SMART SENSORING AS A PLANNING SUPPORT TOOL FOR BARRIER FREE PLANNING

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Abstract: As more and more people face mobility constraints due to the natural aging process of the population, barrier-free planning becomes an important urban planning issue. There are two different research approaches for integrating these needs in an objective, bottom-up and sensor based planning process. A core element is the use of the ambulatory assessment methods in combination with GPS-sensor data. The result is a planning instrument for identifying and optimizing city spatial barriers for handicapped people. This “bottom-up-approach” is based on research fields of barrier-specified city planning, subjective well-being and the field of emotional research. It is elemental to know the place of spatial barriers associated with the negative emotion - the “stress” of test persons. To achieve this, the new method of psycho-physiological monitoring is utilized in two projects, using a special technical device to measure autonomic bodily functions as indicators for emotions - the Smartband. The first project, named EmbaGIS (Emotional-Barrier-GIS), aims at the measurement of the emotional component of handicapped people (one target group: users with walking troubles) in the context of barriers, geo- and time located in a GI-System. The result is a psycho-physiological monitoring, which can help to identify city spatial barriers in a personal view of handicapped people. The objective of the second project is to formulate an evaluation model for mapping the relative accessibility of pedestrians' pathways, in which the potential mobility conditions of particular users groups were taken into account. The proposed model is initially based on a multicriteria evaluation, which is subsequently adjusted to show levels of relative accessibility. The method was applied in two university campuses, and one of the validation processes was based on field results obtained with the Smartband. The main characteristics of both projects are presented and their outcomes are thoroughly discussed in the paper.

Keywords: barrier-free planning, smart sensoring, people with disabilities, planning support tools.

1. INTRODUCTION

The origin of this joint paper was a meeting at CUPUM 2009, in which the involved universities from Brazil and Germany discussed the potential of "human as sensors" (Zeile *et al.*, 2009). After two years of exchange with technology, it is now possible to present new results on this topic. Interestingly, in both projects, the topic "planning for people with disabilities", is the central object of examination. Such an interest is not limited to those two countries, as shown by the international literature (Axelson *et al.*, 1999; Beale *et al.*, 2000; Blennemann *et al.*, 2003; Church and Marston, 2003; Childs *et al.*, 2005; EMCT, 2006; Yairi and Igi, 2009; just to mention some).

Only through a high level of accessibility in a city, the subjective quality of life of disabled and handicapped people increases. In the past, a "measurement of life's quality", an analysis and assessment of quality of life, was only possible by using surveys and retrospective self-reports. Urban planning practice is a mix of two approaches: top-down (urban planning regulations / DIN standards) and bottom-up (here: a survey of affected, handicapped population groups). This process is also known as "mixed planning". Especially in planning processes, concerning the topic "planning for handicapped people", there is a large gap between planners' opinions and surveys to a special topic, made for mobility-impaired users, where they could express their subjective impressions or situation, to another situation actually experienced.

A method for an "objectively measuring the mental state" in connection with the identification of barriers in the city for people with disabilities is currently not available. It is not yet possible to detect barriers for disabled people from their conscious and unconscious perception. Spatial planning needs primarily objective and valid data to identify issues for this special planning topic. From this motivation, there is a need to create a methodology for objectification and validation of such subjective, target group-specific data in spatial planning.

2. PLANNING METHODS

The idea of using smart sensoring methods for identifying "points of negative emotions" is not new. From the idea of the "Mental Maps" by Kevin Lynch, where he worked out the idea that humans are able to memorize paths and to recall these if needed. These maps contained the following elements: paths, border lines, areas and focus points as well as landmarks. Thus, paths are the predominant aspects of a city, because they are like canals through which the spectator can move. Moreover, areas have been marked that have been experienced as pleasant or threatening (Lynch, 1960). Critics of this technique point out that not every participant had the drawing skills needed to adequately express his exact imagination using a graphical plan. These days, the use of GPS technology and the automatic tracking of a walk in a city can help to reduce these deficiencies. This approach was for example made by Phillips *et al.* (2001). In 2003, GPS technology was used to identify areas with potential exposure to environmental contaminants by children (Elgethun *et al.*, 2003). The integration of “feelings” or “well being” into GIS was introduced by Sorin Matei with his Mental Maps. His work is strongly oriented on Lynch’s’. Matei mapped feelings for the first time on a map and visualized them additionally in a three-dimensional VRML model. The result was a 3D-Map that shows areas of well being and fear in the city of Los Angeles (Matei *et al.*, 2001). Another work in this context is the project "GPS-based construction risk pilot study” (Birdsall and Brühwiler, 2007). In this study the concept of GPS-based analysis of the personal risk is being researched. Stress as an indicator of risk is recorded automatically and localized via GPS-Tracker. Only an art project, but with a lot of inspiration for the visualization of emotions in a city, is the project Biomapping by Christian Nold (Nold, 2008 and 2009). He sent many test persons, each equipped with an indicator through a city and recorded their vital signs and skin resistance. The latter was geo referenced with a GPS-Logger and visualized in a BioMap (Nold, 2008). Also, some of the works of MIT Senseable City Labs cover the topic of collecting human sensor data in cities (actual Martino *et al.*, 2010 and Resch *et al.*, 2011). Within the research of emotions, the psycho-physiological monitoring is the optimal method for the measurement of urban barriers by identifying georeferenced stress reactions. The experimental research shows consistently that emotional reactions are associated with changes in the activity of the autonomic nervous system. Specific physiological parameters, such as the skin conductivity and skin temperature, (Kreibig, 2010) can be used for psycho-physiological monitoring. The use of self-reports of test-persons to their emotional reactions could be ignored now.

