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Dashboard for Ubiquitous Analytics

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Abstract

As Mark Weiser predicted in 1991, computer access is everywhere, completely embedded in our everyday lives. They are always in the background, not requiring active attention, but data is always ready to be used. All these devices, collecting and presenting data from our environments, make that not only computing is ubiquitous but also the data. Embedding this data in our environment amplify human cognition, since the data is part of our physical world and consequently part of our cognition process. Public displays are one of the most ubiquitous elements of our visual culture, being completely ingrained in their specific physical, social, and cultural setting. However, they should not disappear in the background. Instead, they should become the backbone of a new global communication medium. The goal is to develop a dashboard to be deployed on displays around the Madeira Islands that give passers-by, locals or tourists, relevant information about the place. A dashboard that becomes part of the environment, but that stands out enough to be useful. This work was developed following an iterative and incremental methodology where user tests were used to validate the system.

Keywords

Ubiquitous Computing; Ubiquitous Analytics; Public Display; Mobility; Human-Data Interaction

Resumo

Tal como Mark Weiser previu em 1991, o acesso a computadores está em todo o lado, completamente embutido nas nossas vidas do dia-a-dia. Eles estão sempre em segundo plano, não requerendo atenção ativa, mas os dados estão sempre prontos a serem utilizados. Todos estes aparelhos, recolhendo e apresentando dados do nosso ambiente, fazem com que, não só a computação seja ubíqua, como também os dados. Integrar estes dados no nosso ambiente amplifica a cognição humana, uma vez que os dados passam a ser parte do nosso mundo físico e conseqüentemente parte do nosso processo de cognição. Os ecrãs públicos são um dos elementos mais ubíquos da nossa cultura visual, estando completamente enraizados no seu ambiente físico, social e cultural específico. No entanto, eles não devem desaparecer em segundo plano. Em vez disso, eles devem tornar-se a espinha dorsal de um novo meio de comunicação global. O nosso objetivo é desenvolver um painel para ser implantado em ecrãs espalhados pelo Arquipélago da Madeira que forneça às pessoas, locais ou turistas, informações relevantes sobre o local. Um painel que se torna parte do ambiente, mas que se destaque o suficiente para ser útil. Este trabalho foi desenvolvido seguindo uma metodologia iterativa e incremental, onde testes de utilizadores foram usados para validar o sistema.

Palavras Chave

Computação Ubíqua; Analítica Ubíqua; Ecrã Público; Mobilidade; Interação Pessoa-Dados

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Introduction

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In 1991, Mark Weiser stated that the most important technologies are the ones that disappear; the technologies that are so embedded in our everyday life that they become indistinguishable from it. Their constant background presence does not require active attention, but the information is ready to use at a glance [6].

From 2013 to 2019, the web traffic that comes from mobile phones grew from 16% of the worldwide traffic to 52%. The idea of ubiquitous computing that Mark Weiser had is now a reality. The majority of people, even more in developed countries, have a mobile phone with Internet access and, as previous numbers state, increasingly use them to access the available information online. Computing access is everywhere: in walls, on our wrists, on our pockets. All these devices are right there, about to be used as needed and that demands that the data resources need to be available anytime and anywhere.

All these networked devices, from smartphones and tablets to large displays and tabletops, can be combined into a single environment. The ensemble of these multiple heterogeneous sources, which can also be distributed in time and in space, provides a more complete data set. Allowing the accessibility to these deep and interactive analytics by several individuals with different backgrounds leads us to ubiquitous analytics [7]. Ubiquitous analytics amplify human cognition by embedding the analytics into smartphones, tablets, laptops, tabletops, and large displays. That will make them part of the physical world and consequently part of our cognition process.

Public displays, of all kinds, are one of the most ubiquitous elements of our visual culture. From road signs and billboards on the streets to posters on stores or notice boards in schools, as we look around in our environment we are constantly facing a very broad range of public displays with multiple forms and serving very different purposes. Most of these displays are deeply embedded in their specific physical, social and cultural setting and they are a crucial part of the already established practices [8]. Although this situatedness is necessary for public displays to fulfill their purpose, it also leads to the disadvantage of making them disappear in their environment and consequently being ignored.

