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Conveying spatial information through tactile maps

MATEUS PAULO BECK
Federal Justice of Rio Grande do Sul, Brazil
mateuspbeck@gmail.com

ABSTRACT

This paper addresses tactile maps as an aid for wayfinding and spatial cognition by visually impaired persons. The overall complexity of given environments and their representation through tactile maps was investigated. The analysis considered a sample of tactile maps installed in airports, subway stations, justice courts and 2016 Paralympic venues in Brazil. The results show significant complexity in most type of maps, adding to the difficulty of the cognitive tasks involved in the map use, especially for visually impaired people.

KEYWORDS

Spatial Cognition, Wayfinding, Visually Impaired, Tactile Maps

1. INTRODUCTION

In Brazil legislation concerning universal accessibility is being improved, following international guidelines by the United Nations. The implementation of new standards is rather slow, especially when it comes to the built environment, where the reformulation of cities and buildings should follow universal design principles. However, the professionals involved in that process often lack information from the actual capabilities and needs of impaired persons in general, and blind and visually impaired in particular. Together with universal design principles such as equitable, simple and intuitive use, accessibility standards require that the built environment should provide audible and tactile information for visually impaired people. This paper investigates how tactile maps may convey spatial information to assist wayfinding and spatial cognition.

The spatial knowledge involved in wayfinding may be described in three levels, as 'overview', 'view' and 'action' (Tversky, 2000). At a global level, 'overview' involves schematized mental representations of spatial elements such as landmarks, nodes, paths, edges, and regions, usually referred as cognitive maps. 'View' corresponds to a more local representation of the surroundings along a given route, especially at choice points. In these representations, spatial information is often simplified or distorted, being influenced by alignments, canonical axes, reference points, hierarchical frames, perspective, etc. And 'action' refers to the somatosensory information and knowledge required to maintain a course and avoid obstacles.

The spatio-cognitive abilities involved in wayfinding might be acquired even without vision and without previous visual experience (Passini et al., 1990). This was demonstrated in an experiment comparing different groups of people in basic wayfinding tasks, such as learning a new route in space and from small-scale models, returning from destination to origin, combining previously learned routes, recalling locations visited along a route, planning shortcuts, making mental rotations of a journey learned on a map, and reproducing the overall layout and spatial organizational principles from a visited setting. In that study congenitally blind subjects performed better than adventitiously blind and sighted blindfolded persons, but not as well as sighted subjects and persons with some residual vision.

As compared to sighted persons, blind subjects tend to prepare their journey in more detail, given their difficulty to retrieve contextual information during wayfinding. They make more decisions during their journey, relying on more units of environmental information, including auditive, olfactory and textural features often ignored by sighted subjects. After finding their way, blind persons are capable of representing their route and understanding the overall layout of the traversed environment (Passini and Proulx, 1988). During wayfinding, visually impaired persons perform difficult tasks and decisions, especially concerning the use of stairs, so as to identify their beginning and end, find the handrail and transfer to one flight of stairs to another, also maintaining a direction when following a corridor or traversing an open space, and finding architectural elements such as doors, which have to be used but are not readily perceived without vision. This increased difficulty may cause errors, hesitation and stress, which might be diminished by former experience in a given context and additional supports such as tactile maps, emphasizing landmarks, routes and organizational principles of the layout (Passini and Proulx, op. cit.).

Tactile maps have been proven useful for blind and visually impaired people in order to learn and retrace unfamiliar routes during wayfinding tasks. Research participants who learned a given route by using tactile maps showed more confidence in retrieving the spatial information necessary to complete the tasks, performing better than participants who learned the route by direct experience and verbal descriptions (Caddeo et al., 2006, Ungar et al., 1998). Tactile maps may also assist visually impaired people in understanding the setting, structure, or layout of the built environment, when blind travellers have to coordinate the information obtained from multiple paths, directions and routes. This cognitive task is extremely difficult without some aid such as a tactile map or plan to help recall spatial relations among features and paths within the environment (Golledge, et al., 1996). In addition, the ability to learn a tactile map depends on the strategies adopted by the map reader. Research showed that good map learners tend to focus on the spatial relationships between map items, on local and global patterns formed by map elements and their location in relation to the external framework of the map (Ungar et al., op. cit.).

Besides from the map representation itself, which might be more or less accurate and complete, the configuration of the depicted environment can be more or less complex as well. In Space Syntax theory, the configuration of an environment can be described using spatial units and their connections, such as convex spaces or axes. An intelligible system is one in which well-connected spaces also tend to be well-integrated spaces (Hillier, 2007). This means that 'connectivity', which is the number of connecting spaces that can be identified locally, might be a good predictor of the 'integration' value of the space, which represents its 'depth' from all others globally.

