Well-Being Indexes - Privileged Tools for Smart Cities Governance

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Abstract. The creation of smart cities aims to improve the quality of life of people and the environment that surrounds them, ensuring a better response of the services they interact with in urban environments. The inhabitants of the cities tend to make concrete opinions about their own city. The possibility of collecting and reconciling these opinions is very interesting for those who have to govern such environments, as these can allow for the identification of some strengths and weaknesses of the various aspects of a city. With this knowledge, a manager can, in a more supported way, having information sent by the inhabitants of the city, knowing the effect of their decisions using a set of dashboards that include well-being indexes, combining the various elements collected, and reflecting people's appreciation of the city in real time. In this work, we will present how we designed and implemented a well-being urban index, applying it in a concrete application of an urban case study – a university campus.

Keywords: Smart cities · Smart governance · Quality of life · Business Intelligence · Well-being urban indexes

1 Introduction

Throughout the last years, humanity has witnessed a constant technological evolution, growing constantly at a great speed, and at the same time seeing a great development and progress of human society itself. The significant increase in human population and the high adherence to migration of a significant part of the population, from rural areas to urban areas, showed to the cities a marked decrease in their capacity for supporting such events, with the consequent emergence of problems related to the management of the city itself [1]. This increase in the population in urban areas forced the cities, and their managers, to prepare themselves in the best possible way, so they could respond quickly and effectively to such new adversities and needs. Thus, with population growth, it is crucial to evade congestion of new or existing services created in the meantime, avoiding obstacles to normal life in a city. Increasing the sustainability capacity of the cities is then essential. Cities now account for more than 50% of the world's population and it is estimated that by 2050 this figure is about 70%. Against the background of these figures, unless we adopt preventive measures for this demographic change, it can be expected that

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cities will suffer even more from problems such as increased pollution, traffic congestion, or insufficient parking spaces [2–4]. In order to solve the problems related to urban management caused by this migratory flow of people and guarantee a better social order to drive economic growth in a sustainable and rapid way, the concept of intelligent cities has emerged in the last decades, using them more effectively in conjunction with the knowledge, intelligence and innovation of their citizens. This conjugation allows for helping in the construction of better solutions to problems such as those mentioned. The concept of smart city is increasingly popular in the most diverse areas. Although it has emerged in academic environments, today it can be identified in many existing real world applications, having been adopted for supporting some well-known international policies, which makes its application an unstoppable trend [1, 4]. To understand the concept of a smart city, it is essential to recognize that cities are the key elements for the future, since them promote growing at all kind of levels. Cities play a key role in terms of social and economic aspects around the world, which in turn has implications for the environment with a major impact. The concept also emerged as a response to the major economic and environmental changes recorded, as well as to the continuous acceleration of technological progress. All this created the need to find new ways for dealing with the problems of cities, such as the aging of their population, urban overcrowding, or climate changes problems [5, 6].

The aim of this work was to exploit a city-based computing infrastructure supported by a data warehousing system to support applications for monitoring various urban aspects - social, cultural, climatic, traffic, among others – in order to feed a *Well-Being Urban Index* (WBUI), having the potential for classifying a city and its environment at any given time. Taking such system as our base platform, we designed and implemented a computational platform that allowed us to set up an application case study for evaluating the quality of services provided in a university campus. This permitted to demonstrate the utility of such analytical platform for feeding the calculus of a WBUI, combining the various elements collected and reflecting student's appreciation in real time, and follow its evolution over time. In this paper, we will expose and explain the process we carried out to study, identify and characterize a WBUI for assessing the quality of service of a university campus, taken as an urban city case study. In the following sections, we will expose and discuss some related work (Sect. 2), presenting the concept of WBUI as well as some real applications cases, and reveal the process of inception and implementation of a concrete WBUI application taking a university campus and the services it provides as an application case study (Sect. 3). Finally, in Sect. 4, we present a brief set of conclusions, pointing out some working lines for future work.

2 Well-Being Urban Indexes

A smart city is an urban area highly technologically advanced as a whole, if we considered its infrastructures, means of communication, viability in the market and sustainability with respect to the goods properties. Information technology is the main infrastructure of a smart city, giving it the possibility for supporting essential services to its citizens. Usually, in smart cities there are many technological platforms involved, such as data centres and automated sensor networks, providing real-time data that can be analyzed posteriorly for improving the quality of living in a smart city [7–10]. A smart city uses modern and advanced technical means for processing information in an articulated way with transmission and communication processes, integrating urban resources, improving competitiveness and guaranteeing a more sustainable future through the symbiosis between networks of people, companies, technologies, infrastructures, consumption, energy and spaces. This connection obviously brings many benefits to all the parts involved.