However, public displays should not disappear in the background. Instead, they should become the backbone of a new global communication medium, as in the ubiquitous computing vision Weiser had.

Our project builds on previous work at Interactive Technologies Institute in the context of the Beanstalk¹ project. Beanstalk is a multidisciplinary project with the aim of designing and delivering a product to the board of the Tourism of Madeira that allows them to analyze trends in tourism and marketing, that can stimulate the local economy. Our goal is to develop a dashboard to be deployed on displays around the Madeira Islands that give passers-by, locals or tourists, relevant information about the place. For that, we need to understand the state of the art in the fields of ubiquitous data, public displays' content development, and human-data interaction, and define the best approach and guidelines to develop a dashboard for public displays that meet its purpose. Therefore, in order to design content and applications for public displays that are more likely to serve their intended purpose, an audience and context should always be

set. Then, already having these premises in mind, there are two major things that should be taken into consideration and that are relevant for this work: content and situatedness.

Regarding content format, although we have many different examples, video format is the one viewers find more attractive and it is important to consider that content that requires more than a few seconds to absorb and understand is likely to be ignored [9]. When it comes to situatedness, digital displays should be designed to reflect both the environment in which they are placed and the actions of the people around them. There are six dimensions that represent the main sources of situatedness for a public display: location, spatial association, activity, community, perceived ownership and place identity [8].

On the other hand, when creating content and design for public displays, guaranteeing utility, usability and likability is not enough. Displays need to grab the attention of passers-by, motivate citizens to interact with them and tackle the issues of interaction in public [10]. The reason for this, is that interaction with public displays does not start with the interaction itself. The viewer is just passing by and its interaction needs to be attracted. Therefore, the major challenge is to catch the attention of passers-by and, in order to overcome the following ones, people must be motivated, since people are not out there looking for displays to interact with.

In the last few years, research has been made in order to understand how people interact with data. The field of human-data interaction places the human at the center of the data flows, and it is concerned with providing mechanisms for people to interact explicitly with the systems and data. [11]. In order to gain information or knowledge from data, people need to interact with data instead of only passively consuming them. This interaction goes beyond data analysis and includes an interactive exploration of data sets.

1.1 Goals

The main goal of this work is to create a dashboard with ubiquitous data that the viewers can interact with, in a way that the dashboard and its analytics are part of their environment. That dashboard will be deployed on public displays scattered around the Madeira Islands. The objectives of the dashboard are:

- The dashboard should give the power to change its content to viewers, based on the information they find relevant in the moment;
- The communication between the viewer and the dashboard should be done through the viewer's mobile phone;
- The development of the system and the personalization of the dashboard has to be developed in a way that does not disclose revealing content or personal identity;

¹<https://beanstalk.arditi.pt/>

- If the dashboard receives contradictory viewers' preferences, it should have a system to choose which is the best option to show at a certain time;
- The dashboard should reflect the environment and the people in the environment where the display will be deployed in, in our case, the Madeira Islands.

1.2 Document structure

In Chapter 2 we review the state of the art in the fields of ubiquitous data, public displays, the relationship between public displays and humans, and human-data interaction. Then, in Chapter 3 we define our project's requirements based on the study presented before, give an overview of the prototype development process, present the functional prototype and explain the architecture of the system. On Chapter 4 is shown the evaluation conducted on the functional prototype and respective results. Finally, in Chapter 5, we expose the conclusions of this work and reflect on the work that still needs to be done in the future.

