AN APPLICATION OF NEURAL NETWORK IN POST-OCCUPANCY EVALUATION OF UNDERGROUND STATIONS

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ABSTRACT: The architectural and construction design deals very often with the word quality. This term is so vague and broad that the main difficulty arises if one needs to determine its aspects. It is rather simple to deal with the quantifiable building standards. The problem is how to demystify and thereafter integrate this fuzzy concept of quality into design.
As an example we will use underground stations as a design problem area for two reasons. First of all, these spaces are rather young structures that have a high potential in the future. The efficiency of underground transport and importance of multiple space usage in the densely built urban areas are only some benefits that these spaces can offer. But yet many realized underground projects were not satisfactory to the users. Second reason lies in a fact that these spaces have their own limitations. Some qualities that are so obvious for the aboveground buildings, such as daylight or view, are rather difficult to obtain in underground spaces. Therefore, in these spaces the word quality is even more sensitive. But the literature that the architects can consult regarding these problems is rather scattered and difficult to obtain. One of the reasons is a lack of detailed documentation on actual applications of the theories followed by the research results and applied techniques. In this paper we used the AI technique, a Neural Network, for data analysis.
The main objective of this paper is to develop a Support Model that will enable quality measurement of underground spaces in a systematic way. In order to avoid the ad-hoc design solutions for underground spaces, there is a need for systematic approach to their design. In such way the intuitive approach to problem solving can be minimized. This paper deals with following topics:

1. *aspects that determine the quality of space*
2. *classification of psychological and spatial aspects*
3. *development of conceptual framework*
4. *application of Neural Network for post-occupancy evaluation*
5. *results and endeavor design guidelines*

First three topics will deal with criteria definition, which were necessary for design of the experimental part of a research. The experimental research, which was carried out at the site of one underground station, provided the necessary data. The main emphasis of the paper will be on Neural Network application (topic 4), which will be used to treat the data gathered on underground station. The main objective is to verify the consistency of the outcomes against the predefined criteria.

KEYWORDS: Quality measurement, underground design, post-occupancy evaluation, Neural Network

1. INTRODUCTION - QUALITY OF UNDERGROUND SPACE

During the last decade a building underground has gained on the importance, especially in a densely populated urban areas. There are few reasons for such popularity of the underground space within a planning community, but perhaps the most obvious one was the growing environmental concern regarding future city growth. The environmental concern became one of the main initiators for a change in urban planning and design. As a result, two very important concepts emerged: *sustainable development* and *compact city* (Jenks, 1996).

Building underground is one of the possible alternatives that supports both of these concepts. Firstly, locating partially some functions underground creates more space for recreation and social activities in the vicinity of residential areas. In such way more compact cities can be realized improving the overall quality of life in urban area. At the same time a valuable land in the downtown area is used more efficiently.
Secondly, only few decades ago people become aware of environmental problems. Just to mention few of them: pollution, global warming, the greenhouse effect, depletion of natural resources, the loss of green and recreation areas etc. Locating some activities underground could help overcome some of the above-mentioned environmental problems.

As building underground slowly paves the way in city planning, other important issues are coming to the surface. Apart from the technical and construction aspects this ‘new and unclaimed’ territory should guarantee its own quality. On the one hand it should be well integrated into the total city context. On the other hand the actual quality of the underground spaces needs to be improved. This paper will deal with the second issue: *the quality of underground spaces*. In that respect a user is a central figure and user’s perception of underground space becomes a valuable information for underground space design.

The quality of underground space is closely related to the perception of space through the prism of various psychological aspects. It is of sensitive nature due to negative associations that people have with these spaces. The information related to quality and perception is in itself vague and difficult to assess. The psychological aspects and negative perception of underground spaces are seen as a potential hindrance in underground space utilization (Carmody, 1993). Very often the negative associations with underground are the result of different prejudices. Sometimes they are based on concrete experiences with the existing underground spaces, which were built without paying special attention to physiological and psychological quality. It is also important to acknowledge that there is still a significant knowledge gap in this area. On the one hand, this leaves the users unsatisfied while on the other hand, there are no concrete solutions for the architects to help to bridge the gap. Therefore, the relation between psychological aspects and spatial characteristics is a key for coming a step further in order to improve the quality of underground space. The satisfaction of psychological aspects together with the spatial characteristics will finally determine the quality of underground space.