3. TECHNICALS

In our empirical studies we used a sensor wristband by which those peripher-physiological parameters are captured, which reflect autonomic nervous activation as outcomes of emotional brain processing of relevant environmental stimuli. Changes of skin conductivity and skin temperature are of mostly valuable, because they are directly and solely connected with sympathicus nervous system, which is mobilized by strainful and risky environments. As it is activated it starts to excitate sweat production of the eccrine sweat glands. So measures of sweat production indicate nervous activity of the sympathicus. These changes in subliminal amounts of sweat can be measured indirectly by applying a weak voltage to the skin. Changes of this voltage indicate changes of sweat, and thereby changes of sympathicus excitation (Dawson *et al.*, 2007). Because neural activity of sympathicus also regulates the contraction of arterioles (very small arteries below skin), mean blood flow at body periphery is reduced. These changes are very small but significant reductions of local skin temperature. Experimental evidence showed that skin temperature reduction at the wrist correlates with high sympathicus activation, mobilized by stressful events (Rimm-Kaufman and Kagan, 1996). Being valuable body indicators for stress related emotional responses, these measures traditionally were limited to laboratory studies. To overcome this restriction and allow for measuring stress-related parameter changes in natural settings, a sensor wristband device was developed at GESIS Leibniz Institute for the Social Sciences (Papastefanou, 2009). This wearable computing device, which is available for research as the bodymonitor Smartband (referring to website www.bodymonitor.de) integrates in a textile band housing electronic processing as well as sensors capturing continuously physiological data. Being designed as comfortable elastic wristband, it allows for long-term and unobtrusive collecting and saving stress-indicating body reactions. But the Smartband also simultaneously measures pressure force of the electrodes as well as tri-axial acceleration, data which are necessary to control for artifactual and non-emotional changes of sweat production and arterioles' smooth muscle contraction.

4. THE PROJECTS

The new method of psycho-physiological monitoring is utilized in two projects, by applying the Smartband.

4.1 The First Project

The objective of the study named EmbaGIS (Emotional-Barrier-GIS) was to work out the development of an innovative, comprehensive instrument for the identification and optimization of urban barriers in a sensible mix of top-down and bottom-up. This was done under the name "EmBaGIS", or emotional barrier GIS. The result is a psycho-physiological monitoring, which can help to identify city spatial barriers in a personal view of handicapped people.

For the development of EmbaGIS, we used different methods in the topics of "ambulatory assessments", a field of sociology and psychology, as well as the geospatial and traditional urban planning. In a first step, every test person collected a dataset with their skin resistance and skin temperature. With a new scientific approach (Kreibig, 2010) it is possible validate this data in this urban examination. In addition, these results were located and aggregated in urban areas via GPS-Tracker. Simultaneously, all urban areas were examined by DIN standard 18024, Part 1 "Barrier-Free Planning and Constructing". In the subsequent step, these results were compared to get findings about the emotional feelings of these volunteers in the city (Figure 1).

Core of the methodology is the “Empirical 3-level analysis and psycho-physiological monitoring” in the workflow phase 3 of Figure 1. The “empirical three-level analysis” figured out urban spatial barriers, based on a three-level system of indicators. Parameters of this analysis are:

- the kinetics, test persons' speed, measured on the GPS logger
- skin conductance, measured by the sensor strap, and
- skin temperature, measured by the sensor strap

All data will be georeferenced using the GPS logger and synchronized in a subsequent step and analyzed as a single barrier indicator. (see Figure 2).