2

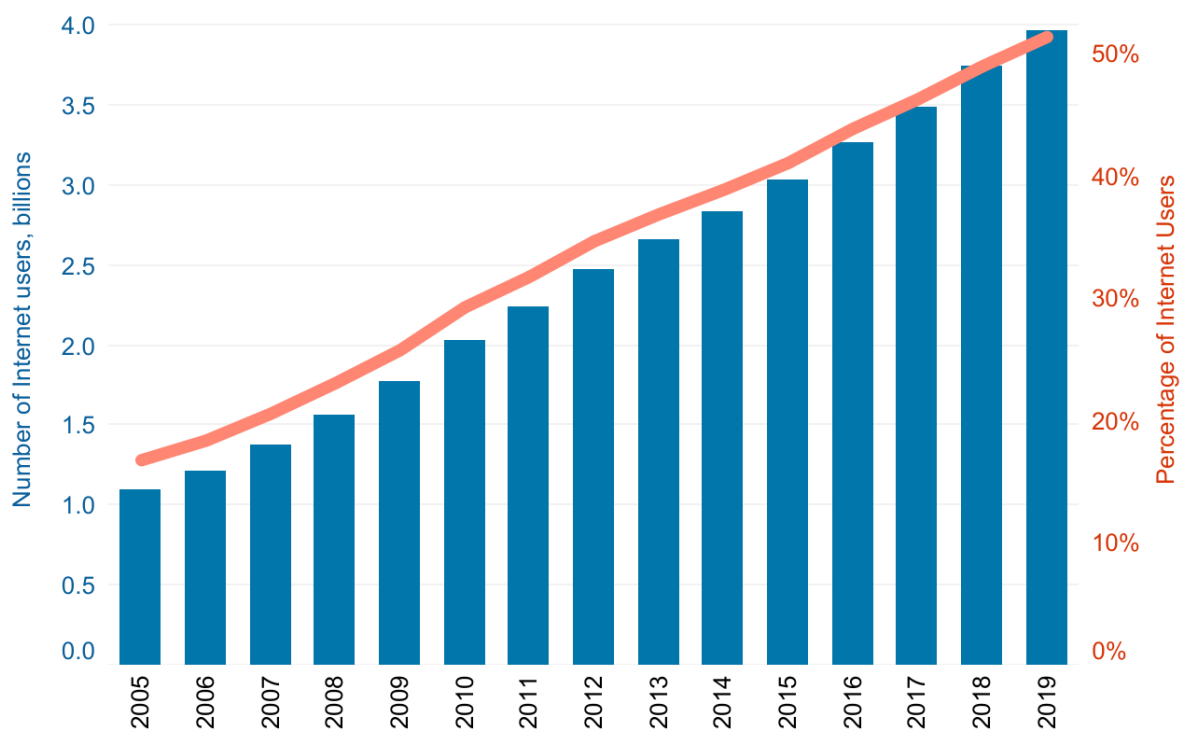
Related Work

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In 1991, Mark Weiser, who is considered the father of ubiquitous computing, stated that the most important technologies are the ones that disappear; the technologies that are so embedded in our everyday life that they become indistinguishable from it. Their constant background presence does not require active attention, but the information is ready to use at a glance [6].

It is difficult to imagine our life otherwise. According to the International Telecommunication Union (ITU) estimates¹, in 2019 we had nearly 4 billion people around the globe using the Internet, in contrast with 1 million in 2005. This represents 51% and 17% of the world population, respectively. In 2005 there were approximately 2 billion mobile-cellular telephone subscriptions, and last year there were 8 billion. Surely not all of them are being used to access Internet, but Statista² compiled data about mobile phone web access and found out that in 2019, 52% of traffic came from mobile phones, while in 2013 mobile phones made up only 16% of worldwide traffic. These numbers prove an on growing use of mobile devices that demands that we are able to access data resources anytime and anywhere.



Source: ITU

Figure 2.1: Number of Internet users from 2005 to 2019

¹<https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx>

²<https://www.statista.com/statistics/277125/share-of-website-traffic-coming-from-mobile-devices/>

2.1 Ubiquitous Analytics

Ubiquitous computing is the idea of having available and nonintrusive computers throughout our physical environment and everyday lives. A world of fully connected devices, that make information accessible everywhere [12].

In the 70s, time-sharing was the prominent model of computing, which allowed many users to interact concurrently with a single computer. After that, and not that many years ago, we moved to a model where every single user has a computer, a personal dedicated machine. We are now at a time where each user has multiple devices. As Wisner predicted, computing access is everywhere: in walls, on our wrists, on our pockets, we can even control our house temperature, lights, or appliances at distance. All these devices are right there, about to be used as needed.