A smart city can also use the most relevant information from urban operations for responding intelligently to urban management activities. Basically, a smart city has the capacity to carry out a smart management, in a way that it is possible to provide a good quality of life as well as a good working environment in different areas for the citizens in the best possible way [1, 11]. However, to analyze all this diversity of information, it is essential to identify whether the people of a given city are satisfied with the course of their life and the environment that surrounds them. Therefore, it is necessary the existence of some indicators for illustrating with accuracy the mood of the people in (almost) everything concerning their city. These indicators referred often as well-being indexes. Well-being can be seen as the presence of the best standard of quality of life, by the state of the life situation of a given individual. In other words, it is a positive outcome very significant for people and for many sectors of society. Through this concept we can understand if people perceive whether their lives are going well or not, discovering the desired state of life in a given community. However, a positive well-being result does not depend exclusively on the material conditions of life, although these are fundamental for the definition of well-being, such as housing, employment, financial conditions, among others. This is because income gains are not always proportionate to happiness, as the Easterlin Paradox [12] portrays, that people's levels of happiness seem to remain constant even in the light of the substantial increase in their income.

A *Well-Being Index* (WBI) aims to provide results that allow for following the evolution of well-being and social progress of a population, taking in consideration two main aspects: material conditions and satisfaction with life. In this way, it is possible to measure economic behaviour, for example, in a given context of sustainability, emphasizing as far as possible the well-being of people. With an indicator like this, we can monitor the main critical factors of the economic and social development of a given city or urban environment in terms of well-being, and evaluate them according to a logic of concrete results, integrating statistical information and providing useful readings to facilitate the process of decision- making. A WBI provides information on the evolution, positive or negative, of well-being of a particular area, at a defined scale. The value of a WBI always depends on several factors, such as the index periodicity, the cause for which it was developed, or the variation of its own characteristics over time. A WBI provides a one-dimensional representation of well-being, allowing for measuring it through the combination of several distinct factors that help to improve people's quality of life. Using WBI, we have access to a large set of information that reveals the strengths and weaknesses of a given population, as well as other determinants of their well-being. Usually a WBI is a composite index and not a conventional panel of indicators, since it aggregates and normalizes information in a single indicator, which may include different variables or even other indexes, providing a statistical evaluation of a given population or sector we need to analyse. A composite index has several advantages, namely: it allows for a richer reading in terms of interpretation, facilitates a systemic approach to the welfare problem, and generates a great flexibility in the analysis of the results of an index in a greater or lesser detail in different perspectives. Having an index established, we can design and set up a panel of indicators for illustrating the evolution of the index and all the information supporting it. A WBI provides information that allows for a simple and quick reading of a positive or negative index evolution in a given work area [13, 14].

Concerning WBUI as an application of WBI to urban environments, it can be seen as a weighted "average", similar to a stock exchange index, of a large set of heterogeneous aspects and characteristics of a smart city, like leisure, traffic, environment, weather, and so on. As we know, a stock index is a value that illustrates the general trend of a particular set of stocks. Its value translates into a calculated average of stock prices selected from a given market or industry, which is under analysis. We can see it as an index containing only a few actions of a given sample to explore. The collective performance of these actions is a good indicator of the trends of the market under study, be it global or local, allowing for making its monitoring in a more effective way. It represents the progression of all or part of a market in a very concentrated way, as a single measure, and provides information for analysing the history of stock events, and verifying improvements or regressions, facilitating the drawing of conclusions. The index is a good indicator of analysis for those who want to analyze the direction that a given market sector is having [14, 15]. WBUI are very useful indicators for monitoring and managing numerous aspects related to a city, and for determining which cities are more global. Over the last few years, different types of methods and measurement indexes have been developed to make this identification. However, these efforts vary according to the definition of a smart city and, consequently, produce quite different solutions and results. As such, it is quite complicated establishing a generic measurement process, without missing specific important information, given the wide variety of characteristics that cities present throughout the world. Take, for example, two very concrete cases presented by the company A.T. Kearney [16], based on a very diverse set of data related to 125 cities in the world, which the company collected since 2008. With this work, the company monitored the progress of cities considered the most important by measuring a set of indicators at the level of each of them, creating two very specialized indexes that used together, namely: *Global Cities Index* (GCI) and *Global Cities Outlook* (GCO). The first index allows making an analysis on the performance of each of the cities taking into account 27 different metrics. These metrics are grouped into five distinct dimensions, taking into account commercial activity, human capital, involvement in politics, cultural experience, and information exchange. The calculation of this index is carried out through a previous allocation of weights to each of the dimensions under consideration - for example the commercial activity and the human capital, have a weight of 30%, while the exchange of information and the cultural experience a weight of 15% in determining the final value of the index. In the second index, 13 other indicators are analysed, grouped into a set of dimensions such as personal well-being, economy, innovation or governance. In this index are measured the characteristics of long-term success, such as innovation capacity, environmental performance or safety. This index is calculated by a weighted average, where each dimension has been assigned a weight of