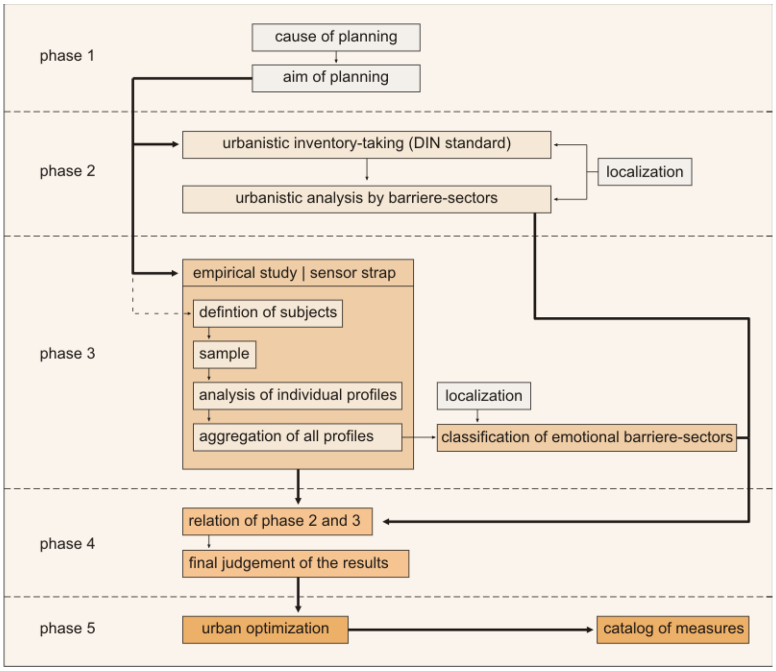
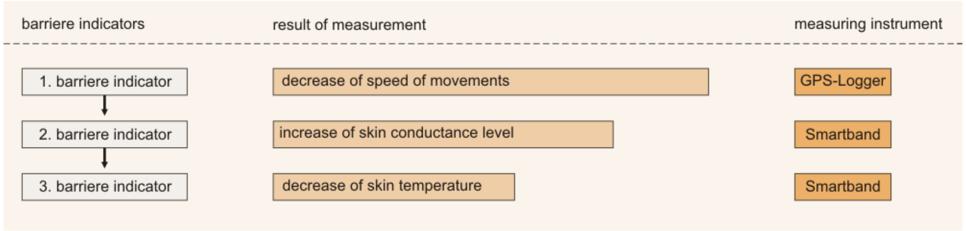


Figure 1 Multi-level phase model for the methodological foundation of EmBaGIS (Bergner, 2010)



barriere indicators	result of measurement	measuring instrument
1. barriere indicator	decrease of speed of movements	GPS-Logger
2. barriere indicator	increase of skin conductance level	Smartband
3. barriere indicator	decrease of skin temperature	Smartband

Figure 2 Empirical 3-level analysis (Bergner, 2010)

The empirical three-level analysis is performed on the basis of the recorded data and bio-signals from the GPS logger and the Smartband (Figure 3). It created curves that are reminiscent of telemetry data from the automotive industry. In order to achieve meaningful results, the curves had to be examined in relation to each other. According to emotion researchers, a negative experience occurs when the skin conductivity increases, and the measured skin temperature decreases (right part of Figure 3). If there is an additionally reduction in the walking speed, this curve indicates a negative experienced barrier in the city (left part of Figure 3).

