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Using the Spatial Knowledge of Map Users to Personalize City Maps: A Case Study with Tourists in Madrid, Spain

María-Teresa Manrique-Sancho [1,*], Silvania Avelar [2], Teresa Iturrioz-Aguirre [1] and Miguel-Ángel Manso-Callejo [1]

1 Department of Surveying and Cartography Engineering, Universidad Politécnica de Madrid, 28040 Madrid, Spain; teresa.iturrioz@upm.es (T.I.-A.); m.manso@upm.es (M.-Á.M.-C.);
2 Geological Institute, ETH Zurich, 8092 Zurich, Switzerland; silvania.avelar@erdw.ethz.ch
* Correspondence: mariateresa.manrique@upm.es

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Abstract: The aim of personalized maps is to help individual users to read maps and focus on the most task-relevant information. Several approaches have been suggested to develop personalized maps for cities, but few consider the spatial knowledge of its users. We propose the design of "cognitively-aware" personalized maps, which take into account the previous experience of users in the city and how the urban space is configured in their minds. Our aim is to facilitate users' mental links between maps and city places, stimulating users to recall features of the urban space and to assimilate new spatial knowledge. To achieve this goal, we propose the personalization of maps through a map design process based on user modeling and on inferring personalization guidelines from hand-drawn sketches of urban spaces. We applied this process in an experiment with tourists in Madrid, Spain. We categorized the participants into three types of tourists—"Guided", "Explorer", and "Conditioned"—according to individual and contextual factors that can influence their spatial knowledge of the city. We also extracted design guidelines from tourists' sketches and developed map prototypes. The empirical results seem to be promising for developing personalized city maps that could be produced on-the-fly in the future.

Keywords: personalized maps; spatial knowledge; cognitive maps; user modeling; map design; travel experience

1. Introduction

The amount of information about urban spaces increases daily. Recent developments in technology, such as data-mining, big data, and "smart city" infrastructure, can supply meaningful information with which to provide personalized city maps on-the-fly for a variety of devices [1]. Personalized city maps can be used to support emergency situations [2,3], improve daily journeys [4], enhance accessibility to urban environments for people with disabilities [5], and supply better information to tourists [6], among others.

The main approaches used to personalize maps are by recommendation and adaptation [1,7]. The personalization of maps by recommendation considers the needs and preferences of individual users in relation to location, distance, cost, time, weather, and transport, which can appear on the map as specific places, layers of information, and itineraries [8–10]. The personalization of maps by adaptation changes components of the map, offering relevant information at the right time and place, considering the context of use and user type [11–13]. The context of use can be determined by the user's needs and interests, the spatial task (e.g., exploring an area, searching for locations), the environment in which the map is used (e.g., location, time, device), and the map itself (e.g., device constraints, design strategies) [14]. The components of the map that can be adapted are geo-information (e.g., level of generalization), the user interface (e.g., access to functionalities or interaction with the map), and content visualization (e.g., orientation, scale, colors, symbolization, focus on area of interest) [15]. Reichenbacher [16] points out that changes in the symbolization are a powerful adaptation method. Nivala and Sarjakoski [17] tested different adaptive options and concluded that contrast enhancement, color highlighting, resizing of symbols, and halo effects were also suitable techniques. For both personalization approaches, information about individual users is necessary to predict their needs, based on a user model [18–20].

User modeling provides a framework that enables the determination of specific interests or preferences of users to best suit their task requirements [1,20]. Even though effective user types can be inferred from meaningful user data, such as individuals' personality traits and their cognitive effects, personalized maps are still in the early stages of development [1,21].

Our main goal is to personalize maps by adaptation—i.e., to create maps that fulfill specific needs of users in a particular context of use, through user modeling. The premise of this work is that personalized city maps, if designed considering the cognitive characteristics of its users, can help users to reinforce their mental links between maps and places in the city. Two research questions are raised with regard to the design of cognitively-aware personalized maps: (1) How to identify types of map users based on the spatial knowledge and behavior of users? (2) How can design guidelines be determined to personalize maps based on users' sketches?

To answer these questions, we proposed a design process with an innovative approach to modeling map users, and to identifying guidelines to personalize maps. We apply this process to a case study in tourism. This was a pioneering experiment for the purposes of personalizing city maps, based on investigating the spatial knowledge of tourists and their performance when completing spatial tasks.

Cognitive Maps, Sketches, and Spatial Knowledge

People perceive their environment based upon subjective experiences that are reflected in their cognitive maps. Cognitive maps are mental representations which contain objects that emerge from an idiosyncratic experience when people interact with a spatial environment or when they solve a spatial problem [22]. These distorted diagrammatic representations act as a link between the real world and people's spatial behavior [22]. Cognitive maps have been studied in different areas to understand the concepts of wayfinding, orientation, and spatial decision-making [23–29]. Many of these studies use analysis of textual descriptions and graphical sketches as methods. As sketches closely mimic the way in which we mentally store information about our physical environment [30,31], just like Downs and Stea [32], we will use the terms "sketches" and "cognitive maps" interchangeably.

To date, very few attempts have been made to incorporate information from people's cognitive maps into the actual design of maps. Roth et al. [33] emphasized the opportunities for research in cartography, as "the possibility of digital interactivity requires us to re-envision map readers as the map users, and to address perceptual, cognitive, cultural and practical considerations that influence users' experience with interactive maps". Caquard [34] suggested that research on empirical cognitive maps could help to enhance the mental relationship between users and maps, as well as with places through maps. Hirtle and Raubal [35] point out that users perceive their environment differently, and that these differences should be reflected on their maps. Klippel et al. [36] suggest that incorporating mental images of geographical spaces into map design could improve the cartographic interfaces of communicating devices. However, neither of them actually proposed a map design process based upon their approaches.

Cognitive maps vary from one person to another. However, specific features can be common to certain groups of people [25,37,38]. In a study on how people perceived, understood, and organized spatial information, Lynch [23] found there were five elements in cognitive maps: paths, landmarks, nodes (or anchor points, when geographical features are structured around them), edges (boundaries), and districts. The way in which spatial knowledge is organized in a reference system also differs in cognitive maps. Moore [39–42] proposed three types of reference systems: egocentric, differentiated, and coordinated (Figure 1). Other researchers defined only two types of reference systems: egocentric (as per Moore [39]), and another one called environmental, geocentric, or allocentric, depending on the author [43–45]. Moore's differentiated reference system considers the presence of anchor points, which are ignored in the other proposals.