25%. The values of both indices vary between 0 and 100. These two cases can be analysed in more detail in the A.T. report [16]. In addition to these two cases, we found a third case, which we find very interesting and inspiring for this work. We refer to a case that was carried out in Portugal by INTELI to create a specific index for smart cities the Smart Cities Index (SCI) [17]. In order to calculate this index, another set of dimensions was used, namely: innovation, sustainability, social inclusion, governance and connectivity, each of which, in turn, is organized into sub-dimensions. For example, the innovation dimension integrates the sub-dimensions competitiveness, research and development, green economy, social economy or creative economy, while the governance dimension integrates sub-dimensions public participation, public services, transparency, or urban policies. The SCI index is a composite index that incorporates 80 indicators, summarizing the average of the results of the referred dimensions. This index was applied to 20 Portuguese municipalities, members of the *Portuguese Smart Cities Network* (RENER), which is a space for the development, testing and experimentation of intelligent urban solutions in real practical contexts [18].

3 Inception and Implementation of a WBUI

3.1 The Application Case

We designed and developed the application case having the objective of identifying and understanding the way students see the quality of some services and infrastructures of our university. To do that, we needed to conceive a system with the ability to collect in (near) real time the opinions of students about their experience when using the services or infrastructures available in one of the university's campi. Opinions should be collected according to a predefined evaluation model, and monitored for analysing students' reactions in real time in order to assess their impact on the academic community. Thus we conceived a WBUI for analysing the involvement of the various human actors (students) in the various application contexts (services and infrastructures of a university campus), as well as the variation of the several analysis metrics for allowing managers or service directors to view how services and infrastructures under their supervision are evaluated.

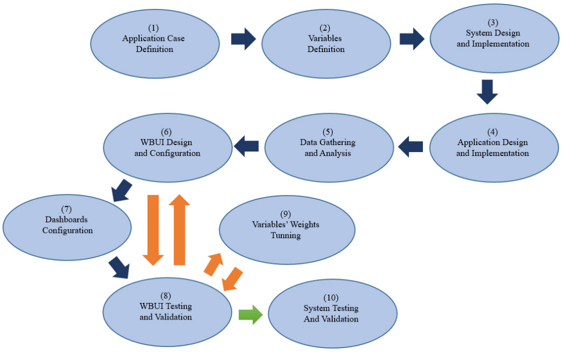

Fig. 1. An overview of the WBUI system life cycle.

In Fig. 1, we can see an overview of the WBUI system life cycle. The first thing to do is to define clearly the case study that we use to define and maintain the WBUI. As mentioned before, we decided to implement a small process of analysis applied to some services and infrastructures of one of our university's campus. We assumed that this application case fits quite well in the domain of smart cities, since our university is technologically advanced and all the people that use the campus (students, in this case) have mobile phones, which have the most typical characteristics to support an initiative for a smart city. For this, we needed to define what the target user community would be. Given the characteristics of the students of the Business Intelligence specialization profile of the Master of Informatics Engineering, it was felt that these would be the ideal community to participate in an initiative like this one. The purpose of this application case for studying the quality of the university's services and infrastructures, gathering the opinion of the target community, provided us a real situation of real world, with real data, and getting valid opinions and lessons about the university itself. In spite of being a test case, the lessons learned were important and relevant for us.