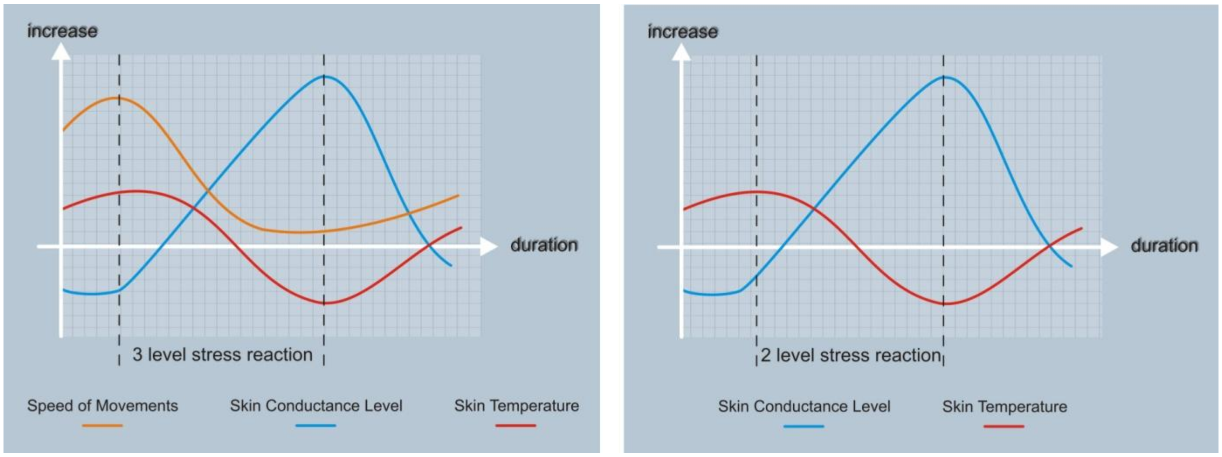
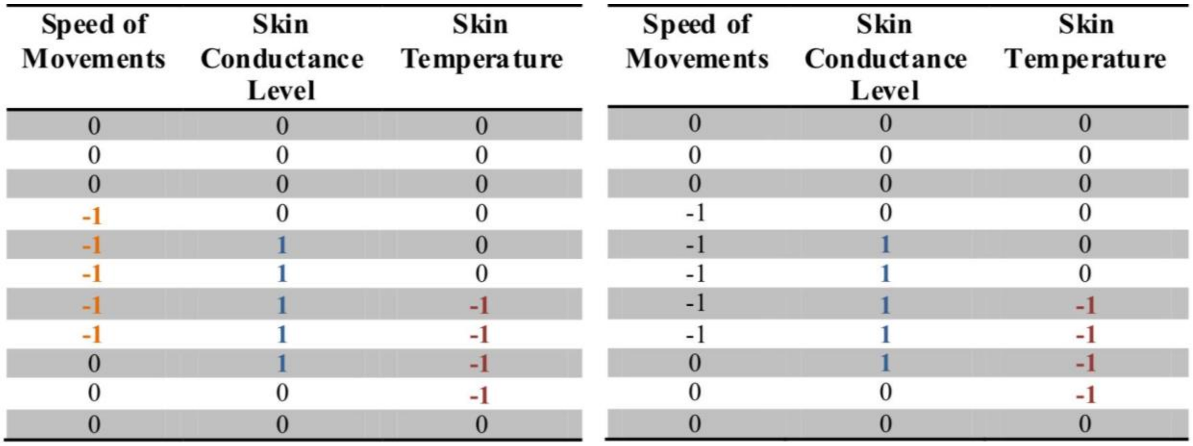


Figure 3 Generic waveform of a negative emotion, in general on the right side, with a physical barrier in urban space on the left side, indicated through decreasing of the speed

To facilitate their evaluation, the curves can be simplified in a statistical analysis on the following criteria:

- decrease the speed of movement: Scoring -1
- increase in skin conductivity: Scoring value +1
- decrease in skin temperature: Scoring -1

By assigning values of scoring, it is possible to get a tabular, statistical evaluation of individual stress reaction (see Figure 4).



Speed of Movements	Skin Conductance Level	Skin Temperature
0	0	0
0	0	0
0	0	0
-1	0	0
-1	1	0
-1	1	0
-1	1	-1
-1	1	-1
0	1	-1
0	0	-1
0	0	0

Speed of Movements	Skin Conductance Level	Skin Temperature
0	0	0
0	0	0
0	0	0
-1	0	0
-1	1	0
-1	1	0
-1	1	-1
-1	1	-1
0	1	-1
0	0	-1
0	0	0

Figure 4 “3-Level-Scoring-Analysis” (left), “2-Level-Scoring-Analyis” (right)

In addition, it became clear that the evaluation of the indicators skin conductivity and skin temperature without considering the moving speed is of interest. This was due to a phenomenon that at a certain point (a pedestrian light), the indicators for stress are measured, but the moving speed increased. So, in this case, we have a barrier with an increasing of speed. The identified stress reactions of all test persons determined by the scoring model were aggregated. They are located as emotional barrier sectors, in analogy to the defined areas, examined by the DIN-Norm. To form an indicator of the accessibility of the individual, emotional sectors, the total number of stress responses of all test-persons has to be divided by the length of the sectors (in meters). Then a fundamental comparison could be made between the previously defined urban barriers sectors and the findings out of the emotional barrier analysis.

4.2 The Second Project

The multicriteria method adopted in the second project was meant to separately assess the accessibility levels of specific groups of pedestrians. This was possible through the Weighted Linear Combination (WLC) of the criteria adopted for each group. In the original formulation, proposed by Aguiar *et al.* (2009), the method also could be used to establish combined accessibility values for several users' groups. Ordered Weighted Average (OWA) operators were then used to establish a relationship between the accessibility levels of the different groups through compensation. In other words, an intermediate value of the final accessibility at any point of the geographical area under analysis could be a result of different combinations of groups' values. It could come, for example, either from the combination of two middle values or from the combination of a very low value for one group with a very high value for another group. However, it does not seem reasonable to talk about average accessibility levels if one of the groups is strongly affected on such a negative way. This was the motivation for the development of the approach now described.

