. number of nodes) increases, the instances become of large-scale and, thus, the development of heuristic and/or meta-heuristic approaches becomes necessary in order to obtain a solution in a reasonable amount of time. This will be certainly the case whenever the University decides to cover not only part of the existing buildings, but rather all the different structures of its huge campus. There are several non-exact methods that have been proposed in the scientific literature and that can be employed to solve large-scale p-center models (see the recent survey by Çalık et al., 2019). Examples of such heuristics include the one developed by Mihelic and Robic (2005) who used a decomposition approach that consists in solving a finite series of minimum dominating set problems. Also, Bozkaya and Tansel (1998) developed a heuristic method in which the p-center model is expressed in terms of the spanning tree problem. Several meta-heuristic approaches have been also developed to solve the p-center problem, such as multi-start local search, tabu-search, variable neighborhood search and memetic genetic algorithm (see (Mladenovic et al., 2003 and Pullan, 2008). The other direction of investigation towards solving p-center instances consisted in identifying lower and upper bounds that were combined with Daskin's algorithm in order to design efficient a multi-level meta-heuristic approach (Salhi and Al-Khedhairi, 2010).

4 CONCLUSIONS

The aim of this position paper is to apply network optimization techniques that will help in designing a walking aid network for visual impaired students in a big University campus. The network will also involve the location of a set of rest lounges to be used by the visually impaired students during their movements from one building to another. We suggest to use here the p-center location method to solve this problem. However, after the coding and carrying out an experimental study it should be easy to understand if the results of these techniques can be considered as satisfactory, or more specialized approaches should be adopted. Moreover, if the number of offices/building increases, then solving exactly the p-center model is not tractable and adopting heuristic or metaheuristic approaches becomes necessary. This is a preliminary work that should be completed.

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APPENDIX

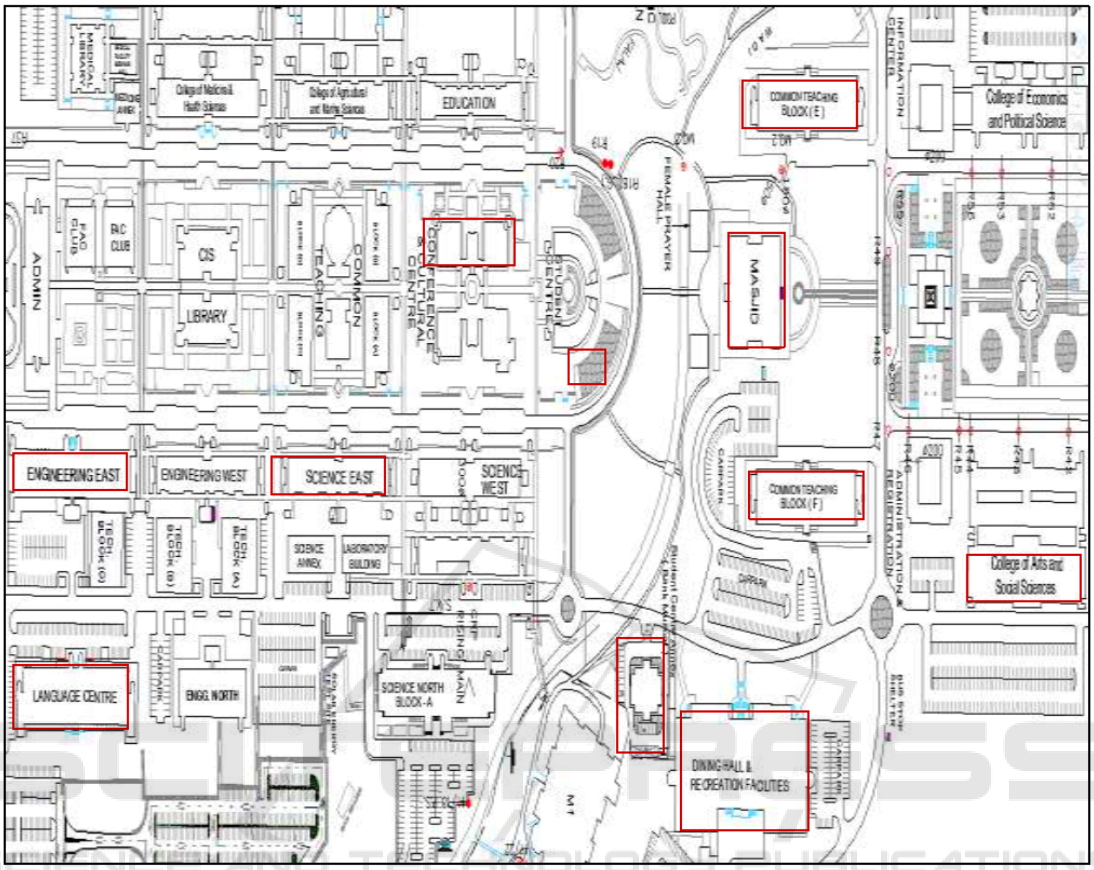

Figure 4: Campus map with the buildings of interest for visually impaired students highlighted in red color.