Two most important psychological aspects, for underground spaces, are the *safety* and *comfort*. This immediately raises the question: How does one measure the feeling of safety and a degree of comfort in underground spaces and what is the relation between these aspects and the spatial characteristics? So this becomes a first issue to be dealt with in this paper. Second issue is the following: When the necessary data is obtained the question raises regarding the method that should be used or in other words how to efficiently select the most representative cases that are closest to the general public opinion. Once these cases are selected a post-occupancy evaluation for an underground station can be obtained taking into consideration the most representative cases. Accordingly the improvements of a design can be suggested, once the general public opinion is known. It goes without saying that these results are extremely valuable since based on them the design guidelines for underground spaces can be provided and in such way avoid the ad-hoc design solutions. In other words, instead of an “intuitive” approach to problem solving, the systematic approach could be used.

In order to create design guidelines a number of case studies should be analyzed. This paper provides a setup for case study analysis as well as the data collection and analysis of a chosen case study.

2. CLASSIFICATION OF PSYCHOLOGICAL AND SPATIAL ASPECTS

It was already mentioned that the quality of underground space is determined through the satisfaction level of psychological aspects which altogether determines the general acceptance of the space. For underground spaces safety and comfort aspects have a central position. The satisfaction of these aspects is highly dependent on the spatial characteristics. Apart from that the individual characteristics, such as age and gender, influence the perception of space as well (Steffen, 1979). In other words, those are all different research variables that need to be defined before conducting an experimental part of the research (see figure 1).

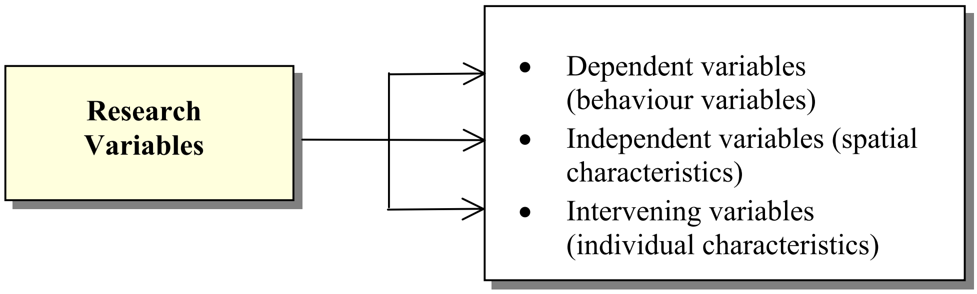

Figure 1. Research variables for an assessment of space perception

2.1 Psychological aspects – safety and comfort

Various authors dealt with safety and comfort aspects (Passini,1992; Voordt, 1990; Korz, 1998; Fisher, 1992; Opperwal,1999), but rarely these two were mentioned together in the literature. We can extract eight most important determinants of comfort and safety. Those aspects are subdivided into two groups (A_n and B_n), where group A_n represents the determinants of safety and group B_n are the comfort determinants (see figure 2).