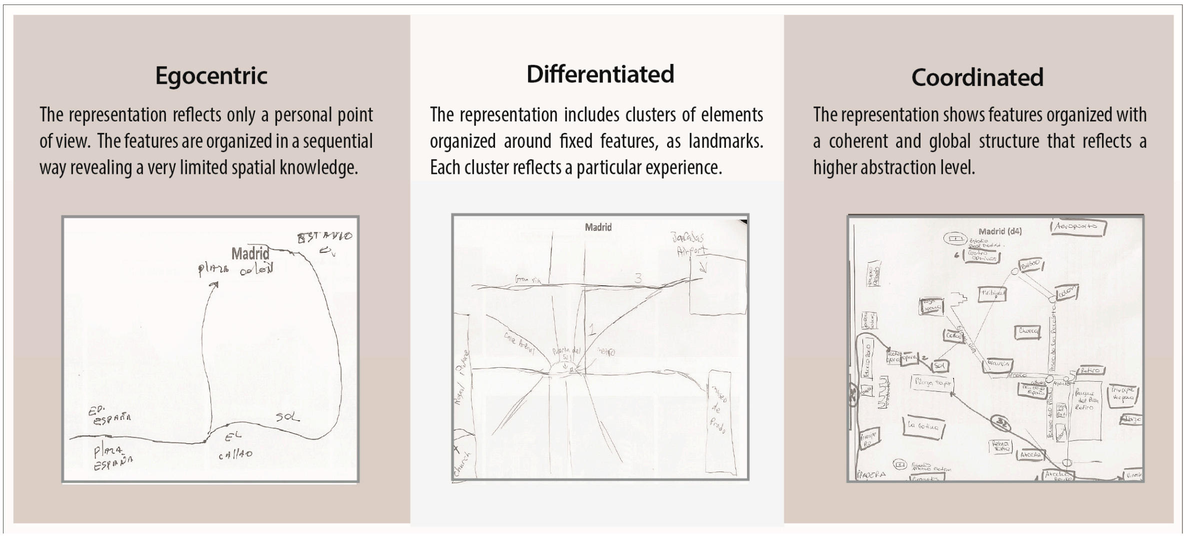


Figure 1. The three reference systems of cognitive maps, as defined by Moore [33] and identified in the sketches drawn by tourists of Madrid.

Many studies identified the factors which influenced people's spatial knowledge of cities. Individual factors include age, gender, education level, place of origin, interests, economic status, previous experience in large urban spaces and in using maps [24,46–49]. Contextual factors include motivation, the people involved, information consulted, time spent in the city, accommodation location, city layout, and the urban infrastructure available [50–52]. Despite the large number of factors affecting spatial knowledge, studies on users in cartography usually only consider two factors—gender and age [53]. Other fields, such as tourism, study users more intensively by considering the historical, geographical, sociological, psychological, economic, anthropological, and environmental factors in their products, which can be personalized according to users' values, motivations, lifestyle, beliefs, behavior, attitudes, or needs [54–56]. However, the design of tourist maps aiming to help link tasks to tourists' spatial knowledge remains subject to research [57].

Our aim is to facilitate map users' mental links between maps and places. We propose to define map user types through user modeling, which will be based on the analysis and synthesis of individual and contextual factors that affect the spatial knowledge of users. We also analyze features and systems of reference in the sketches drawn by map users to extract design guidelines for personalizing maps.

2. Materials and Methods

2.1. The Design of Cognitively Aware Personalized Maps

Our personalized map design process associates a user with a spatial task in an urban space and with a map. Spatial tasks included the exploration of an area, navigation, and information retrieval of nearby places. To perform the user modeling, we gathered data from users and synthesized them through analysis, pattern identification, and meaning assignment. This resulted in the identification of different user types, as well as in the definition of design guidelines for the personalization of maps (Figure 2).

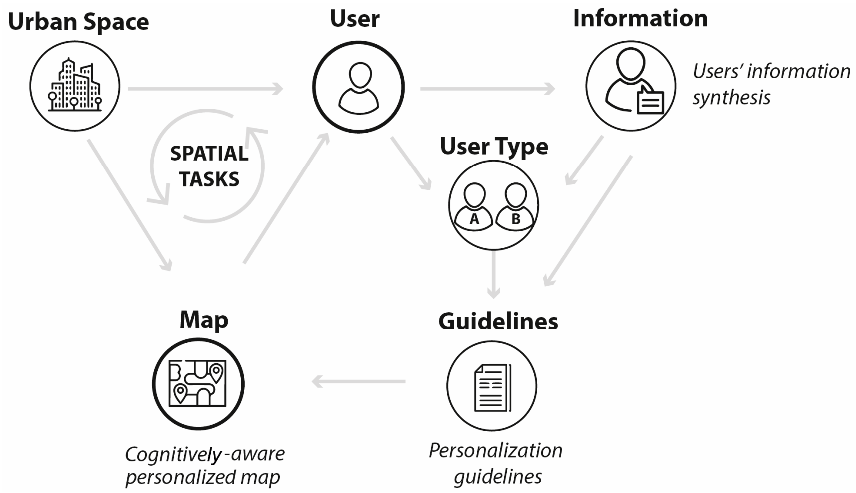


Figure 2. The conceptual framework to developing cognitively aware personalized maps.

The design process consisted of six steps:

1. Identification of factors affecting spatial knowledge: Identifying individual and contextual factors that could influence the spatial knowledge of map users.
2. Data collection: Gathering data about the factors affecting users' spatial knowledge, including their hand-drawn sketches.
3. General analysis of sketches: Analyzing the sketches drawn by users and identifying the elements most used to represent the urban space, as well as particularities in the content of their drawings.
4. Identification of user types: Analyzing data about factors affecting the spatial knowledge of participants to make choices about the parameters for user modeling. This analysis enables an understanding of how map users perform their spatial tasks and how they reflect on their cognitive maps. The result is the identification of different types of users and the factors necessary to categorize them.
5. Identification of patterns: Describing the sketches of users by user type, the average number of features, types of features, and reference systems applied. The evolution of these characteristics over time is also considered.
6. Definition of design guidelines: Top-down extraction of guidelines to design personalized maps, covering three levels: (1) for all maps; (2) for user types; and (3) for individual maps.

2.2. Case Study: Personalizing City Maps for Tourists in Madrid, Spain

Tourism is a subjective experience determined by the motivation, preferences, and interests of the tourists. It also depends on the attributes of the destination, activities to be undertaken, map products available, and the context in which maps are used. Our experiment was conducted over a four-month period with tourists in Madrid.