Considering wayfinding, directions inside a building might be described as axes, and their connections represent turning possibilities and decision points along a route leading to any destination within the system. Together with angularity, the configurational properties of building layouts are closely related to navigation rules and patterns of building exploration (Peponis et al., 1990, Dalton, 2003). Space syntax research has widely addressed human spatial perception and behaviour related to movement and wayfinding, nevertheless few studies are dedicated to the particularities and subtleties of spatial cognition by the visually impaired. In the present paper, the overall complexity of given environments and their representation through tactile maps was investigated as follows.

2. MATERIALS AND METHODS

In this study a sample of 18 tactile maps was considered, comprising seven types of maps with similar features as follows. **Type A** is a map in an airport terminal in *Porto Alegre*, made of colored acrylic shapes with descriptions in textured lettering and braille within the map, depicting space boundaries and partitions, tactile guidelines in part of the floor and architectural elements such as walls, elevators, stairs and parking places. **Type B** are maps from subway stations in *Rio de Janeiro*, comprised of colored and textured shapes with descriptions only in braille in map and captions, depicting space boundaries, tactile guidelines on the floor and architectural elements such as walls, parapets, elevators, stairs, escalators and turnstiles. **Type C** is a map in a subway station in *Rio de Janeiro*, constituted of textured lines, symbols, lettering and braille within the map and captions, representing tactile floor guidelines, stairs, escalators, turnstiles and ramps, but no constructed boundaries. **Type D** are maps from subway stations in Rio de Janeiro as well, comprised of textured lines, symbols, lettering and braille within maps and captions, depicting space boundaries, discontinued tactile guidelines on the floor, which follow along walls and parapets, and other architectural elements such as elevators, stairs, escalators, turnstiles and ramps. **Type E** is a map in a Justice Court in *Soledade*, made of colored and textured lines, symbols, lettering and braille within the map, representing tactile floor guidelines and destinations without boundaries or other architectural elements. **Type F** is a map in a Justice Court in *Cruz Alta*, produced with 3D-printed colored and textured shapes, lettering and braille, with descriptions in captions, depicting boundaries and partitions of two building floors, guidelines along walls, destinations and other architectural elements such as elevator, stairs and doors. And **Type G** are tactile maps from 2016 Paralympic venues in Rio de Janeiro, made of textured lines, symbols, lettering and braille, within maps and captions, representing tactile floor guidelines, elevators, stairs, seating and ramps, but no spatial boundaries.