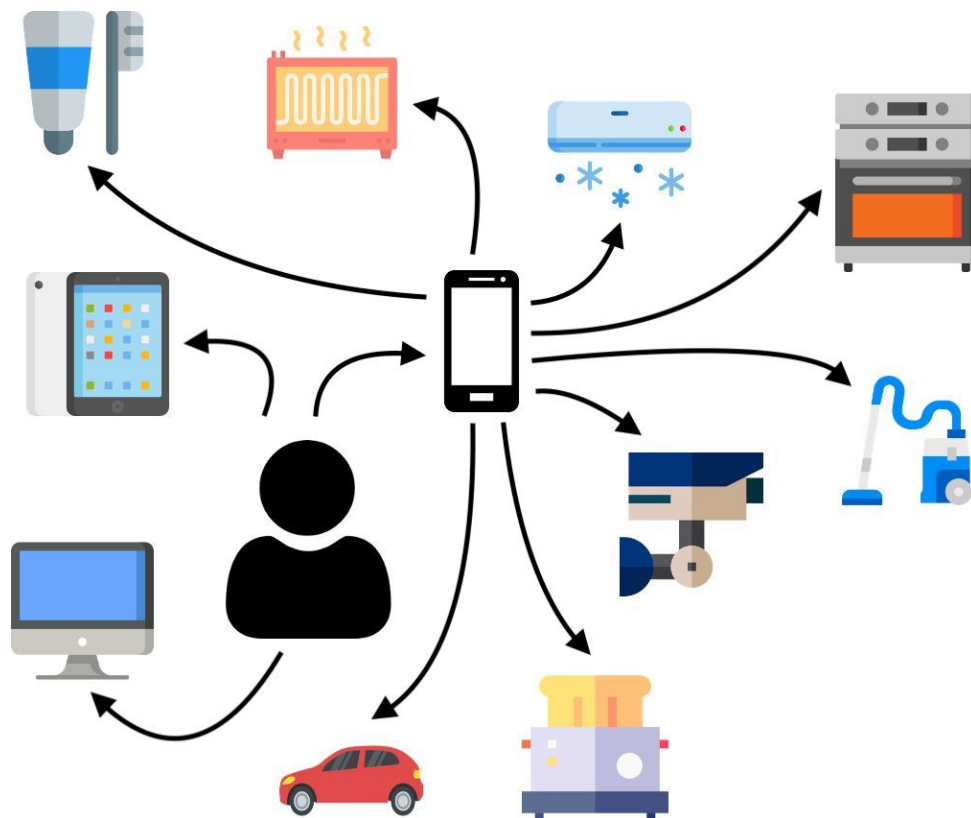


Figure 2.2: Ubiquitous computing

With the rise and spread of mobility and at a time we can say that we achieved ubiquitous computing goals, we can apply these realities to data. All these networked devices, from smartphones and tablets to large displays and tabletops, can be combined into a single environment. The ensemble of these multiple heterogeneous sources, that can also be distributed in time and in space, provide a more complete data

set. Allowing the accessibility to these deep and interactive analytics by several individuals with different backgrounds leads us to ubiquitous analytics [7].

Ubiquitous analytics amplify human cognition by embedding the analytical process into the physical environment [7]. This concept is sustained by a framework called distributed cognition, used for understanding how the cognitive properties of aggregates emerge from the interactions of component parts. Distributed cognition is a manner of thinking about cognition that permits one to examine the relationships between what is in the mind and the world the mind is in [13]. Therefore, embedding interactive analytics into smartphones, tablets, laptops, tabletops, and large displays will make them part of the physical world and consequently part of our cognition process.