2.2.1. Participants

We selected foreign tourists visiting Madrid for the first time (unconditioned by previous visits) and staying for at least two days. 47 volunteer tourists took part in our study. All participants completed a questionnaire, which also included "thinking aloud" observations. In addition, 6 of the 47 participants submitted diaries.

2.2.2. Materials

- Questionnaire: We prepared a questionnaire to be completed just before the tourists left Madrid, asking for information about (1) individual factors: age, gender, education, place of origin, previous experience of visiting big cities, experience using maps, and their interest in the city; and (2) contextual factors: travel motivation, travel group, means of transport used, location of accommodation, and length of stay. We also requested information using open-ended questions, such as which places they had visited in the city, and asked them to draw a map of Madrid.
- "Thinking-aloud" notes and observations: we encouraged tourists to verbalize their thoughts while completing the questionnaire, and observed them, taking notes such as: "The man travels with a woman. The woman starts to complete the questionnaire, but when the questions about city attractions and locations started, she says it is better that he answers that, because he used the maps, so he knows the names and locations better." This kind of information complemented the questionnaire data and gave us new clues for interpreting them.
- Travel diaries: We asked 6 participants to register daily any information that could influence their spatial knowledge of the city, such as the maps consulted, transport used, Points Of Interests (POIs) visited, and the situations in which they felt disoriented. Tourists registered their information using a mobile phone and/or paper notes. These diaries allowed us to monitor tourists so as to understand their motivations, needs, preferences, interests, aptitude, and constraints while performing spatial tasks in the city.
- Maps: We offered various maps of the city upon arrival to the participants that wrote diaries. Furthermore, all participants were asked to sketch maps of Madrid.

2.2.3. Procedure

Most participants of the survey were approached within the airport's departure area and in the train between the city center and the airport. Tourists answered the questionnaire for around 15 min, which included to make a hand-drawn sketch of Madrid, showing tourist attractions, main streets, zones of interest, the indication of the north, the location of the airport and their accommodation, and the transportation routes or stops they knew. Figure 3 shows an example of such a sketch.

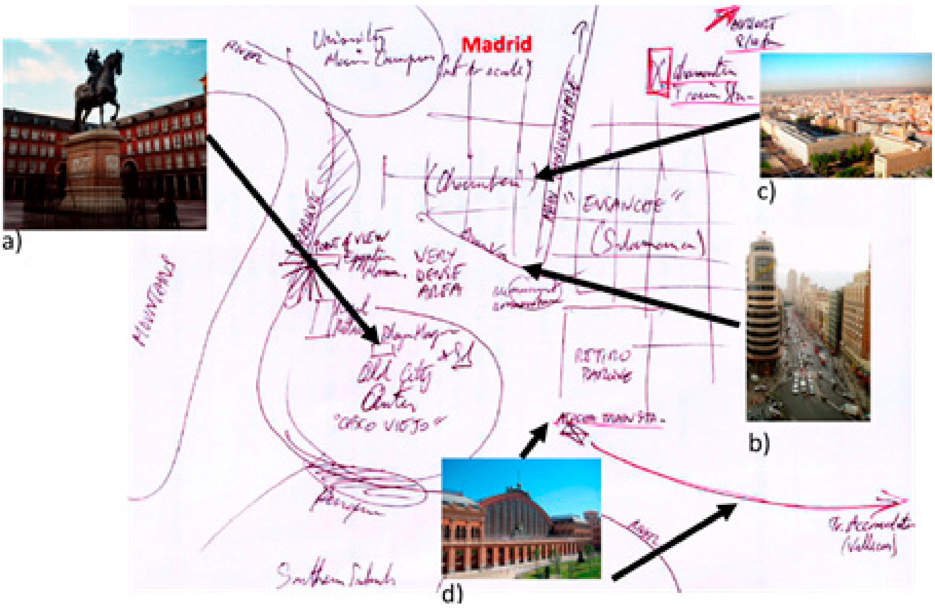


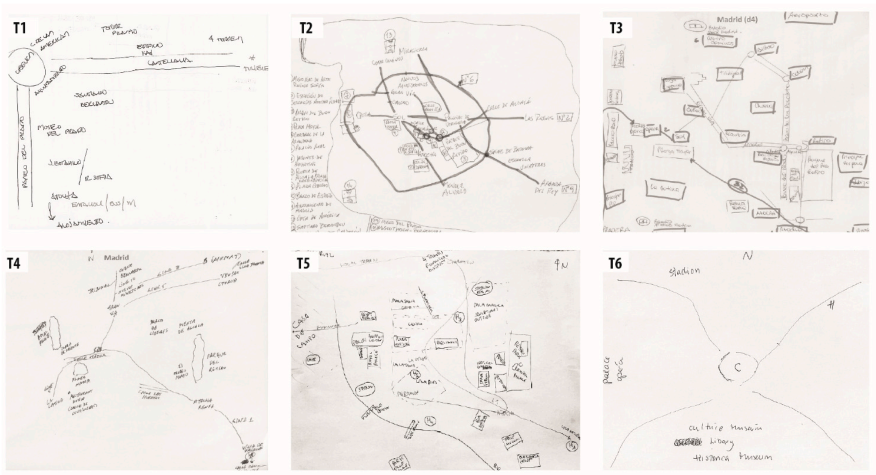
Figure 3. Sketch of Madrid drawn by a tourist. It shows: (**a**) Plaza Mayor; (**b**) Gran Vía street; (**c**) Chamberí zone; and (**d**) the Atocha train station and subway.

For writing diaries, we recruited 6 tourists before they travelled to Madrid. The selection of participants considered their travel motivation, length of stay, and travel group (Table 1). The selected tourists completed the questionnaire and delivered a hand-drawn sketch of Madrid when they arrived in the city, and another one before they left. They also supplied information on a daily basis about their travel experiences. Additionally, 2 tourists, who stayed longer than ten days, also drew a sketch map in the middle of their visit (tourists T4 and T5 in Table 1).

Table 1. Individual and contextual factors, profile, and final sketch of tourists who wrote diaries.