In this new approach we studied the relationships between the accessibility levels of four different users groups. Time was the measure used in the multicriteria evaluation model to assess the impedance associated with the movements, because it is directly related to the walking ability of the individuals of each group and also to the quality of the built environment. Physical elements of the geographical space that can influence on the mobility of particular users' groups, such as steps and steep slopes, were treated separately in the model. They were transformed into numerical elements and added to the travel times of users without mobility constraints. In addition to the adjusted travel times calculated for the different groups of users, the importance of key-destinations was also part of the criteria used in the model. Finally, a complementary form of analysis, which provides levels of service (LOS) as a measure of relative accessibility, was added to the multicriteria analysis method.

The LOS concept was used in the analysis of indices of relative accessibility for users with and without mobility constrains, as discussed by Aguiar *et al.* (2010). The accessibility index could then be expressed by two variables separately measured in linear scales and combined in the bi-dimensional space presented in Figure 5. The x and y values are defined as follows:

$$A_{RI}^{u} = \left(\frac{A_i^{woc}}{A_{i_{\max}}^{woc}}, \frac{A_i^{u}}{A_i^{woc}} \right)$$

where:

A^{u}_{RI} : index of relative accessibility of a location *i* to the group of users *u*, which have mobility constraints;

A^{woc}_{i} : index of accessibility of a location *i* to the group of users without mobility constraints (*woc*);

$A^{woc}_{i_{\max}}$: maximum value of the index of accessibility of a location *i* to the group of users without mobility constraints (*woc*);

A^{u}_{i} : index of accessibility of a location *i* to the group of users *u*, which have mobility constraints.

The combination of the x and y values resulted in the five LOS categories (from A to E) shown in Figure 5, where A corresponds to the best level of service and E, to the worst. In such a way, it is possible to map relative accessibility levels of different users' groups by taking as a reference the values found for users without mobility constraints.

Two methods were considered for the model validation, due to the nature of the element evaluated (i.e., the relative accessibility of spaces for pedestrians), which has both static and dynamic components. In the static part, which is not discussed in this paper, the focus was on an integrated evaluation of the criteria used in the model (weights of the key-destinations and calculation of the impedances). The validation method used in the dynamic part was meant to evaluate subjective factors that may influence the pedestrians' movements. That part of the validation was conducted with the application of the Smartband for measuring the subjective reactions of selected users. These reactions were compared with the relative accessibility values obtained with the model in a predefined geographical area, in order to check if they were consistent with one another.

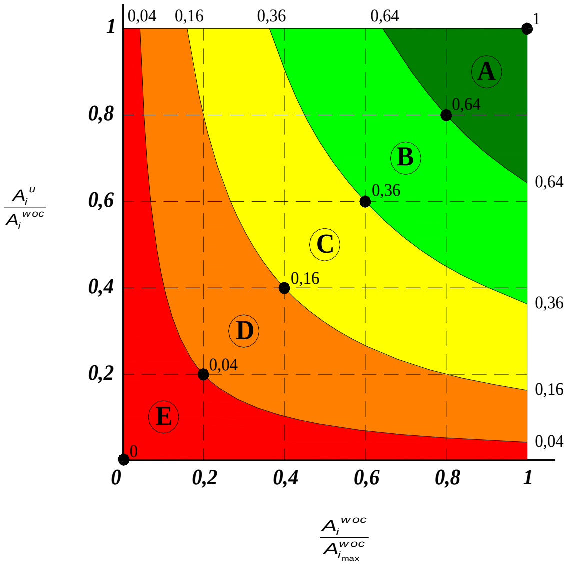


Figure 5 Scale of level of service proposed for the assessment of relative accessibility

5. RESULTS

In this section, some of the results of the two projects are presented and discussed.

5.1 Results of the First Project

The full method of EmbaGIS is described through in the study "Inner-city spatial experience and mental exposure of disabled people in a pedestrian zone”. The “mental space experience” of the test-persons (n = 21) has shown significant need of action according to the parameters “surface barriers” such as cobblestone pavements, bridge's ramps and stairs. The investigations resulted in an optimization of urban planning standards. The results are part of a proposed catalogue of measures for this area. As a result, the described stress indicators are pointed out in different forms. The higher the indicator was, the more stressful was each “emotional barrier sector” for the volunteers. As shown in Figure 6, for each sector, the stress indicator values were evaluated in a “3-level” and a “2-level” analysis. This shows in particular that sector 3 (traffic light crossing system) has an almost dual 2-level indicator, in contrast to the 3-level indicator. This points to the interval of the traffic light, which is too short and forces physically handicapped people to walk faster while putting them under stress. In addition, sector 7 is noteworthy: the sector has, in relation to the length of the sector, a very high indicator value. The reason is that the ramps for wheelchairs can not be overcome. Both, the emotional and the urban analysis proved this. Based on the empirical results of the Smartband, in comparison with the urban development analysis according to DIN standards, it can be figured out that there is now a methodology to gain valid and objective individual data for urban planning, as a bottom-up process.