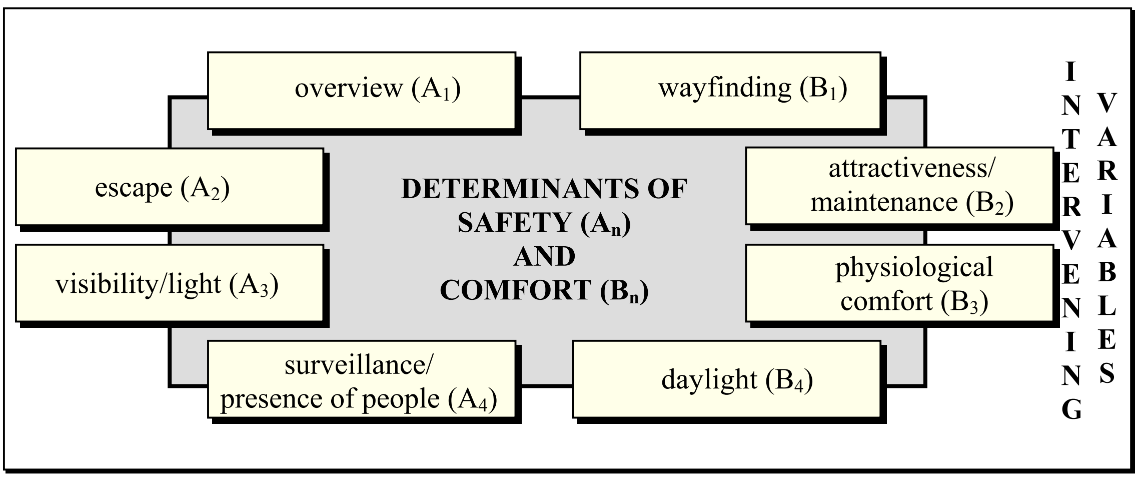

Figure 2: Determinants of safety and comfort

Both comfort and safety are crucial for integral space perception. A person may feel comfortable but not safe and also the other way round. Only together, being experienced as positive can provide confirmatory judgement and experience of space. Even though they are inseparable, analytically they can be distinguished. In other words, the variables can be defined for both aspects, which makes their assessment easier to control. First of all, an operative distinction can be made in a following way. Fulfillment of safety aspect is a must and therefore the determinants of safety are seen as standard requirement. Fulfillment of the comfort aspects is an additional quality and should be satisfactory in so far as possible. In such way different dimensions of safety and comfort can be distinguished and accordingly manipulated and handled in an organized manner. It is rather interesting to see if a poor satisfaction of one or more determinants of safety or comfort can be compensated through high satisfaction of other determinants. This will be discussed in section 4 of this paper.

2.2 Spatial characteristics and context

Having defined the psychological aspects, the spatial aspects need to be defined as well. Based on interviews that were carried out with different architects two groups of aspects were defined and further specified[1]. In other words, if we try to reduce a space to basic components we can see it through two main aspects (see figure 3).

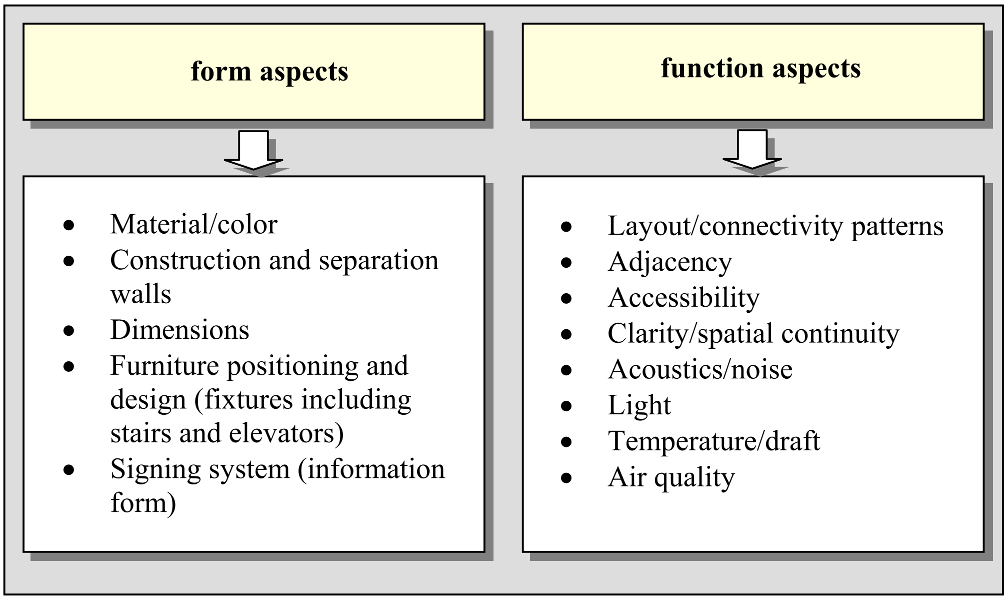

Figure 3: Spatial aspects defined through form and function aspects of a design

Form aspects include the physical space as it is, excluding the physiological requirements such as light, temperature and acoustics. Functional aspects are those that deal with spatial organization in order to fulfill the specific requirements of the stations. By combining *figure 2&3* the dependency of psychological aspects (comfort and safety) and spatial aspects (form and functions) are summarized (see figure 4).
It is this figure which forms the basis for questionnaire setup, showing directly the impact of spatial characteristics on psychological aspects and other way round. The questionnaire was carried out at the underground train station in Rijswijk (the Netherlands). The station was constructed in 1996 and it is not without reason that such rather new station was used for this