Tourist	Origin, Age, Gender	Stay (days)	Travel Motiv.	Travel Group	Transport Used	Profile
T1	Mexico, 39, female	8	work	alone	on foot, taxi, tourist bus	Professional travelling alone for work (congress). She visited the city in her spare time guided by local friends. She also joined a tourist tour by bus provided by the congress organization.
T2	Argentina, 30, male	4	holiday	couple	on foot, metro	Young couple with much experience travelling in South America together and on their own. They planned together the places to visit before they arrived, but also included spontaneous activities during their stay. They shared spatial tasks.
T3	Argentina, 25, female					
T4	UK, 34, male	6	work	alone	on foot, metro	Executive with large experience travelling alone. He came for a work course but also visited the city, looking for direct contact with the local culture. When his classes finished, he visited Madrid with colleagues, guiding them.
T5	Denmark, 49, male	12	holiday	couple	mainly on foot	Professional with extensive travel experience, accompanied by his wife. He guided his wife, performing all spatial tasks. He looked for direct contact with local people, avoiding touristic places.
T6	Denmark, 52, female					Housewife, always travels with her partner. She was guided by him throughout the trip and depended on him to get information and make spatial decisions.

Final sketch



3. Results

The spatial knowledge of tourists was reflected in their written answers and hand-drawn sketches. We analyzed the sketches using three categories, based on Lynch's elements [23]: points (e.g., touristic points, transportation stops); hubs (e.g., streets, transport lines); and zones (e.g., city areas). The map in Figure 4 presents the most frequent features identified by tourists, showing the collective conception of Madrid. The size of the circles and lines reflects the number of times the feature appeared in their answers or sketches. Except for Gran Vía hub, the most frequently-mentioned features were POIs: Puerta del Sol, Plaza Mayor, Palacio Real, and Parque del Retiro. The number of zones written or drawn were minimal.

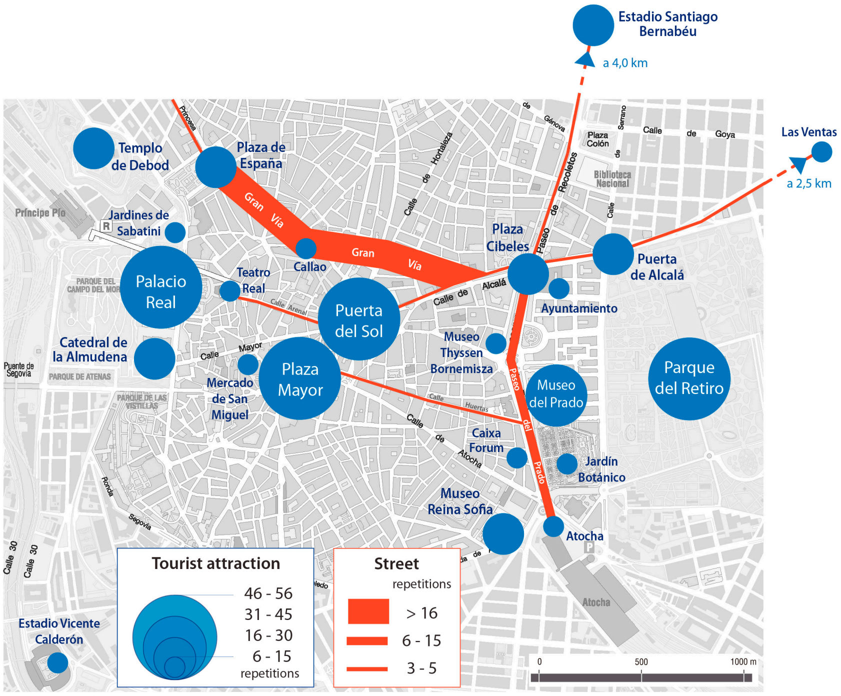
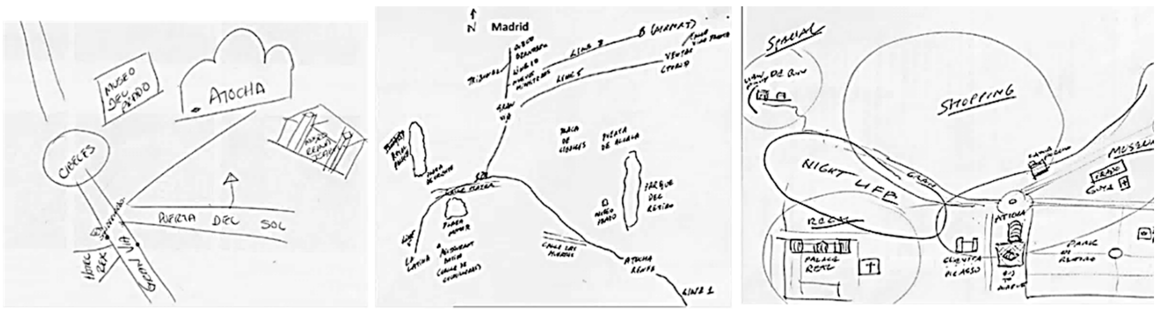


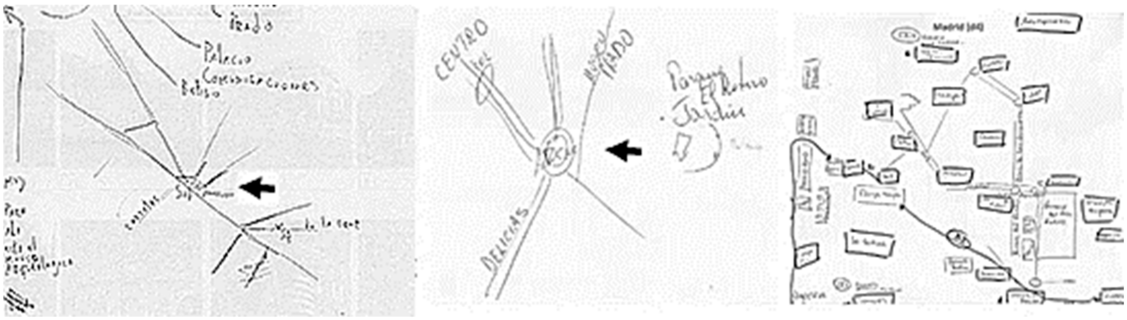
Figure 4. Collective conception of Madrid, with the features most frequently identified by tourists.

Among the particularities observed in the sketches of all participants, there were POIs with distinctive architecture represented in 2D and 2.5D (Figure 5a), and POIs structured around metro lines (Figure 5b) and zones associated with shops, museums, and bars/restaurants (Figure 5c). For anchor points, some sketches were structured around a POI close to the tourist's accommodation (Figure 6a) or around the most frequently used transport stops (Figure 6b). However, some sketches did not feature any anchor points at all (Figure 6c).