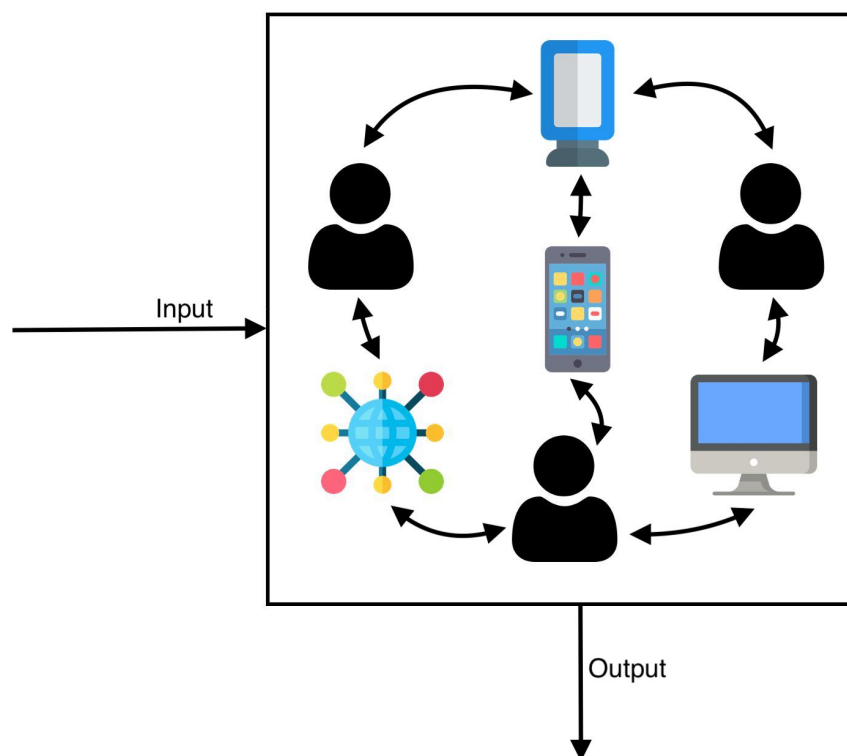


Figure 2.3: Distributed cognition system

2.2 Public Displays

Public displays, of all kinds, are one of the most ubiquitous elements of our visual culture. From road signs and billboards on the streets, to posters on stores or notice boards on schools, as we look around in our environment we are constantly facing a very broad range of public displays with multiple forms and serving very different purposes. Most of these displays are deeply embedded in their specific physical, social and cultural setting and they are a crucial part of the already established practices [8].

Although this situatedness is necessary for public displays to fulfill their purpose, it also leads to the disadvantage of making them disappear in their environment. This phenomenon was identified as display blindness. Several studies have shown that most public displays are ignored by the majority of passers-by or receive only very few glances. In other areas, lack of attention for aspects of the environment has been explained by the fact that attention is highly selective. In an environment with so many inputs, people expect the content of displays to be useless so they tend to classify it as a low-priority input and ignore it [14]. This effect is similar to banner blindness, the people's tendency to ignore page elements that they perceive to be ads.

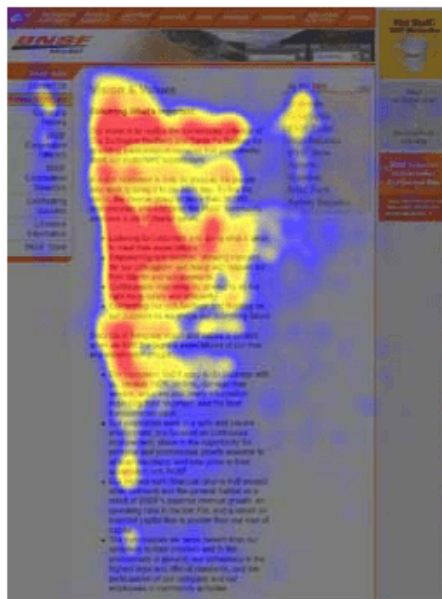


Figure 2.4: Heatmap illustrating banner blindness

However, public displays should not disappear in the background. Instead, they should become the backbone of a new global communication medium, as in the ubiquitous computing vision Wisser had [15].

2.2.1 Content and situatedness

In order to design content and applications that are more likely to serve their intended purpose, an audience and context should always be set. Then, already having these premises in mind, there are two major things that should be taken into consideration and that are relevant for this work: content and situatedness.

When it comes to the type of the content, what we can find on public displays is varied, from art and education to news and advertising, advertising being the most common [9].