After this first part of the work, we made the definition and the choice of the analysis variables that we want to use in the evaluation carried out by the target population – students. The definition of the variables was based on the characteristics of the infrastructures and university services covered by the case study. We organized the analysis variables into two distinct categories: 1) dimensions – "Academic Services UM", "General Library UM", "Classrooms/Study", "Information Technology Department", "Bar/Restoration", "Parking Places", "Gardens/Green Spaces", and "Sports Conditions"; and 2) metrics – "Online Services", "Accessibility", "Space Comfort", "Number of Passwords" "Employees", "Waiting Time", "Time/Availability", "Air Conditioning" and "Customer Service Efficiency". After all the variables defined and analysed, we designed the system for supporting the execution of the WBUI process, from the initial phase of data gathering to the last one where we calculate it. During the design of the system, we realized that its base structure should be able to integrate new cases of study without the need to be adapted. Thus, we used a JSON configuration file for defining the incorporation of a new case study into the system, where we define the case and all the dimensions. Later, the system will import this file by during its initialization, serving as well for configuring the corresponding WBUI evaluation system, which includes system's dashboards and the data gathering application for collecting the opinions of the users.

The JSON specification presented in Fig. 2 allows for hosting a structure of analysis for each case study considered, organized in several levels of interest, according the following basic configuration: <Service>, <SubService>, <SubSubService>, <…>. One possible instantiation of this configuration could be <"UM Academic Services">, <"Accessibility">, or <"UM Academic Services">, <"Number of Passwords">, among others.

The configuration file presented in Fig. 2 contains several analysis elements and the respective specifications of its properties. Additionally, we also see the specification of other variables, namely: "application", which identifies the name of the case study; "image", which is the image of the application study case and that will function as an application logo; "dateExpiration", which is the date set by the body for the closure of

```
{
    "application": "Turras",
    "image": "Turras.png",
    "dateExpiration": "2019-06-10 20:59:59",
    "dimensions": [
        {
            "shortName": "SAUM",
            "longName": "Serviços Académicos UM",
            "imageUrl": "https://image.flaticon.com/icons/png/512/309/309264.png",
            "weight": 1,
            "metrics": [
                {
                    "shortName": "Online",
                    "longName": "Serviços Online",
                    "imageUrl": "https://image.flaticon.com/icons/svg/235/235196.svg",
                    "weight": 1
                },
```


Fig. 2. A JSON fragment of a system's configuration file.

the study; "dimensions", which includes the dimensions to be evaluated; "shortName", which is a smaller name for the dimension so that it can appear on the mobile applications display; "longName", which is the full name of the dimension; "imageUrl", which is the image of the dimension; "weight", which is the weight that the dimension in question has in the category in which it is included, which can vary between '0' and '10'; and, finally, "metrics", which is very similar to dimensions only applied to metrics. Complementarily, the system contains another configuration structure: the equalizer. This is quite similar to the previous configuration structure. However, it contains only a single variable, which varies from '0' to '1', and it is used to inform the system whether or not a given dimension or metric will be included in the calculation of the index to which it is associated. It is counted only in cases where it has a value greater than '0'.

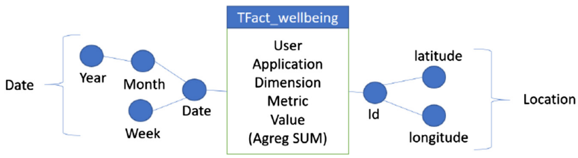

Fig. 3. The conceptual schema of the WBUI multidimensional database.

After the materialization of the data model, it was also necessary to create a data structure specially oriented to provide the data elements required by system dashboards. For this, we designed a multidimensional database (Fig. 3), with the ability to store the data about the opinions of system's users and to perform the calculations of the desired WBUI. To receive this data structure, we implemented a specific data warehouse for receive and store the votes, removing unnecessary information and consolidating the data into a single data structure. In the schema of Fig. 3, we clearly identify the fact table ("TFact_wellbeing") of the data warehouse. This table is also stored in a NoSQL database, adopted by the system in a key space named "cube_well_being", in which is store all user identifiers ("User"), metric names ("Metric"), dimensions ("Dimension"), application ("Application"), for the application case, and the value ("Value") voted by a certain user. All this information was associated with the date ("Date") of the vote and in which location ("Location") occurred. In our application case, in particular, the location refers to the campus of the university, so that one could verify if a user classified the canteen in the canteen or in a classroom, for example. The data warehouse allows for cataloguing the opinions received in the system according to the case study used, storing the data in a specific data system, organized according to the various previously identified analysis perspectives. In addition to the table "TFact_wellbeing", it was also necessary to create another table, index_table, to accept the WBUI values that were being calculated. This way, it was possible to store the WBUI history, facilitating later its calculation and analysis. After defining the main data elements for supporting the operation of the system, we implemented the WBUI management system (Fig. 4), paying particular attention how to support the application of data collection and the integration of the data collected.