(**a**) (**b**) (**c**)

Figure 5. Features portrayed in the sketches: (**a**) POIs in 2D (Atocha train station) and 2.5D (Reina Sofía museum); (**b**) POIs structured around the metro lines; (**c**) zones related to spatial tasks.



(**a**) (**b**) (**c**)

Figure 6. Different anchor points in the sketches: (**a**) POI close to the tourist's accommodation; (**b**) the most-used public transport stop; (**c**) no anchor point.

We compared the answers of the questionnaire with their respective sketches to identify the most relevant factors of spatial knowledge, in order to use them as tourist modeling parameters. We observed that conventional individual factors, such as age and gender, were not reflected in the number and types of features, nor in the reference system used in the sketches. The same occurred with other individual factors, such as previous experience of visiting cities, level of education, and place of origin. However, several contextual factors had a meaningful occurrence in the sketches, including the motivation for the visit and the tourist group. When visits were work-related, tourists drew fewer elements than tourists on holiday for the same length of stay. Tourists traveling in an organized group used the egocentric reference system in their sketches, while tourists traveling alone often used a differentiated or coordinated reference system.

We then analyzed the information in the travel diaries. We noticed that a couple who traveled together under similar travel conditions drew very different maps (see T5 and T6 in Table 1). The map drawn by T5 demonstrated a high spatial abstraction level, with a large number of elements linked through streets and transport lines and grouped in zones. In contrast, T6 drew a basic representation, only illustrating the city center with a circle and a few POIs. This fact disclosed an important aspect that affects the spatial knowledge acquired by tourists—the approach with which the tourist faces the travel experience. We identified three different approaches among the participants: "Guided", "Explorer", and "Conditioned". Guided tourists (such as T6) prefer to let themselves be conducted, while Explorers (such as T5) are spatial decision-makers. Being Guided or being an Explorer could be seen as a person's intrinsic characteristic, but for our design purposes, an Explorer "in nature" would also be considered as Guided if, for example, s/he was visiting a friend in a new city and let her/himself be guided. The Conditioned tourist type applies to users whose travel experiences strongly depend on constraints, such as the time available. For example, T1 and T4 (Table 1) came to Madrid for a work trip, and the small amount of leisure time available to them affected their spatial behavior and cognitive maps. Although Conditioned tourists can behave similarly to the Guided (T1) or Explorer (T4) approach when they visit a city, it was found that their travel experience would mostly be affected by constraints, such as the time they had available after work.

With the knowledge acquired about tourists, we identified the main factors needed to characterize the way they approach their travel experience, which are travel group, transport used, travel motivation, interests, and length of stay. Figure 7 shows a decision diagram describing the relation between these five main factors and the three types of tourists.

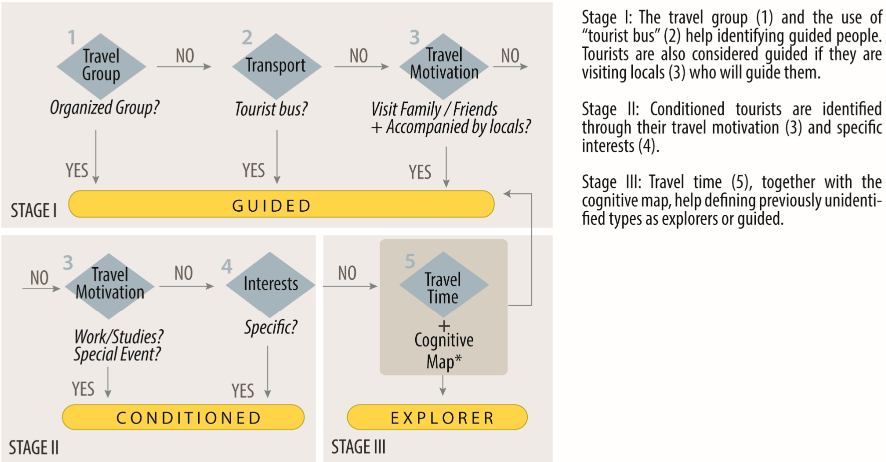


Figure 7. Decision diagram for determining the type of a tourist, according to the five main factors impacting the travel experience.

Using the decision diagram in Figure 7, we identified the types of the 47 participants. We found 13 Explorers (including T2, T3, and T5 of Figure 1), 19 Guided (including T6), and 15 Conditioned participants (including T1 and T4). We next looked for patterns in their sketches, looking for the number of elements in each category (POIs, hubs, zones—Figure 8) and reference system used (egocentric, differentiated, and coordinated, as in Figure 1). The characteristics of tourist types and their sketches can be described as follows:

- Guided: These tourists value simplicity and convenience above all. They do not travel alone and let others guide them, delegating decision-making to another member of their traveling group. Their sketches include few POIs, and hubs (named streets or transport lines) and zones are almost non-existent (Figure 8). The maps reflect isolated perceptions of the city, usually associated with one or two specific travel experiences, e.g., as in a tourist bus tour. The positioning of graphical elements bears little to no resemblance to their real locations (Figure 9).
- Explorer: These tourists are interested in learning about the real essence of the city, finding locations that do not belong to typical tourist attractions, and in fully immersing in the local culture. They travel alone or with others, but never in organized groups, and they walk a lot during their visit and take public transport. Their sketches show an organized structure of the city with a large and varying number of features (Figure 8), with a relatively good resemblance to their real locations, especially compared to the sketches of the other types of tourists (Figure 9).
- Conditioned: The experience of these tourists is characterized by time and/or location constraints, due to work commitments or specific interests, e.g., watching a concert or sporting event. Their behavior can be similar to the Explorers (walking around the city, seeking contact with locals) or to the Guided (visiting the city on a tourist bus). The average number of features in their sketches fall in between the two other types (Figures 8 and 9).