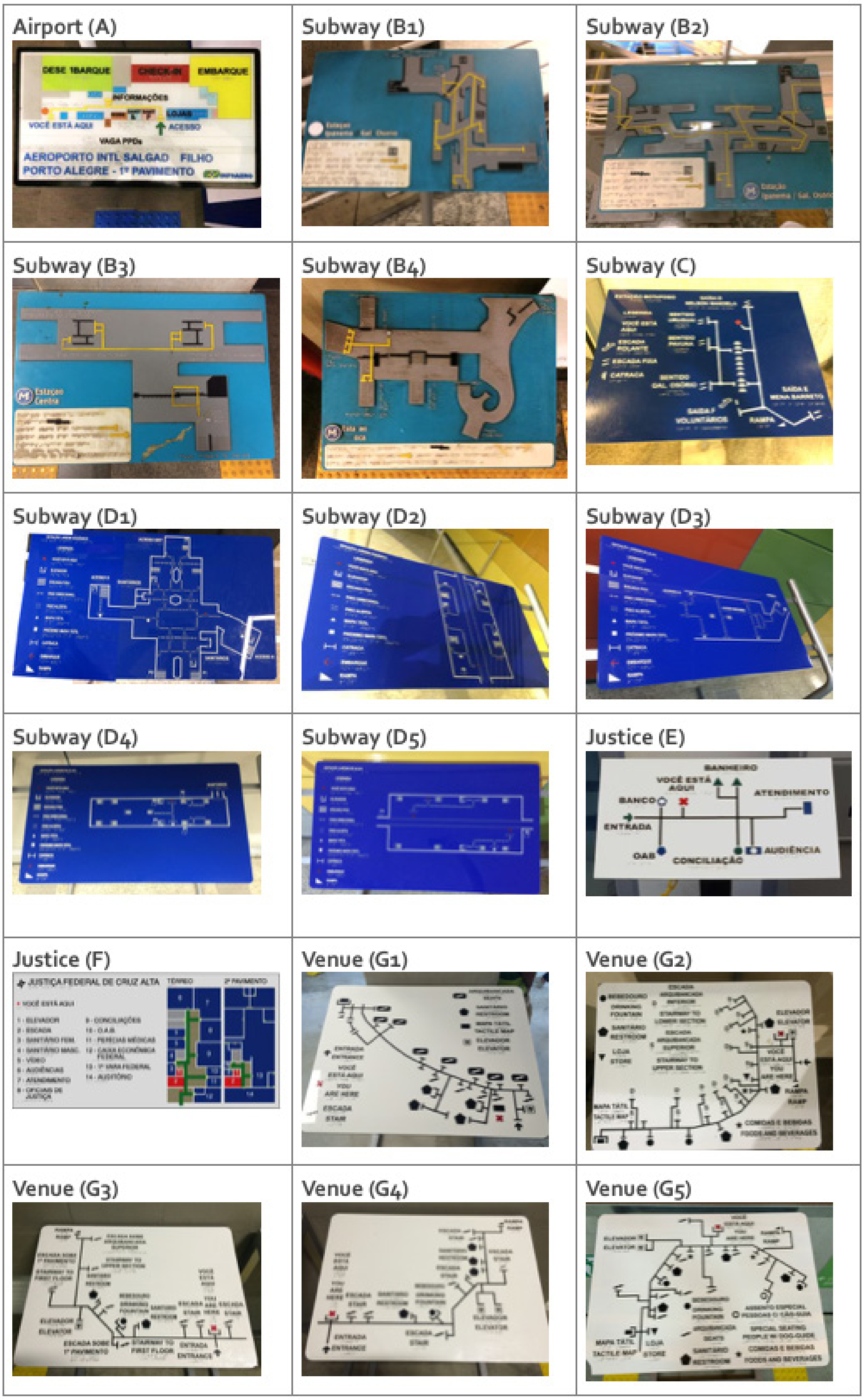

Figure 1 - Sample of tactile maps installed in airports, subway stations, justice courts and paralympic venues

In order to investigate how different types of tactile maps might relate to key aspects of wayfinding and cognitive mapping by visually impaired people, this study was based in the following method. First the configuration of the environment described in each chosen tactile map was drafted as an axial map, to be computed using space syntax software *Mindwalk* [1] . The syntactical properties of the axial maps were then considered so as to evaluate the intelligibility of each environment, correlating local and global syntactical properties in two ways. The first value for intelligibility (I1) was considered as the correlation coefficient (R^2) between the value for connectivity and global integration for each axis, following Space Syntax method. The second value for intelligibility (I2) was the correlation between the global depth of each axis and its depth from the axis containing the map (R^2). This coefficient represents how close the map is located to the core of the system and therefore how easy or difficult it would be to navigate from that point to any other destination within the setting. These two coefficients were multiplied, resulting in an INTELLIGIBILITY value varying in a scale from zero, for poorly intelligible situations, to one, corresponding to highly intelligible environments and map locations.

Second the map ORIENTATION was analysed, both in relation to the environment and to overall wayfinding directions departing from the location from the map. The difficulty or the ease of use of the map was evaluated by attributing numerical values from 0,5 to 1 to the following situations. When the map was aligned to the environment it was graded one (1). When the map was not aligned, demanding mental rotations for route planning or recalling, it scored only half point (0,5). Regarding overall navigation courses from the map, forward wayfinding was evaluated as one (1), sideways graded intermediately (0,75) and backward navigation was graded half a point (0,5). Both values were then multiplied, resulting in a scalar value for the complexity related to map and space orientation.

Third the REPRESENTATION of crucial spatial information in the maps was analysed, once again grading in a scale from half a point for more complex situations to one point for easier ones. The maps scored one (1) when constructed boundaries or partitions were depicted and half a point (0,5) when not. Concerning guidelines, the presence of continuous paved tactile guidelines or reference walls was evaluated as one (1), and discontinued or partial guidelines were graded lower (0,75). And the overall complexity of the maps, represented by the number of segments from the corresponding axial maps, was graded one (1) for fewer segments and half point (0,5) for larger systems. Finally the results for each group of features were multiplied, resulting in a scalar numerical value for the relative complexity or FACILITY of use attributed to each tactile map. The results were compared and discussed, with regard to present literature and further studies.

3. RESULTS

The results for seven chosen maps were the following. The tactile map in Airport (A) depicts a rather simple spatial configuration. Whereas connectivity was highly correlated to global integration (R^2=1,00), global segment depth and map depth were poorly correlated (R^2=0,29), with a low resulting intelligibility (0,29). The map is rotated in relation to the terminal, and destinations are along a continuous hallway but backwards from the map, resulting in a very low degree for orientation (0,25). The map represents constructed boundaries and partitions and there are tactile paved guidelines connecting two entrances and the information booth, without further references to guide to other destinations within the building. The spatial configuration corresponds to very few axes, with a relatively high result for representation (0,75). Considering all features together, the overall facility of use was very low (0,05), chiefly because of the complexity determined by the location and orientation of the tactile map.