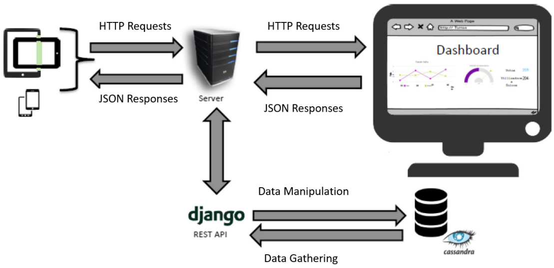

Fig. 4. Functional model of the WBUI system.

In Fig. 4, we can see a sketch of the functional model of the WBUI system, having a representation of each one of its main components. The server component is responsible for providing users with references for the various dimensions and metrics they can evaluate, and processing each one of the votes in the application, together with other information relevant to the calculation of WBUI. Then, the server works the data collected by the application, producing the values for presentation in the dashboard component. This component generates several graphical elements and *key performance indicators* (KPI), revealing the various results that compose the value of the WBUI.

The application for evaluating services and infrastructures (Fig. 5) was designed especially for collecting the various data elements necessary for calculating the WBUI of the application case study we used. We transformed this tool into a mobile application, quite easy to install and use by students, so that the process of gathering opinions was easy, fast and versatile. In addition to these components, we also have another system's component: the monitor. It receives the data it works through the server, periodically revealing information for analysis, facilitating decision-making by decision-makers.

3.2 Calculating the WBUI

In order to calculate the WBUI, it was necessary to proceed gradually, adopting and adapting calculation expressions, improving them gradually to be more effective. Throughout the process we have taken into account some of the calculation models used by other systems, in particular the ones used in calculations of indexes of the so-called global

Fig. 5. Some screenshots of the application used for service evaluation.

cities. The process adopted takes place in two stages: the calculation of the index itself and its maintenance over time. First, it was necessary to calculate the value of the index of the day in question, taking into account the values obtained by the application up to the moment in which the request for calculation of the index value was registered, guaranteeing that new votes would not adulterate the result of the index calculation process.

Table 1. Dimensions and metrics relationships.

		Metrics								
		1	…	j	…	S_1	S_2	S_3	…	S
Dimensions	C_1	C_{11}	…	C_{1j}	…	C_1S_1				
	C_2	C_{21}	…	C_{2j}	…	…	C_2S_2			
	…	…	…	…	…	…	…	…	…	…
	C_i	C_{i1}	…	C_{ij}	…	…	…	…	…	…
	…	…	…	…	…	…	…	…	…	…
	C_K	C_{K1}	…	C_{Kj}	…	…	…	…	…	C_{KS}

Let us see, how is calculated the WBUI for our application case. We assumed that K is the total number of dimensions and S is the maximum number of existing metrics for all dimensions. Variable S is required since the number of metrics that a dimension has may be different from the other existing dimensions. Table 1 shows a matrix M, which illustrates the relationship between dimensions and metrics. With it, it is possible to see that each position (i, j) identifies a metric, and i identifies a dimension, where $1 \leq i \leq K$, $1 \leq j \leq S_i$ and $S_i \leq S$, being S_i the maximum number of metrics of dimension i. For example, for dimension C_1 the maximum number of metrics is S_1, which is less than S, whereas for dimension C_2 the maximum number of metrics is S_2, since dimensions may not have the same number of metrics. However, when it is stated that pair (i, j) identifies a metric, this means that the value of j represents the position and not the denomination of the metric, which may be different for the same j at different i positions. As for C_{ij}, this is a trio that is in position (i, j) of matrix M, which may contain three distinct values, namely: the weight of the metric in the dimension index, p_{ij}; the value of the metric, that is, it represents the sum of all votes, v_{ij}; and the total number of votes in the metric,

n_{ij}. Only the last two are determined by voting, the first being previously defined in the configuration phase of the system. In Eq. 1, we can see the expression representing the value of the pair (i, j) in the matrix M:

$$C_{ij} = \langle p_{ij}, v_{ij}, n_{j_j} \rangle \tag{1}$$

The process of calculating the index begins with the sum of all the values corresponding to the votes made. To do this calculation, the voting date must be lower than the date of the request – we only consider the values recorded on the day of the request. The dimension of the vote should be equal to the dimension of the metric that is under analysis. The same must succeed for metrics. Then we calculate the index for each metric (Eq. 2) and the sum of all weights of a given dimension (Eq. 3). The value of the weight $P_{i,j,}$ associated with a given analysis variable, varies accordingly the value we set up previously in the system equalizer.