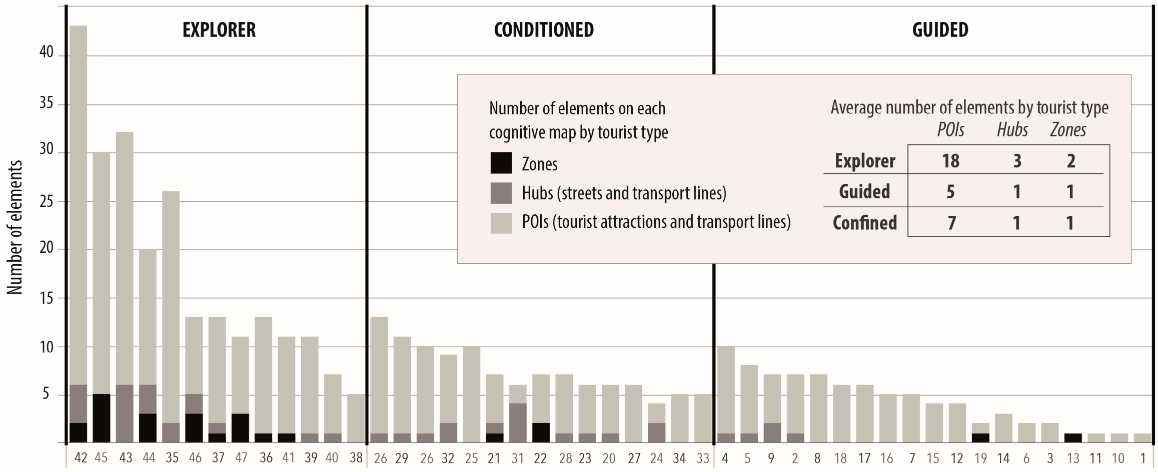


Figure 8. Number of POIs, hubs, and zones in the sketch of each tourist, by tourist type.

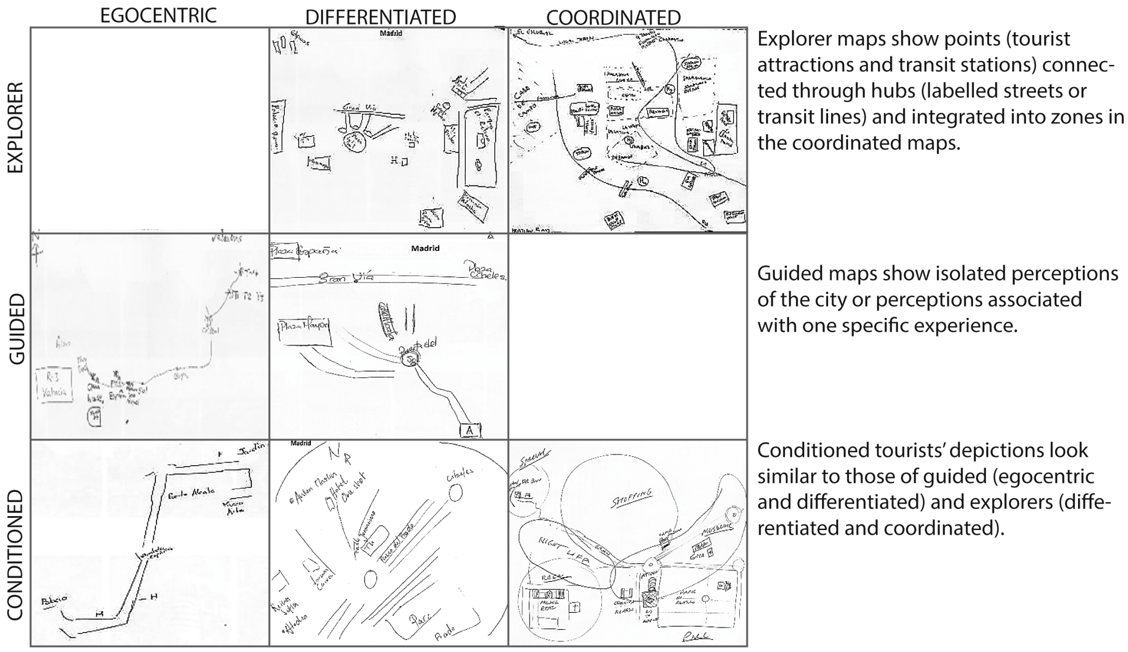


Figure 9. Sketches classified by type of tourist and reference system.

It should be noted that the sketches drawn by the participants who wrote diaries reflected, throughout their stay, a gradual increase in the number of features, whereas the reference system used remained constant, regardless of the tourist type (see Figure 10).

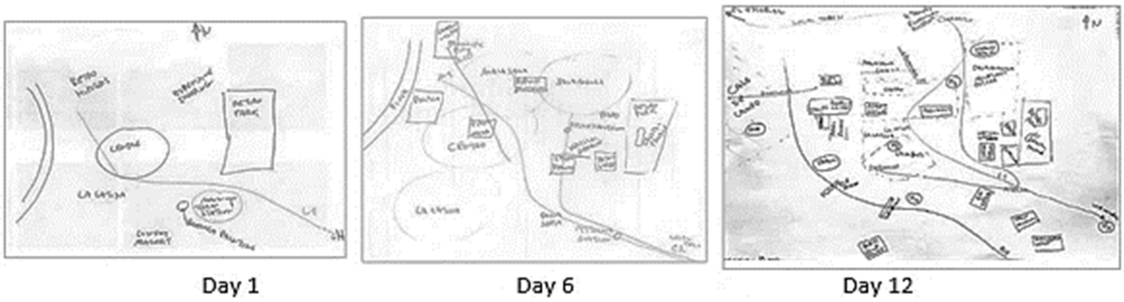


Figure 10. Evolution of sketches of an Explorer tourist throughout the stay (T5 in Figure 4). The number of features is shown to increase, while the coordinated reference system stays the same.

4. Discussion

The empirical results of our case study pave the way for designing cognitively-aware, personalized city maps, which should follow three main guidelines:

1. For all maps: The map content should integrate the main features included in the collective conception that tourists have of Madrid (Figure 4) to help tourists make sense of the city. These features will have customized icons similar to the 2D and 2.5D depictions drawn in the tourists' sketches (Figure 5a).
2. For tourist-type maps: The map content for each tourist type will take into account the average number of features and the most evolved reference system used in the sketches of the respective tourist type, i.e., differentiated for Guided tourists, coordinated for Explorers, and either coordinated or differentiated for Conditioned tourists (Figures 8 and 9).
3. For individual maps: The map content will gradually integrate new features as the tourist accomplishes spatial tasks. This guideline is to ensure the function of the map as an interface between the tourist and the city, in coherence with the evolution of tourists' sketches through time (Figure 10). Key POIs for the experience of the tourist will be added to the map. They include those where the tourist stayed longer or visited more than once, as well as POIs evaluated especially positively or photographed profusely. Similarly, the transport lines and city zones most relevant to the tourist's experience will also be included in the map (Figure 5b,c). Each tourist map will be a unique "here and now" map.