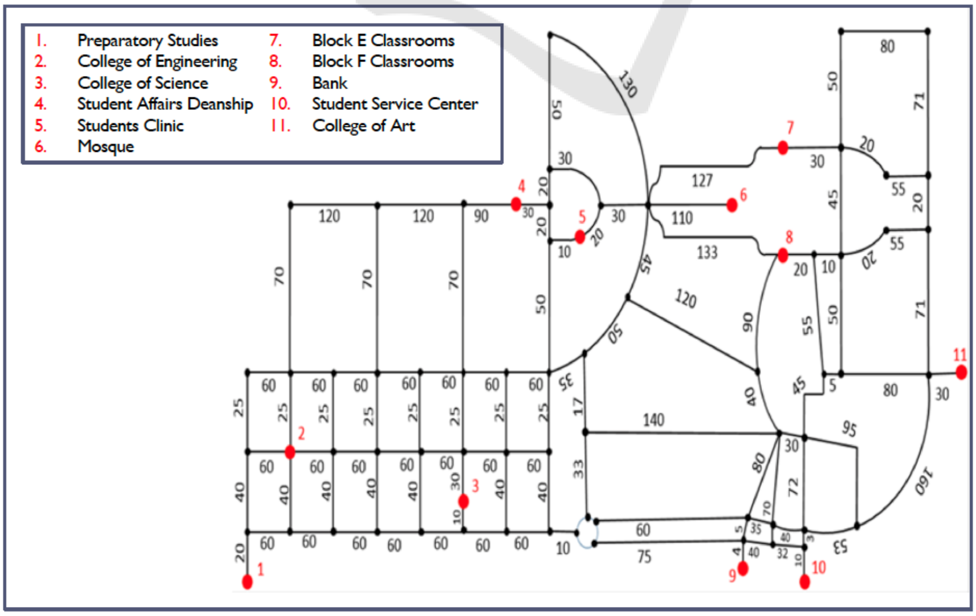

Figure 5: Resulting network (a simplified graph showing only a subset of possible connections between nodes).

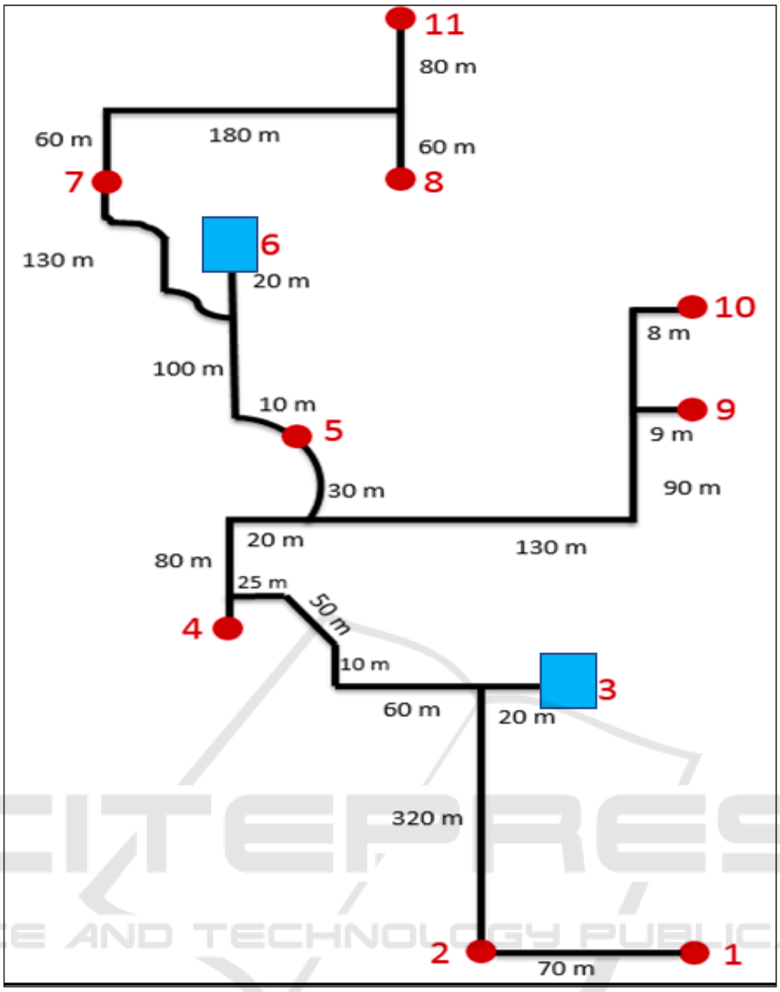

Figure 6: A solution representation with 2 rest lounges (placed in nodes 3 and 6).