[1] Interviews were carried out with ir. Moshé Zwarts (February 1999), ir. L.I. Vákár (April 1999) ir. Theo Fikkers (December 1998) and ir. Harry Volker (who is consulted on various occasions). First three architects had an experience in designing underground spaces which was of great value for this research. The last architect, H. Volker, has been a practicing architect for more than 30 years and his suggestions were also an important contribution for this research

study. The intention was to see till which extend it satisfies today's users based on the predefined criteria.

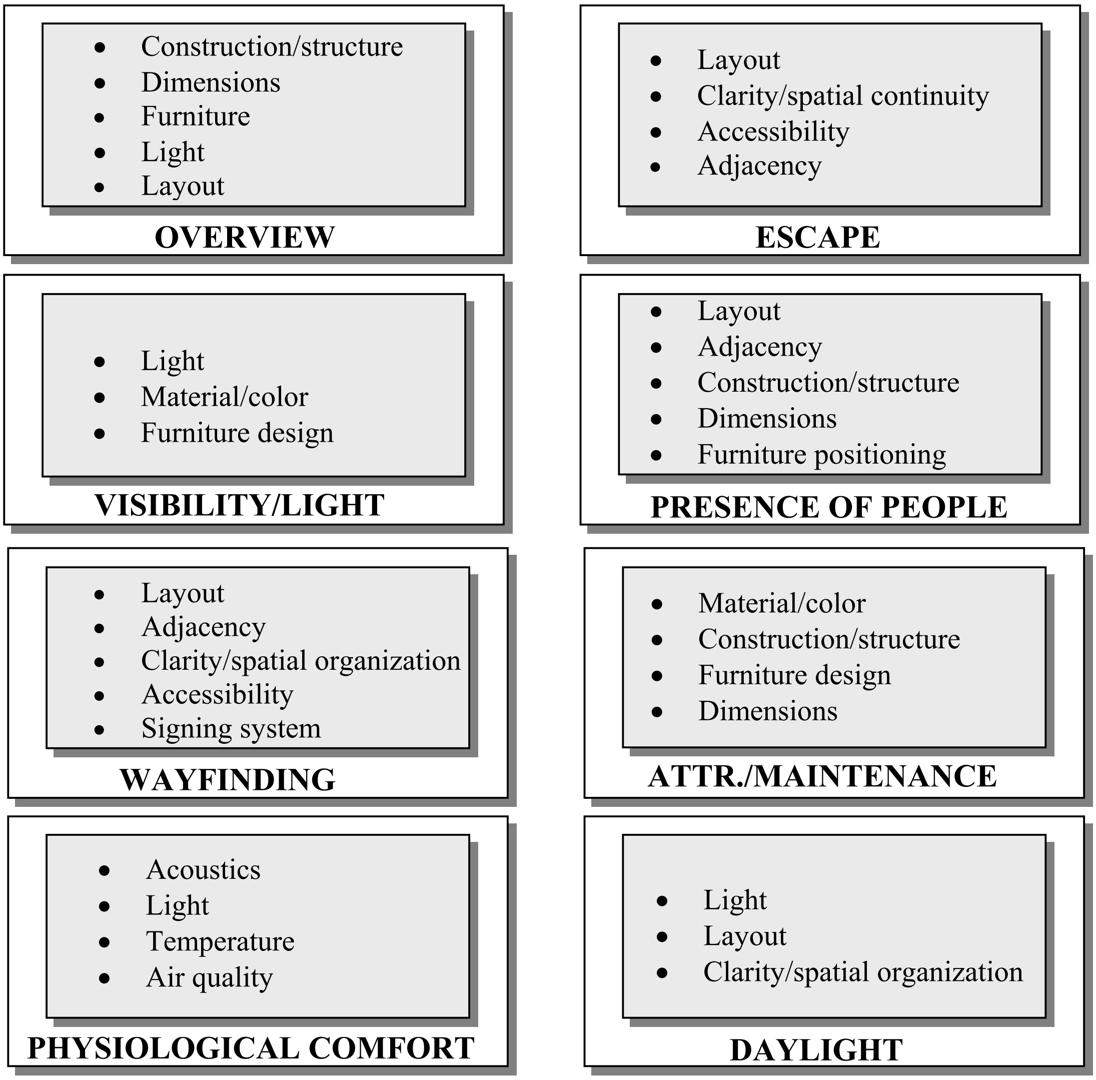

Figure 4: The dependency of psychological and spatial aspects

Apart from spatial characteristics, the context may also influence the feeling of safety and comfort. Korz (1998) explained the meaning of context saying that with a given context people have certain expectations and their judgment of the space depends on the provided context. The author showed that there was a relationship between context and experience of public safety for the above and underground stations in relation to aspects such as light level and presence of people. The contexts that are most commonly present in underground spaces and that should be taken into account are (Durmisevic, 2000):

1) Spatial organization:
a. Linear spaces (only one transport system)
b. Complex spaces (where transfer areas are present)

2) Functional organization:
a. Mono-functional (one function only)
b. Multifunctional (transport in close relation with other functions – for example shopping)

3) Space in relation to function

a. Entrance level
b. Interchange level
c. Platform

In this respect (see figure 5, 6, 7), Rijswijk underground train station is a linear space, has only entrance level (which is multi-functional) and platform level (which is mono-functional).

Figure 5, 6, 7: Rijswijk train station-atrium area (5), platform (6) and entrance level (7)

3. CONCEPTUAL FRAMEWORK AND METHOD

In the previous sections various variables were introduced and defined, which are summarised in the following figure, showing at the same time the relation and dependency of various variables and serving also as a conceptual model around which all further activities are build upon (see figure 8).