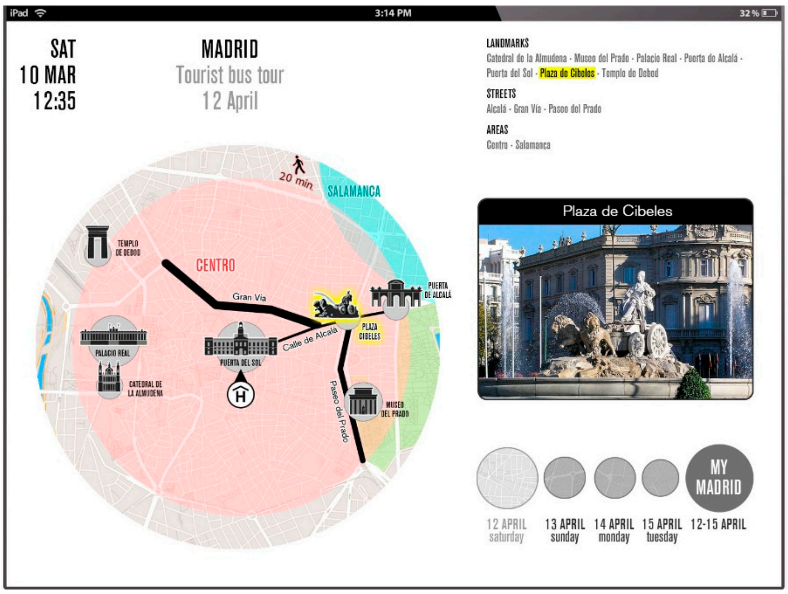
We applied the personalization design guidelines in a specific map-use context for two tourists of different types—the Guided tourist, T1, and Explorer tourist, T2. Table 2 summarizes their individual and contextual factors, as well as their spatial tasks for completion using the maps. Table 3 describes the design decisions to personalize the maps for tourists T1 and T2. Figures 11 and 12 show drawings prepared to illustrate the proposed map designs (map prototypes).

Table 2. User type and context of use for tourists T1 and T2.

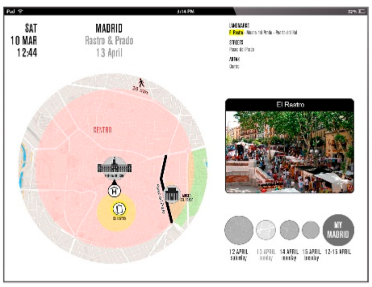
			Context of Use	
Tourist	Users Type	Interest of Users	Map Use Environment	Spatial Tasks
T1	Guided	Museums and monuments	At home, not yet in Madrid, with no time pressure to complete spatial tasks, using a computer.	Check the travel plan sent by a tourist agent to visit Madrid for four days with a friend.
T2	Explorer	Local gastronomy, music, and arts	At the hotel, after three days in Madrid, with no time pressure to complete spatial tasks, using a tablet.	Get an overview of the places already visited and check new suggestions of restaurants, and music- and art-related places to visit.

Table 3. Map design guidelines for tourists T1 and T2.

	Map Design Decisions		
Tourist	**Guideline 1**	**Guideline 2**	**Guideline 3**
T1 (Guided)	Include POIs and streets that are common to all tourists and are needed to support the spatial tasks of tourists. POIs will be represented by 2.5D icons customized over circles or through lines with sizes representing the amount of that specific feature in the collective conception of Madrid.	Visualize the travel plan, using one map per day. The day map will include POIs (around 5) and relevant streets (1 or 2), with a differentiated reference system, and an anchor point at the hotel (Figure 11a–d). An extra map will be designed, integrating all information in a coordinated reference system (Figure 11e).	During the tourist stay in Madrid, the maps will evolve to distinguish the POIs and streets already seen from the ones to be visited. If the tourist takes photos, they can replace the generic images. Places visited out of the initial plan will also be included.
T2 (Explorer)		A unique map integrates the zones and streets visited, public transport lines taken, and POIs seen, with a coordinated reference system (Figure 9). The number of features to give an overview of the visited places can extend to more than 2 zones, 3 hubs, and 18 POIs (see Figure 8).	Cafés and restaurants where the tourist stayed longer or visited more than once will be included. Suggestions will be included in the map considering the interests of the tourist, the timetable of public transport. and the weather forecast. The suggestions will be presented in colors, while previously visited places will be shown in grey.



(**a**)



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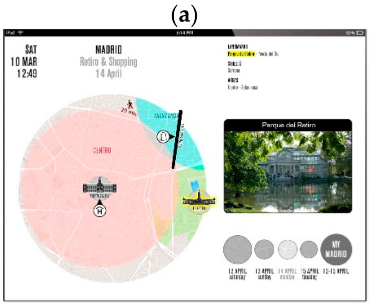

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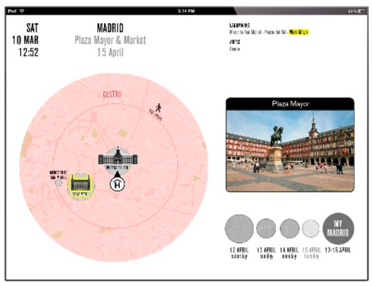
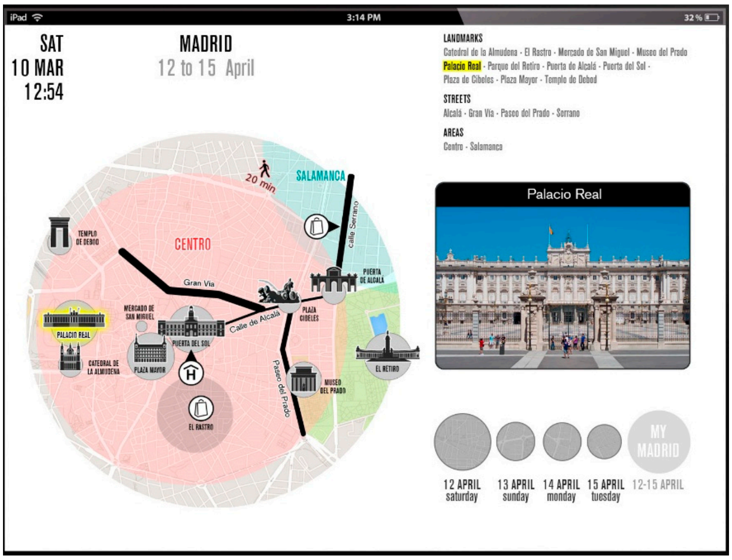


(**d**)

Figure 11. *Cont.*



(**e**)

Figure 11. Maps created for tourist T1 (Guided), illustrating the places to visit daily in Madrid. The pink circle shows the POIs reachable within a 20-min walk from the tourist's accommodation, located in the city's "Centro" zone. Maps in (**a**–**d**) take into account the average number of features and the differentiated reference system of the Guided participant's sketches (cluster of elements organized around a fixed feature, the hotel). The map in (**e**) summarizes the information on the four previous maps in a coordinated reference system, in order to help user T1 to integrate the information of the daily experiences in a single map. During the stay in Madrid, the maps will evolve to distinguish the POIs and streets already visited, from the ones yet to be seen. If tourist T1 takes photos, they will replace the generic images. Places visited instead of or in addition to the initial plan will also be included.