1 *Mindwalk* is a registered software by Lucas Figueiredo de Medeiros, Copyright © 2002-2005

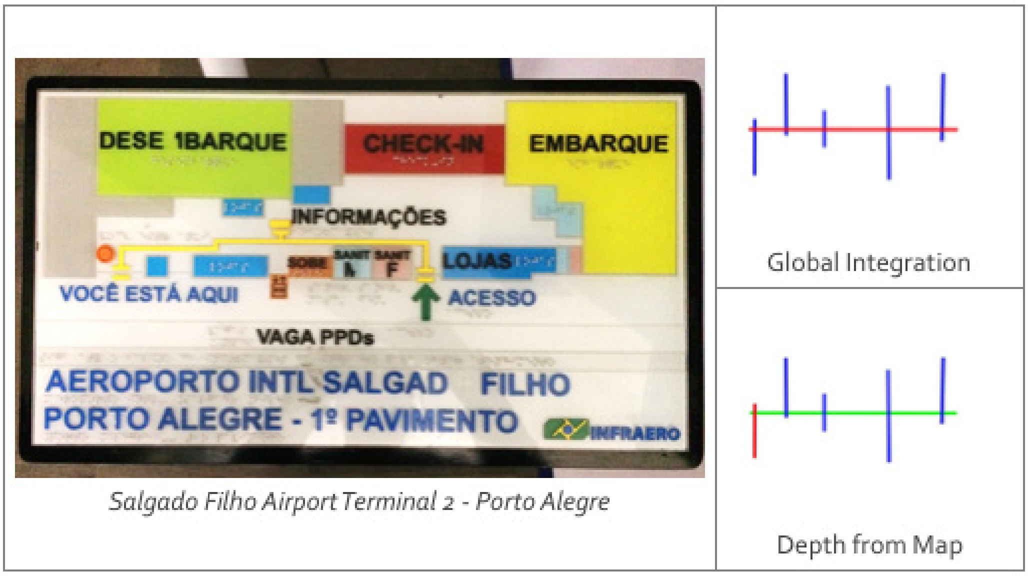

Figure 2 - Results for tactile map in Airport (A)

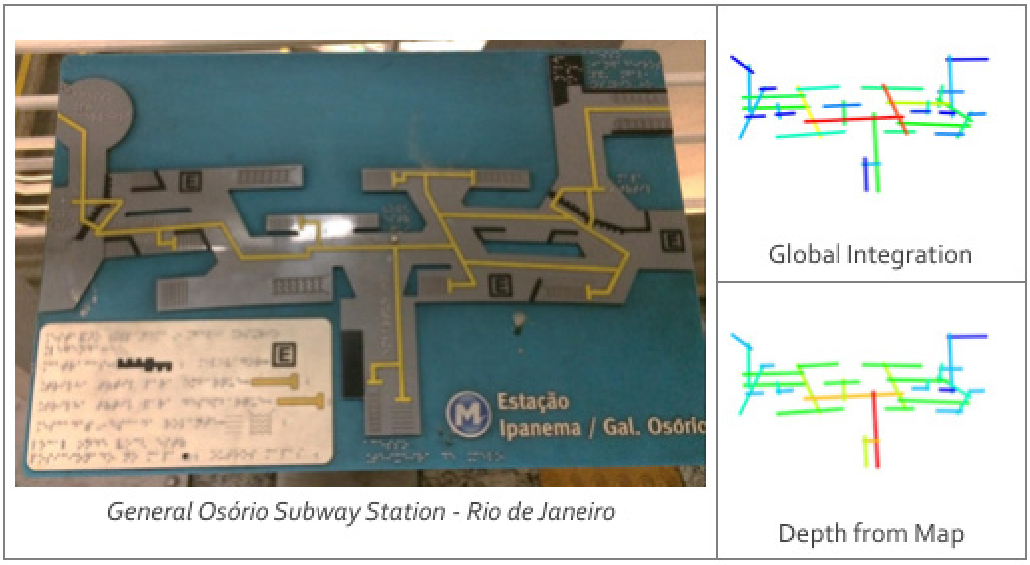

Figure 3 - Results for tactile map in Subway (B2)

The tactile map in **Subway (B2)** represents a more complex environment, representing the distribution level of the station, with several axes, loops and destinations. The intelligibility of the system is relatively high (0,65), because of good correlations for both connectivity with global integration (R^2=71) and global segment depth with map depth (R^2=0,92). The map is aligned with the station and located close to its centre, with destinations to both sides, which corresponded to a regular degree in orientation (0,75). The map includes boundaries, such as walls and parapets, and tactile paved guidelines along the station. However, the complexity related to the large number of segments resulted in a low degree for representation (0,5). Computing all features together, the overall facility of use was regular (0,25), especially in comparison to map A.

The tactile map in **Subway C** is relatively simple, showing the control level in one side of a station, with ten axes forming one loop. The correlation between connectivity and global integration is high (R^2=0,89), but poor between global segment depth and depth from map

(R^2=0,43), resulting in low intelligibility (0,38). The map is aligned to the built environment, but destinations are backwards to the reader of the map, which resulted in a poor score for orientation (0,50). Regarding representation, the map depicts no constructed boundaries, only continuous tactile paved guidelines to all possible destinations and few segments, resulting in a poor degree for representation as well (0,50). The result for the overall facility was low (0,10), indicating prevailing complexity in map use.