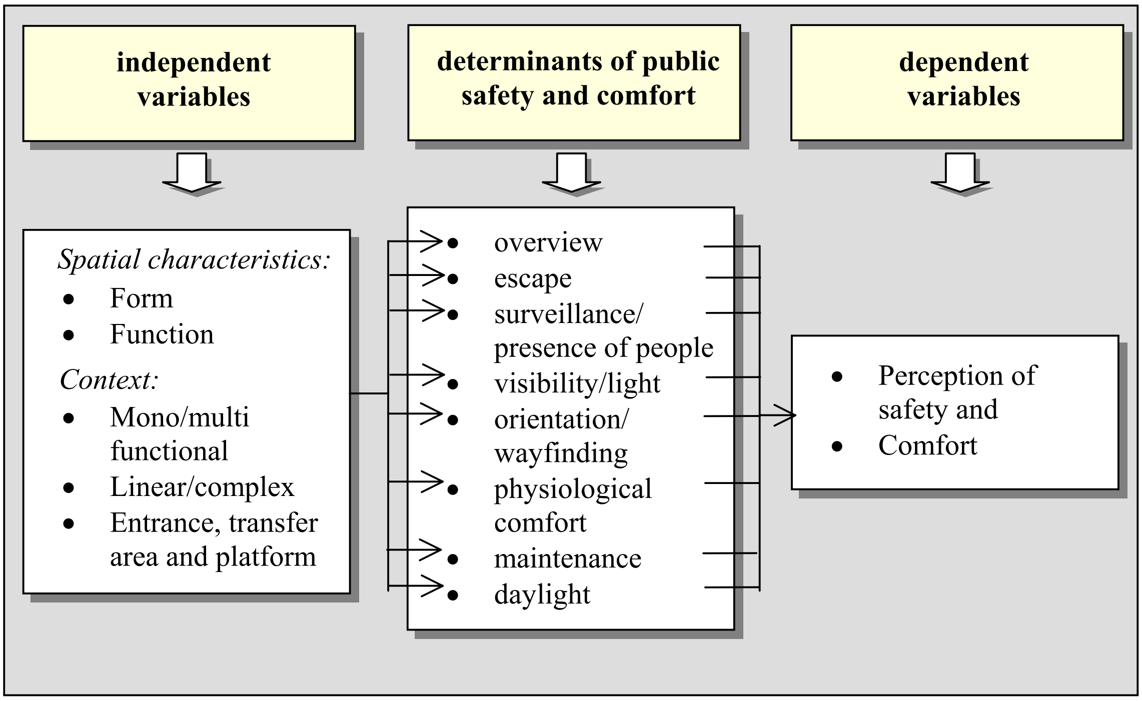

Figure 8: A conceptual model

Having set the boundaries of this research, we come back to data collection and method that will be used for data analysis. On one hand, the data regarding spatial characteristics was collected in collaboration with the station's architect (form and function aspects). On the other hand, the questionnaire was prepared in such way that one group of questions corresponds to one group of spatial characteristics and indirectly assessing the safety and comfort aspects.

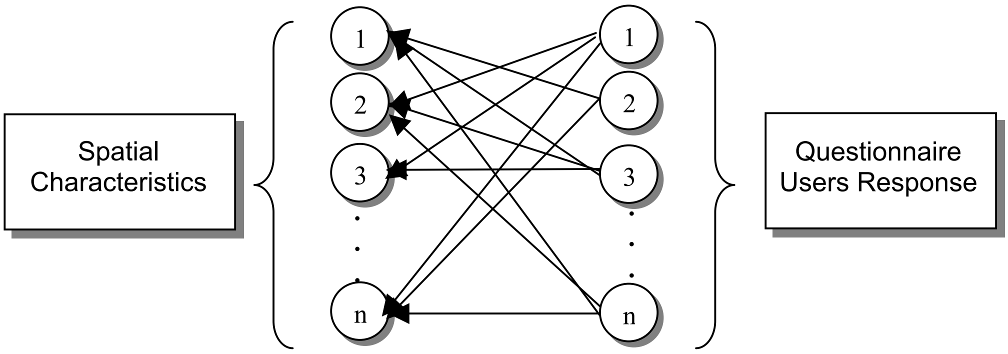

Figure 9: Assessment of safety and comfort

In such way we have the objective measurements on one side (the space as it is), and on the other side the post-occupancy evaluation done by users. For this station 22 cases were introduced, where group of answers dealing with each aspect separately were the inputs for a neural network (NN) and final safety and comfort assessment was the output data for the NN.

4. APPLICATION OF NEURAL NETWORK FOR POST-OCCUPANCY EVALUATION

Why neural network? The NN have been successfully used in areas where observational data is accumulated and goal oriented processed. Among others, it has been successfully used in the medical science, where on the basis of the symptoms that a patient has a diagnosis of a disease is obtained, and further treatment related to specific disease can be provided. In the similar sense, this can be applied to the design as well. In other words, according to the specific spatial characteristics (symptoms) the state of the underground spaces can be obtained (diagnosis) and eventual steps can be proposed to improve the quality of these spaces in a form of the guide lines (treatment).

The neural network is especially suitable for dealing with ill-defined problems where using complex information at hand and finding the logical connections within the whole data range is aimed. For feed-forward type neural networks these relationships are in the form of input and output so that the input and output associations are stored in the neural structure after the training. The training algorithm therefore is called supervised type. However the associations are not revealed explicitly. Such a trained neural network is used for the estimation of cases where only input data are available. Such estimation process can be seen as a case-based reasoning since the reasoning employed for the estimation is based on the cases used to train the network. The reliability of neural network outcomes increases with the increased number of cases used for the training of the network. In this research, the network used is also a feed-forward type. However a special type of training method is applied for it which is particularly relevant to the goals of this research. Namely, the network type is known as Radial basis Function Network and the training algorithm is known as orthogonal least squares (OLS) (Chen, 1991). By means of this algorithm, the input output associations are established by means of radial basis functions which are gaussians and the base function centres are determined by means of input space, that is, the information applied at the input. By means of