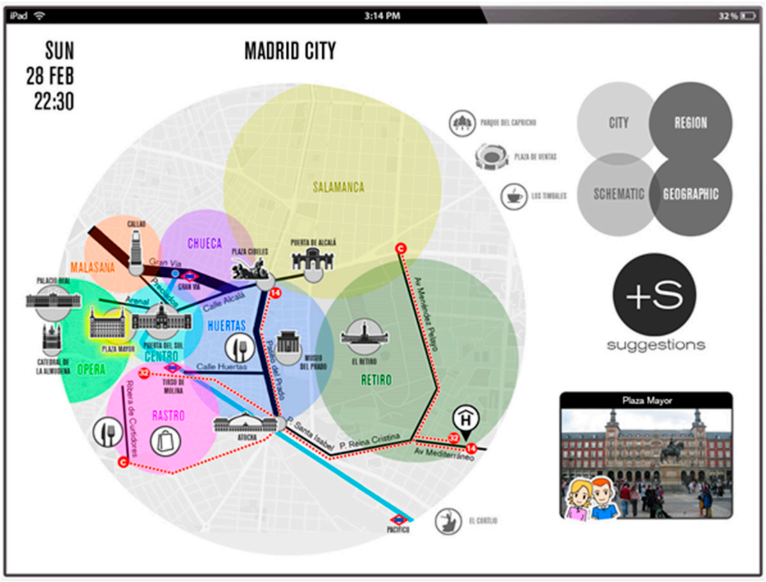


Figure 12. Map created for tourist T2 (Explorer), presenting a summary of places visited during the stay in Madrid. Drawn upon the sketch maps of the Explorers, the map design includes a large number of features, with hubs and zones (colored circles), and applies a coordinated reference system. If tourist T2 selects the suggestions button, several recommendations will be shown on the same map, changing the previous content to grey, and displaying the new one in color. The suggestions will consider the interests of tourist T2, as well as public transport lines, timetables, and weather forecasts.

Maps for T1 and T2 include features from the collective conception of tourists in Madrid and customized icons (guideline 1). However, the number and type of features, as well as the reference system, is adjusted to the type of tourist (guideline 2). Finally, the elements included in each specific map adapt to the spatial task (context of use) and the individual's interests and knowledge, and evolve over time, as the cognitive maps also do, in line with the tourist's experience in the city (guideline 3). In the case of tourist T2 had a conditioned experience because, e.g., s/he had come to Madrid to take part in a conference, s/he would have moved as an Explorer in the free time, but his/her tourism experience would have been restricted and influenced by the amount of free time available and the location of the conference. Thus, the map presented in Figure 12 would have contained fewer elements but retained the same reference system. It would also have included the location of the conference, the transport lines used to go there, and the suggestions would take into account the location of the conference and transport timetables.

We conducted a basic evaluation test of the map prototypes illustrated in Figures 11a and 12 with 3 Guided tourists and 3 Explorer ones, respectively. All participants valued the clarity of the information in the map design. Some tourists appreciated the usefulness of the map and highlighted that the icons helped greatly in remembering places of the city. Two tourists observed that they were accustomed to using conventional maps and that the personalized map caused them some worry and uncertainty. However, one of these tourists suggested the option to switch between personalized and conventional maps, so that users could visually compare them and feel more comfortable when using the personalized map.

5. Conclusions

The aim of this work was to reinforce map users' mental links between maps and places in a city though the use of personalized maps. The maps were designed from a user-centered perspective that empower the users' roles in the map design process, in which users were more than mere map readers, and cognitive aspects influenced by their experience as map users in the city were also considered. We proposed the design of "cognitively aware" personalized maps by adaptation, bearing in mind the type of map user and the context for its use.

We identified the types of maps users by considering individual and contextual factors that could influence individuals' spatial knowledge of the city. The personalized maps included geographic features common to all map users (according to a collective conception of the city), patterns identified in the sketches of each type of user (e.g., number and type of elements, and reference system), and also took note of how sketches evolved along with users' experiences in the city (gradual increase in the number of features).

We applied the proposed design process in an experiment with tourists in Madrid. Analyzing the collected data about the spatial knowledge and travel experience of tourists, we identified three main ways in which tourists approached their travel experience, which we called "Guided", "Explorer", and "Conditioned". The design guidelines for personalizing city maps were determined in a top-down approach for all tourists. We developed map prototypes for two tourists of different types and context of use in Madrid. A basic evaluation of these prototypes showed a high acceptance of our personalized city maps.

Our map personalization process can be applied to tourists in other cities, and our results are also promising for developing cognitively aware personalized maps that could be produced on the fly in smart cities, under the big data paradigm. Nowadays, it is easy to predict that technology can provide systems that identify the profile of map users through information gathered by sensors, i.e., users' movements, snapshots, and the environment. Instead of collecting sketches of users to find commonalities in the experience of users, big data analysis of photos and videos posted by users on the internet could be performed. Thus, we envision that it is possible to model map users and determine design guidelines in top-down levels to personalize maps for different user types and cities. Meanwhile, in the case of studies such as ours, a simple, clickable questionnaire could be used to set the profile of users. Tourists could categorize themselves as being "Guided", "Explorer", or "Conditioned", specifying the existing constraints for their visit.

We plan to continue this study, performing empirical tests with larger numbers of tourists in different contexts of map use and evaluate the effectiveness of geo-information and symbolization in the personalized city maps. The results of the evaluation will be used to improve the current design of map prototypes. We also aim to implement a system to generate personalized maps for mobile devices, where we can apply the proposed user modeling and design guidelines.

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