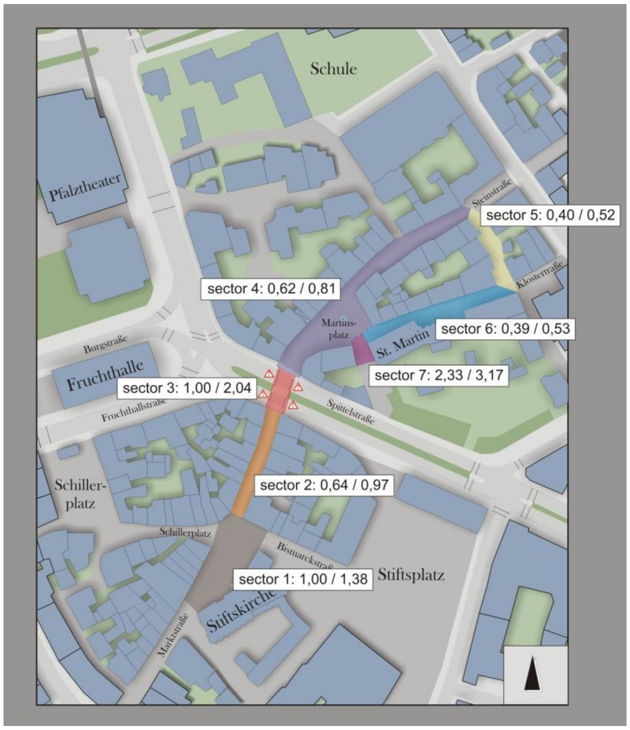


Figure 6 “3- and 2-Level-Stressindicator” for all sectors in a part of the pedestrian precinct in the city of Kaiserslautern, Germany

5.2 Results of the Second Project

The application of the multicriteria model in two case studies was essential to consolidate the proposed criteria for assessing the relative accessibility levels of public spaces for groups of selected users. The method was applied in two university campuses, but in only one of them the validation process was based on field results obtained with the Smartband. In order to simplify the application of the model while keeping its relevance, only the buildings used for pedagogical purposes were considered as key-destinations.

The multicriteria evaluation of accessibility conducted with the model resulted in a map with the deficiencies of the spaces for the circulation of pedestrians. The highest levels of accessibility were concentrated in certain areas of the campus in which several buildings used for pedagogical purposes are clustered. It became evident from the application that the size and spatial distribution of the buildings containing the key-destinations influenced the accessibility values. Those conditions, when combined with the irregular topography of the campus area, had a negative impact on the mobility conditions of all users' groups. However, it was found in both campuses that the accessibility levels vary among groups of users. The groups of visually impaired (blind) users and wheelchair users had the worst levels of accessibility. This can be seen in Figure 7, in which the accessibility levels are shown along the pathways in open areas (i.e., outside the buildings). The green points indicate places with a good level of service (A, B, and C combined) for both groups. Points in red indicate a poor LOS, and those in yellow have intermediate conditions. The letters associated with the levels of service of each group appear side by side in the legend of Figure 7 - the first is related to blind users and the second to wheelchair users.

A route with 400 meters was selected for the dynamic validation of the model using the Smartband (the blue line in the central part of Figure 7). Only the relative accessibility of blind users was considered. The selected route was an uphill pathway not very steep, along which one can find virtually flat stretches, stretches with different slopes and steps. The points plotted in Figure 8 correspond to the network nodes found along the route. The values marked on the x-axis are the distances measured from the starting point of the route. The values on the y-axis represent the relative accessibility of blind users when compared to the accessibility of users without mobility constraints. The level of service for each one of the points was previously obtained from the graph displayed in Figure 5, according to the accessibility values of the nodes. The LOS categories were then transferred to Figure 8 as different symbols, according to the legend on the right side of the graph. No points have a LOS A or B along the route, only a few points have a LOS C, and most of them have a LOS either D or E.

The LOS data along the route were organized in such a way that the sequence of nodes visited and the distances between them (in meters) were accurately registered (Figure 8). That allowed the direct comparison of these values with the users' perception data (Figure 9) and it was used for validating the model, as detailed in Aguiar (2010). The comparison of the two datasets (Figures 8 and 9) has shown that the points with a level of service E were located near the stress peaks recorded with the Smartband. It was also possible to observe, in the same figures, that the model represented the points of equilibrium and reduced stress levels recorded with the Smartband at the beginning of the route and after 250 meters as LOS C or D.