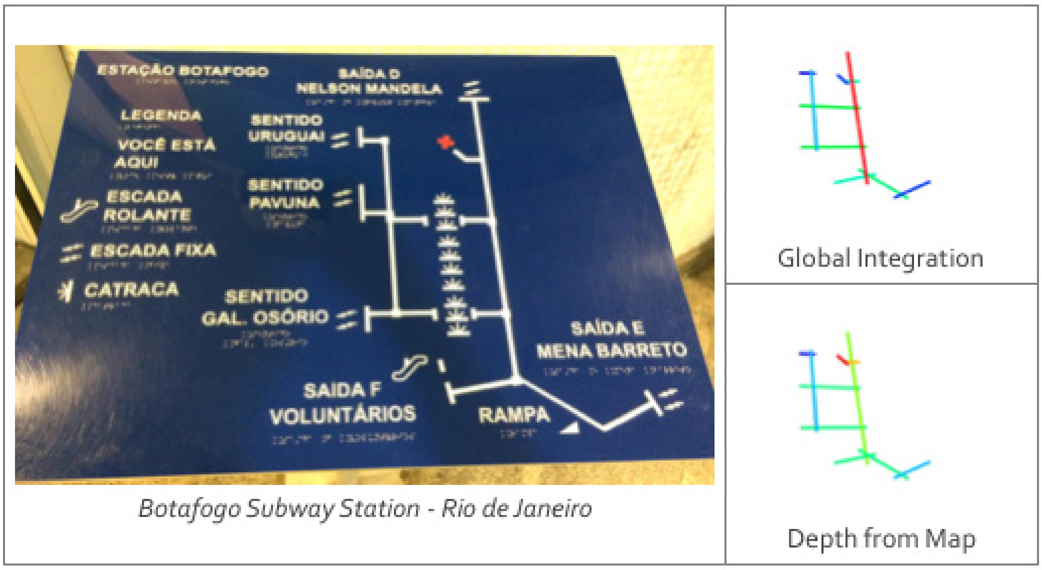

Figure 4 - Results for tactile map in Subway (C)

The third tactile map in **Subway (D1)** represents the main control and connection level from a larger station, corresponding to many axes and loops. The intelligibility of the system is poor (0,37), due to both correlations between connectivity and global integration (R^2=55) and global depth and map depth (R^2=67). The map is correctly aligned to the actual environment, but destinations are to the side and back of the map reader, which resulted in an intermediate value for orientation (0,75). The spatial boundaries from the station are represented, including walls and parapets along voids and stairs. The tactile paving is very detailed in the map, showing both directional and warning tiles; however the guidelines on the floor are discontinued, when reference follows along walls and parapets. The system has also many segments, with a low result for representation (0,38). Considering the complexity presented by map orientation and the discontinuity of the guidelines, the overall degree for facility of use was low (0,10).

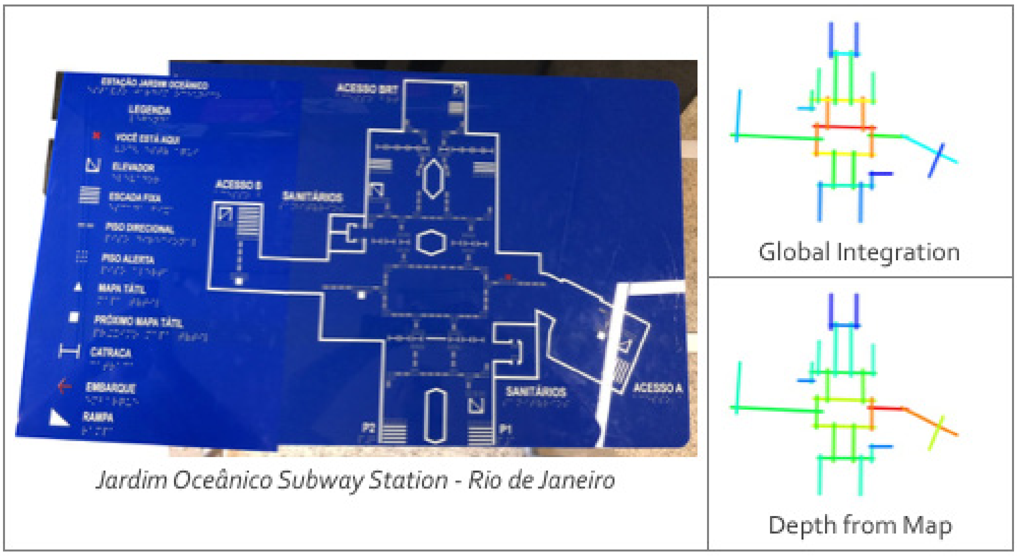

Figure 5 - Results for tactile map in Subway (D1)

The fifth tactile map in **Justice (E)** depicts a very simple environment, with court rooms and units distributed along a unique hallway. The correlation between connectivity and global integration is high (R^2=0,94), and between global depth and depth from map as well (R^2=0,82), resulting in high intelligibility (0,77). The map is aligned to the built environment and destinations are to both sides departing from the map, with an intermediate degree for orientation (0,75). Concerning representation, the map depicts no boundaries or other architectural elements, showing only guidelines that correspond to the continuous tactile directional paving. The system has few segments, resulting in a low degree for representation (0,50). The result for the facility of use was regular (0,29), mainly because of the lack of information on the constructed boundaries.