OLS algorithm, each set of input information i.e., the cases are graded in a sequence according to their relevance to the information applied to the network output. Since the network structure is in the form of multi-input and multi-output, the relevance used as a criterion is a global relevance concerning the total input and output pairs each time. The gradation identified reveals the important input sets which serve as important input data for the actual design. Therefore, it is of great importance to stress-out that in this research, estimation was not our goal. Neural network in this case was used for the input-output associations to be able to select the most representative cases in the input space that are closest to the general public opinion which can serve as a base for design or design evaluation if an underground space is already realised. The advantage of using this method for data analysis is that it rather quickly provides the reliable information by selecting the most suitable case which is the representative of the general public opinion of the randomly selected group. However more importantly, such information acquisition is an ill-defined problem in term of exact sciences and it is difficult to obtain using conventional mathematical data analysis tools. It goes without saying that by increasing a number of cases the refining of the outcomes would take place, but at the moment this was not our primary concern since the extension of the analysis with increasing number of cases is straightforward. The experiment showed that some cases appeared to be nearest to the common opinion than the others.

The tests were done for each aspect independently:

- overview, escape, visibility, presence of people (determinants of safety)
- way-finding, attractiveness, physiological comfort and daylight (determinants of comfort)

Some test examples done by neural network are given in figure 11 and figure 13, where the graphs show the input/output associations (in both cases they match almost 100%). Figure 10 and figure 12 represent an ordered list of representative cases provided by NN as well.
An experiment was done for all safety and all comfort determinants. In such way representative cases were obtained for each separate aspect, for group of aspects and for final estimate.

representative cases - safety aspects

1	**7**	*12*	**11**
2	**22**	*13*	**10**
3	**17**	*14*	**13**
4	**9**	*15*	**20**
5	**21**	*16*	**5**
6	**12**	*17*	**2**
7	**8**	*18*	**3**
8	**16**	*19*	**6**
9	**15**	*20*	**1**
10	**4**	*21*	**14**
11	**18**	*22*	**19**

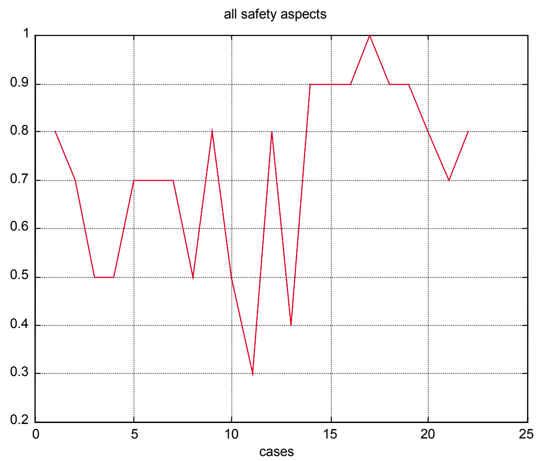

Figure 10, 11: Table showing the order of the representative cases (10) and a graph of input-output associations for the safety aspect (11) representative cases - comfort aspects

1	**18**	*12*	**4**
2	**9**	*13*	**20**
3	**16**	*14*	**7**
4	**2**	*15*	**13**
5	**21**	*16*	**3**
6	**22**	*17*	**14**
7	**5**	*18*	**17**
8	**8**	*19*	**11**
9	**10**	*20*	**15**
10	**19**	*21*	**12**
11	**1**	*22*	**6**

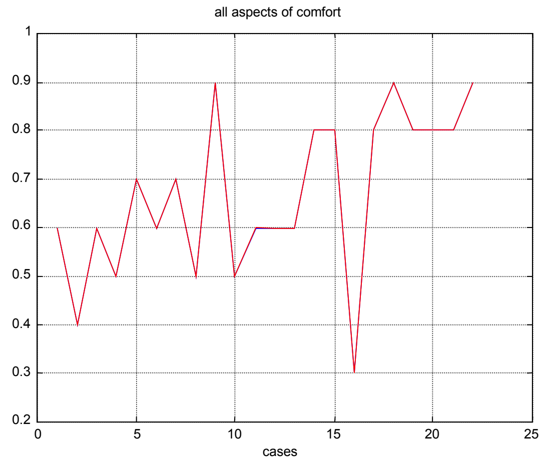

Figure 12, 13: Table showing the order of the representative cases (12) and a graph of input-output associations for the comfort aspect (13)