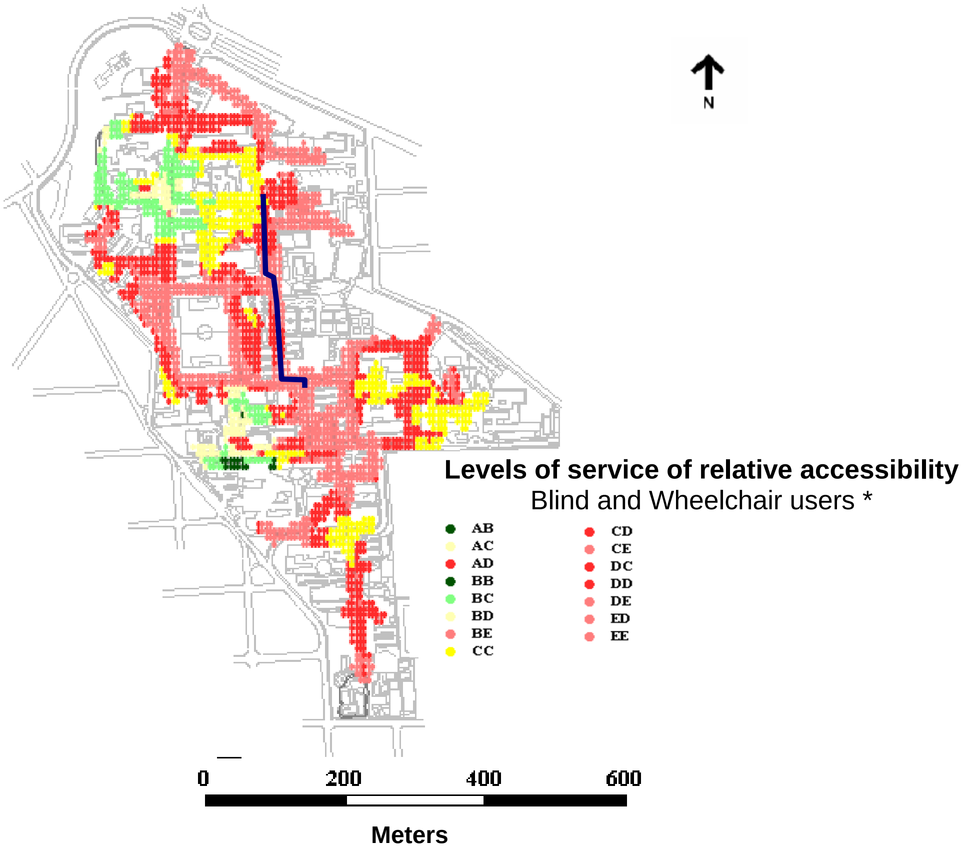


Figure 7 Levels of service of relative accessibility for blind users and wheelchair users

* The letters shown side by side in the legend are the levels of service for each group - the first is related to blind users and the second to wheelchair users

The combined analysis of the two datasets also showed some conflicting values, as in the case of the stretch between the milestones of 50 and 100 meters. A level of service D was coincident with the points where the highest stress level was registered with the Smartband. A LOS E could be expected for matching such a stress level. Those conflicting results led to a review of the model. As no problems were found in the assumptions and input data used in the model, a field inspection was conducted to look for any possible explanation for the apparent inconsistency.

The explanation was indeed found on the field. The first point with a level of service D was found 50 meters after the route beginning (Figure 8). At that particular location, the longitudinal slope registered for the model became smoother. However, due to a street crossing at this point of the route, a ramp was built to connect the sidewalk with the zebra marker. That became a problem for the volunteer, who was not used to that particular environment, even considering the absence of vehicular traffic at that moment. He momentarily lost the sense of direction, what was probably the cause of the first peak of stress (Figure 9). In order to better understand it, though, it is worth mentioning that the blind volunteer was using the curb (or the limits of the sidewalk) as a reference for following the pathway. This procedure is needed when directional tracks built with tactile indicators are not available along the way.

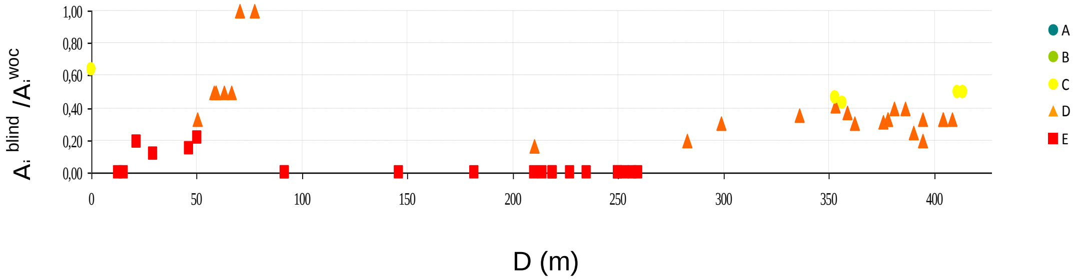


Figure 8 Relative accessibility values for blind users along the route selected for model validation using the Smartband