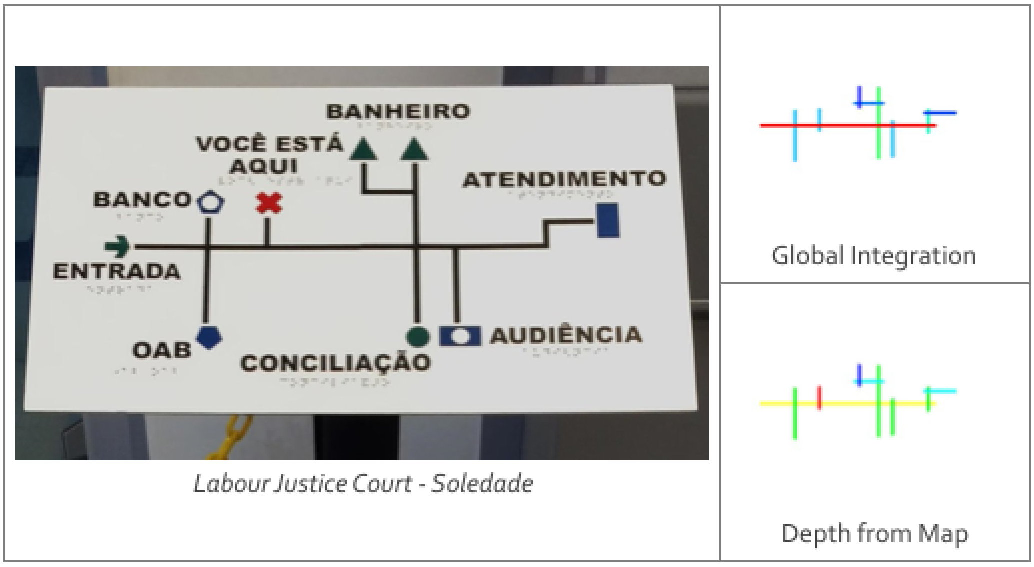

Figure 6 - Results for tactile map in Justice Court (E)

The map from the second court, **Justice (F)**, presents more information, depicting the two main floors from the building with relatively few axes. The intelligibility of the system is regular (0,52), due to both correlations between connectivity and global integration (R^2=78) and global segment depth and map depth (R^2=67). The map is located in the entrance of the building, correctly aligned and with main destinations to the front of the map observer, which scored a high degree for orientation (1,00). The map represents the boundaries of the spaces, including partitions and doors of the rooms. There are continuous guidelines in the map, corresponding to reference walls along the main hallway. The system has few segments, scoring a high degree for representation as well (1,00). Computing all features, the overall facility in the use of the map is high, with the best score in the sample (0,52).

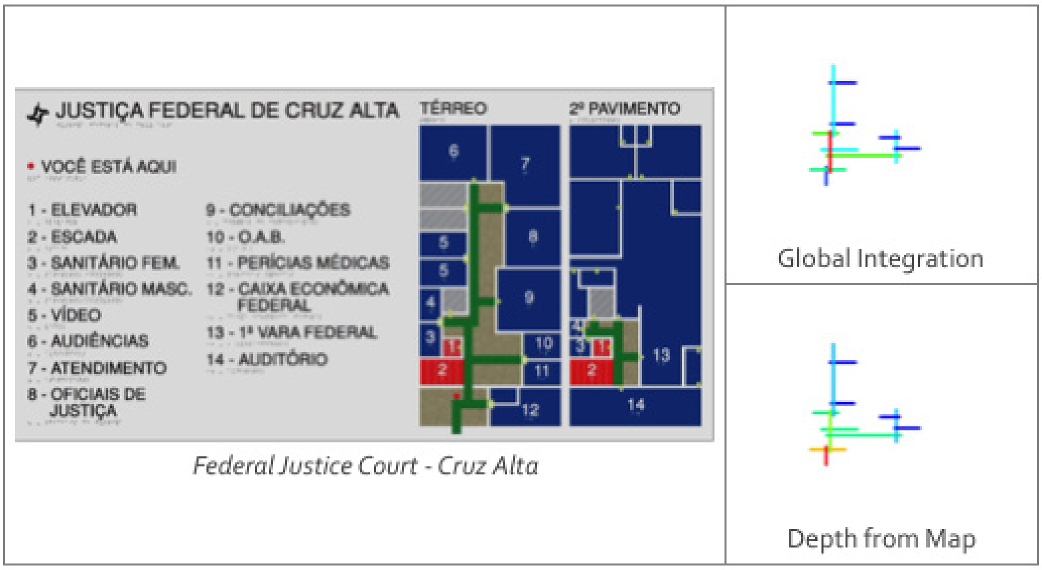

Figure 7 - Results for tactile map in Justice Court (F)