With such detailed analysis it becomes much easier to trace the possible drawbacks that the station has only by looking at the representative cases and accordingly to provide design guidelines once the problem areas are defined. Not only the problem areas are in such way easily defined but also the positive aspects of the station with such analysis become evident, which again is a valuable information for the guideline design. This method actually gives a quick scan of whether or not the station should undergo some reconstruction in order to improve the quality of underground station or not. It also points out where the possible problems are, helping to focus on their solution. Therefore, it was also rather important to conduct independent tests for each aspect, which provided detailed insight into possible problems. Based on these results, the design guidelines can be developed so that problem areas can be minimised and most preferably totally prevented.

During the experiment with the neural network some rather interesting thing happened. It turned out that for safety aspects of the station (all four of them) the perception of safety of the surrounding in which the station is situated happened to be an extremely important background information. This means that in some stations the aspect of safety may deteriorate significantly, not so much due to the conditions inside the station as due to the fact that the station is situated in the "unstable" and unsafe surrounding. Therefore, to assess the feeling of safety in an underground station it is necessary to take into consideration the context of the surrounding as well, which was the case in this research.

	overview	**escape**	**visibility**	**people pr.**	**wayfinding**	**attract.**	**physiological**	**daylight**
1	22	13	22	17	9	18	18	14

Figure 14: Representative cases for all safety and comfort aspects

Finally, having analysed the data by neural network (see figure 14) and taking into consideration *figure 4* following conclusions were drawn. Even though the Rijswijk station is rather new (1996) still it is not as satisfactory to the users regarding some aspects as it could have been. The most complains were regarding physiological comfort (which is one out of four comfort aspects, with case number 18 as a representative for this aspect):

- the draft both on the platforms and on the entrance level was experienced rather negative (tracing this back to the spatial characteristics the positioning of large and massive stairways in the atrium and placing of the main exit door were the main cause of draft);

- unpleasant temperature in the wintertime (this is caused by draft, which in winter is experienced less pleasing than in summer time);
- noise hindrance (no additional isolation was placed to reduce noise, reflective rather than absorbing materials were used);
- due to its mono-functionality station was experienced as rather monotonous and without identity;

Those were the main reasons why in general people estimated the comfort of this station less satisfying than the safety of the station. Yet, it is interesting to notice that these complains didn't reflect as much on the overall experience of comfort, since it was compensated through positive estimation of other three comfort aspects. So for this station wayfinding, attractiveness and daylight were more determining for overall comfort than the physiological aspect. It is important to mention here, that people questioned were the passengers and didn't need to spend long time at the station. If this was not the case, an influence of this aspect on the overall comfort would have been probably more negative.

Regarding safety aspects most positive comments were regarding:
- good lighting and visibility
- good overview

These two aspects influenced the most the feeling of safety.

5. FUTURE WORK

The questionnaire design for the Rijswijk underground train station, data gathering and later on the analysis serve as a test case for the large public questionnaire that will be carried out in the summer this year. Four different underground stations are selected and some 1000 cases per station will be obtained and later on analysed with the neural network as well as with the SPSS package (Statistical Package for the Social Science). Based on the results the design guidelines will be provided.

6. CONCLUSION

In this paper we have provided a systematic approach to the post-occupancy evaluation of the underground spaces, with the emphasis on underground stations. This approach focuses on predefined criteria, making problem/solution mapping more obvious and finally promising satisfactory results. For data analysis a neural network was used which proved to be a valuable tool for conducting such research. With neural network the input-output associations for various aspects were obtained and thereafter the representative case for each aspect was obtained. Those were the cases that were closest to the general public opinion regarding the quality of underground stations, and therefore represent also the focus for the development of the design guidelines. A neural network is by no mean a replacement of the statistical packages but is a valuable tool for data analysis and in a different light it tells us the other side of the story.

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