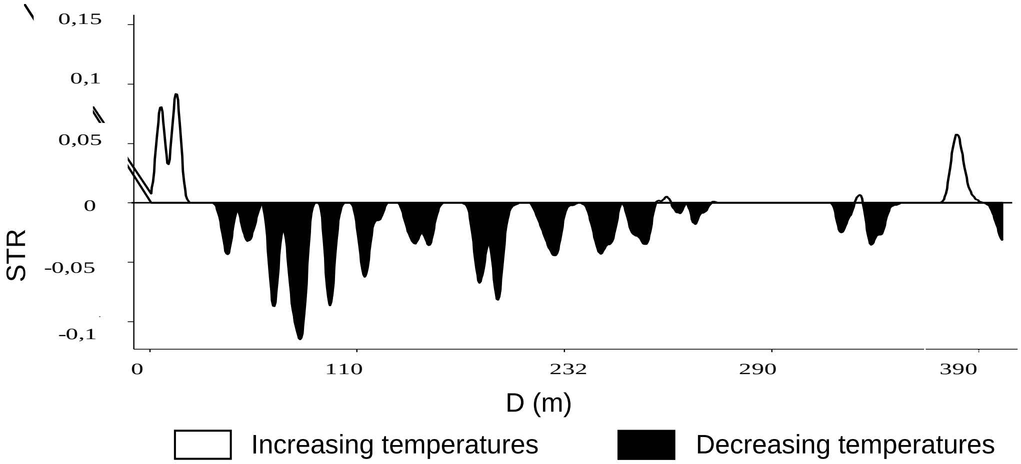


Figure 9 Skin Temperature Response (STR) of a blind user with the Smartband along the route selected for model validation

Another peak of stress was also registered a few meters ahead. Again, the level of service in the correspondent location should be E to match the stress level, but the model had classified it as a LOS D. The problem was not visible at the ground level, but above, and it was noticed only when the volunteer hit a public telephone with his head. Although the support of the telephone was not in the pathway, the telephone itself (and the shell protecting it) penetrated in the ´aerial` space above the pathway. That has been exactly the maximum peak of stress registered in the entire experiment. The model was not able to capture the interference in the accessibility value because, in general terms, the conditions evaluated on that location were all favorable. The exception was that sort of 'aerial' obstacle, which is not considered in the model. As a consequence, the assessment with the model was quite good, due to the nearly flat surface of the pathway in that part of the route.

The discrepancies in the results were then reasonably justified. In other words, the validation process with the Smartband was successful. As a consequence, the results of the validation process may indicate that the multicriteria model is able to capture the most important elements influencing accessibility.

6. CONCLUSIONS

In the case of the first project, a new interdisciplinary approach to research fields of psychology, sociology, geoinformatics and urban planning was combined to a new method in spatial planning. Specifically, the validation of the results from the emotion research is new in this field. The approach of an objectively measuring of personal well-being in a bottom-up planning process, focused on people with disabilities is novel and trend-setting within the urban planning. The results of the Smartband empirical analysis can help to identify more barriers for handicapped people in urban areas. In the case of Emotional Barrier-GIS, there is a large range of tools, which can help to improve the dataset. By using the following indicators, the collected data can be more clearly classified: localization and filming data can help to filter the results of the physiological measurements consisting of negative emotions and the speed of movement. So, in a next step there is a correlation of all these indicators with the urbanistic inventory-taking and the identified city spatial barriers for specific groups of handicapped people. The correlation should deliver us as valid data as possible in a real world application. Within the urban area of Kaiserslautern different areas could be identified that need to be re-examined by the results of acquired sensor data. The interest of the public administration in this subject is very high. Especially in the field of awareness on "living together with people with disabilities or limited mobility", this approach seems to be, even by the local government, very innovative, targeted and useful.

In the case of the second project, the use of the Smartband to validate the results of the model to evaluate the relative accessibility of pedestrians with and without mobility constraints produced interesting outcomes. The so-called dynamic validation process was introduced as a strategy to evaluate subjective factors that can influence the movement of pedestrians. The Smartband can register those subjective reactions as a high level of stress, if they are negative. That assumption was tested along a route selected in a university campus where the accessibility model was applied. That led to the following conclusions: i) the multicriteria model was able to capture the most important elements of the space and to transform them into an accessibility measure; ii) the validation process with the Smartband was able to confirm most of the model outcomes. Moreover, the device was also useful to highlight problems that were not captured by the model structure. Further research on the topic is clearly needed. It may consider, for example: the application of the model to other users' groups, the introduction of subjective elements (such as those mentioned in the case discussed here with a blind user) into the model structure, and an expansion of the validation process in order to include more users.

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