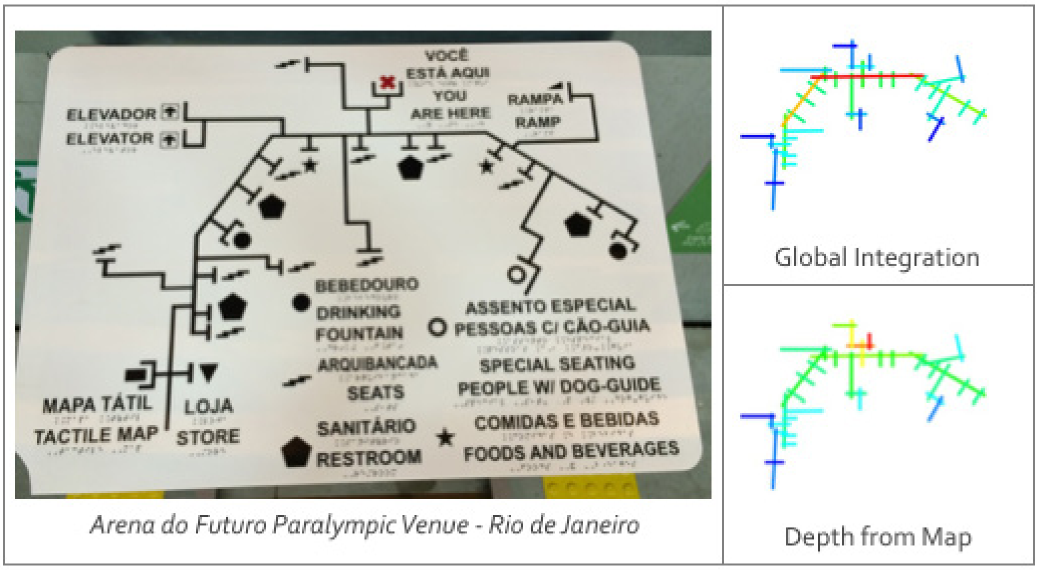

Figure 8 - Results for tactile map in Paralympic Venue (G5)

The last map, from a 2016 Paralympic **Venue (G5)**, shows part of the distribution level inside the arena, corresponding to several axes. The system's intelligibility is low (0,40), with better correlation for connectivity and global integration (R^2=0,72) than for global segment depth and map depth (R^2=57). The map is aligned to the actual building, but all destinations are to the back of the observer, resulting in a poor degree for orientation (0,50). The map represents continuous guidelines paved on the floor, leading to all destinations, but no constructed boundaries such as walls, parapets, thresholds or doors. The complexity of the system is increased by many segments, resulting in a very low score for representation (0,25). The overall facility result for the map is extremely poor (0,05), mainly due to map size, location and lack of boundary information.

In summary, the chosen tactile maps correspond to different types of spaces, floors and buildings, some of them representing the whole building, as in both Justice Courts, or a complete building floor, such as the Airport, and others showing chosen sections of buildings, as in all Subway Stations an Paralympic Venues. Except for the map in the airport, all other maps are correctly aligned to the actual environment, promoting user facility in reading and learning the map. As for wayfinding directions departing from the map, only the map in one of the Justice Courts presented the best situation, which is to have all navigable space towards the front of the map reader. All other maps require some level of mental rotation while reading the map, planning the journey and recalling it later.

MAP	LOCATION	ORIENTATION	BOUNDARY	GUIDELINES	ARCHITECTURAL ELEMENTS	DESTINATIONS	REPRESENTATION	DESCRIPTION
Airport (A)	Salgado Filho, Porto Alegre	Rotated/ Back	Partitions	Partial tactile paving	Walls, elevators, stairs, parking	Exits, information, check-in, boarding, landing, toilets, shops	Colored shapes	Textured lettering and braille in map
Subway (B2)	General Osório, Rio de Janeiro	Aligned/ Front	Continu-ous	Continuous tactile paving	Walls, parapets, elevators, stairs, escalators, turnstiles	Exits, platforms, next tactile maps	Colored tex-tured shapes	Braille only, in map and captions
Subway (C)	Botafogo, Rio de Janeiro	Aligned/ Back	No	Continuous tactile paving	Stairs, escala-tors, turnstiles, ramps	Exits, platforms	Textured symbols	Textured lettering and braille in map and captions
Subway (D1)	Jardim Oceânico, Rio de Janeiro	Aligned/ Side	Continu-ous	Discontinue d tactile paving ans walls	Walls, parapets, elevators, stairs, escalators, turn-stiles, ramps	Exits, platforms, toilets, next tactile maps	Textured symbols	Textured lettering and braille in map and captions
Justice (E)	Justiça do Trabalho, Soledade	Aligned/ Middle	No	Continuous tactile paving	No	Entrance, units, toilets	Textured symbols	Textured lettering and braille in map
Justice (F)	Justiça Federal, Cruz Alta	Aligned/ Front	Partitions	Continuous reference walls	Walls, doors, elevators, stairs	Floors, units, toilets	Colored tex-tured shapes	Textured lettering and braille in captions
Venue (G5)	Arena do Futuro, Rio de Janeiro	Aligned/ Back	No	Continuous tactile paving	Elevators, stairs, seating, ramps	Special seating, toilets, snack bar, drinking fountain, next tactile maps	Textured symbols	Textured lettering and braille in map and captions