$$I_{ij} = \frac{v_{ij}}{n_{ij}} \tag{2}$$

$$\sum_{j=1}^{s_i} P_{ij} = 1 \tag{3}$$

$$I_i = \sum_{j=1}^{s_i} P_{ij} \cdot I_{ij} \cdot E_{ij} \tag{4}$$

Then we make the sum of all the weights of the existing categories (Eq. 5), which allows for obtaining the value of the global index (Eq. 6). As for $P_{i,j}$, P_i varies accordingly the value previously defined in the system equalizer for the other dimensions.

$$\sum_{\boldsymbol{i}=1}^{\boldsymbol{K}} \boldsymbol{P_i} = 1 \tag{5}$$

$$\boldsymbol{I_{global}} = \sum_{\boldsymbol{i}=1}^{\boldsymbol{K}} \boldsymbol{P_i} \cdot \boldsymbol{I_i} \cdot \boldsymbol{E_i} \tag{6}$$

After completing the first phase of the index calculation – the daily index, we need to calculate incrementally the index, day after day, taking into account the values we calculated before. This is done using Eq. 7, which allows us to obtain the index value for a given date. In this equation, i_h represents the actual value of the updated index, i_0 the value of the index on the previous day, $f(i_0)$ the origin of the value of the index of the previous day, and i_c the value of the index calculated for the day in question.

$$i_H \leftarrow f(i_0) + i_C \tag{7}$$

$$i_H \leftarrow f(i_0) \cdot 80\% + i_C \cdot 20\% \quad (8)$$

When the requested index value is relative to the first day, we apply Eq. 7, since this value obviously does not exist. However, this equation does not guarantee that the index value always varies between '−1' and '1'. As such, it is necessary to define weights to the participants in the calculation of the value of the index, namely to $f(i_0)$ and to i_c, which allowed a gradual variation and ensure that the index value will be within the predefined limits. Equation 8 ensures that these limits are not exceeded. Additionally, this equation calculates the index at the level of the dimensions and metrics. For example, when we want to calculate the index value for a given metric, we apply Eq. 2 followed by Eq. 8, which allows us to obtain the trend value of the same metric. WBUI results were quite interesting, even knowing that the application case study involved only a student class. They showed us the potential of a WBUI for the evaluation of services. Just to see one of the system's dashboards, we selected to show the values of the WBUI of one of the most curious dimensions: "Parking Places" (Fig. 6). In this figure, it can be seen that the metric with the greatest positive impact on "Parking Places" is "Signalling", with a value of '1'. As already mentioned, all subcategories were "weighed" with the same value, and, as such, this conclusion holds. Conversely, the metric that most influences negatively the index of this dimension is "Number of Parking Places", with has a value of approximately '−0.3', which lowered, obviously the value of the dimension's index.

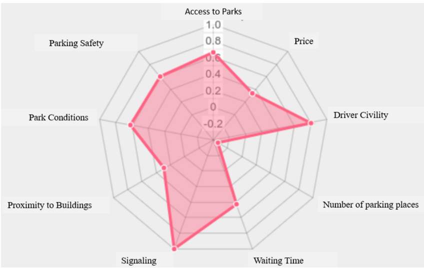

Fig. 6. WBUI results for the dimension "Parking Places".

4 Conclusions and Future Work

WBUI are very interesting and useful management tools. In fact, when properly implemented, they allow us following the behaviour of a given system, in a given application context. However, the definition of a WBUI, regardless of its nature, is very subjective, often depending on the expertise and knowledge of its designers and users, who combine their life experience with heuristics and mathematical models in a very heterogeneous "cocktail". This diversity of aspects, when transformed into a single element, an index, does not always have the desired effect or fulfil the previously established objectives.

The greatest difficulties were in the definition of the WBUI calculation process, in particular in the identification of the various relevant aspects to be included in the calculation expression, and later in the definition of its relevance, of its weights, in determining the final value of the WBUI for the case study that we considered. After that, we designed the architecture of the system and the application used for collecting opinions, a test case for WBUI. With this work, it was possible to have a rather concrete, although synthetic (an index) view on the level of satisfaction of a set of users on a set of services and infrastructures of the campus of the university. In spite of being a case we have idealized, it reflected (and reflects) a concrete opinion of a group of students, during a given period of time, revealing its behaviour and demonstrating in an unequivocal way the utility of an WBUI, as it can with the results obtained. In a near future, we intend to extend the focus of the system, enlarging and diversifying the set of dimensions, and find a real-world application case having its genesis and materialization in a recognized smart city.

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