Table 1 - Summarized analysis chart for the seven types of tactile map

As for the information depicted in the maps, the constructed boundaries or partitions were represented in four types of maps (Airport, Subway B, D and Justice F), being absent in the other three types (Subway C, Justice E, Venues). All maps presented guidelines for visually impaired users, most of them corresponding to continuous tactile directional paving, one representing continuous reference walls (Justice F) and one type of map combining tactile floor guidelines and reference walls and parapets (Subway D). Most types of maps used textured symbols and captions to represent architectural elements and destinations, while three types used textured and colored shapes instead of symbols (Airport, Subway B and Justice F). The descriptions of the elements was made in braille and textured lettering in all types of maps, except for one which used braille only (Subway B), hampering the use of the map by visually impaired or sighted persons without the ability of reading braille. Most maps included descriptions within the area representing the building, combined with symbols and captions, except for one map (Justice F), which presented the descriptions through numbered captions at the side of the architectural representation.

Summarizing the syntactical and numerical analysis, the tactile maps combined more or less intelligibility and complexity related to map orientation and space representation. The worst evaluated maps (Airport and Venue) presented poor results concerning intelligibility, even though the first one had the best correlation for global connectivity and integration, which was due to the small size of the system, with all axes directly connected to one main axis and a maximum global depth of only one step. While the first map had the worst degree for orientation, with a rotated map indicating backwards (Airport), the last one combined a poor representation of a very large building section, with many possible directions and routes (Venue). On the other hand the best evaluated map (Justice F) has relatively low intelligibility in terms of space configuration and map location, but this is compensated by the orientation from the map, the availability of spatial information concerning boundaries and guidelines, together with the relative simplicity of the map, with few axis corresponding to wayfinding directions and decision points within the building.

MAP	I1 (GLOBAL INTEGRATION X C ONNECTI VI TY)	I2 (GLOBAL DEPTH X DEPTH FROM MAP)	INTELLIGIBILITY (I1xI2)	MAP ALIGNMENT	WAYFINDING DIREC- TION	ORIENTATI ON	BOUNDARIES	GUIDELINES	SEGMENTS	REPRESENT ATION	OVERALL FACILITY
Airport (A)	1,00	0,29	0,29	0,40	0,50	0,25	1,00	0,75	1,00	0,75	0,05
Subway (B2)	0,71	0,29	0,65	1,00	0,50	0,75	1,00	1,00	0,50	0,50	0,25
Subway (C)	0,89	0,43	0,38	1,00	0,50	0,50	0,50	1,00	1,00	0,50	0,10
Subway (D1)	0,55	0,67	0,37	1,00	0,75	0,75	1,00	0,75	0,50	0,38	0,10
Justice (E)	0,94	0,82	0,77	1,00	0,75	0,75	0,50	0,75	1,00	0,50	0,29
Justice (F)	0,78	0,67	0,52	1,00	1,00	1,00	0,50	1,00	1,00	1,00	0,52
Venue (G5)	0,78	0,57	0,40	1,00	1,00	0,50	0,50	1,00	0,50	0,25	0,05

Table 2 - Numerical results for intelligibility, orientation, representation and overall facility in use of the tactile maps

Table 1 - Summarized analysis chart for the seven types of tactile map

4. CONCLUSIONS

Resuming universal design principles, the use of tactile maps should be simple, intuitive and equitable for all users, including congenitally or adventitiously blind people, persons with some residual vision or sighted ones, and also people with cognitive and mental disabilities. Nevertheless, the results from this study showed that most of the maps in the sample presented a significant level of complexity, besides the intelligibility of the spatial configuration of each building itself.

The cognitive tasks required for the use of the tactile maps include the understanding of symbols and captions and the recognition and mental representation of spatial patterns and organizational principles. Additional complexity was related to map rotation, orientation and size, the representation and description of guidelines, boundaries and other key elements. These aspects should be more carefully regarded in the design and installation of tactile maps, especially considering the particularities of visually impaired people and their inherent difficulty in cognitive tasks such as wayfinding and learning new built environments.

The study has shown how Space Syntax research may contribute to the analysis and design of more simple and easy to use tactile maps. Further studies might investigate the actual use of different types of tactile maps by visually impaired and sighted users, analysing the contribution of each feature to the overall complexity of the maps. These findings may enhance the empirical knowledge on spatial cognition using tactile maps, contributing for the design and implementation of more effective information dedicated to visually impaired people, eventually promoting the accessibility of buildings and cities.

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