Regarding content format, we can find many different examples: text, animated text, still images, animations, sound, holograms, 3D images, projections. Although video format is the one viewers find

more attractive [9], viewers are more likely to spend time looking at physical signage. This is explained by the fact that, while digital signage is more attractive and dynamic, users prefer to have control in what they want to see at the moment. This is an important fact to have present and the main argument that supports the need for personalization.

There are also some other discoveries from extensive investigations that are important to consider when creating content for this type of medium. Viewers decide extremely fast if the content of a display has relevance or not. This results in content that requires more than a few seconds to absorb and understand is likely to be ignored [9].

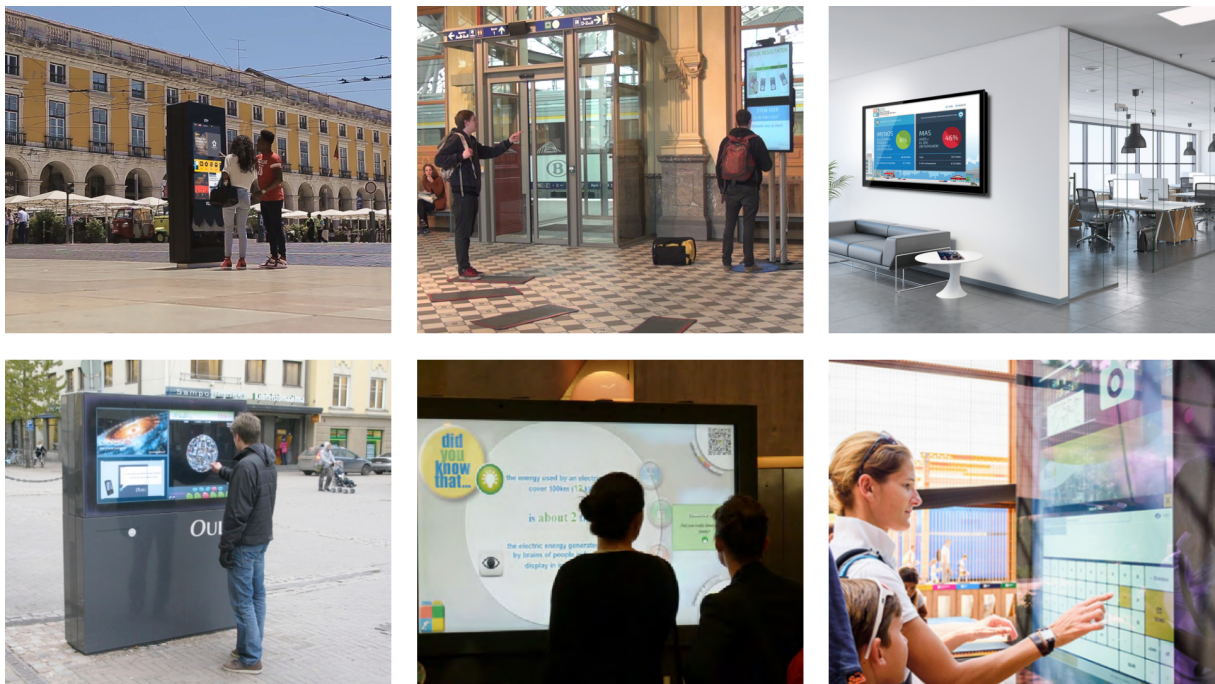


Figure 2.5: Examples of public displays

When it comes to situatedness, the majority of large displays in public areas are designed without proper consideration for the space where they are deployed in, the people around and the local activities [9]. In turn, that may affect the relevance of those displays, leading to lower utility and less attention. Digital displays should be designed to reflect both the environment in which they are placed and the actions of the people around them.

There are six dimensions that represent the main sources of situatedness for a public display: location, spatial association, activity, community, perceived ownership and place identity [8]. Location, activity, community and place identity are the ones related to the development of the content itself and that are more relevant to this work.

The location dimension results directly from the location of the display, that is, is a consequence of physical proximity in the same sense as in location-based services. This can include a map of the

neighborhood or the local weather forecast, for example.

The activity dimension considers the way in which a display reflects on-going activities taking place in its environment. At the most basic level, this may involve raising awareness about those activities. But the displays can also be dynamic and have the ability to represent their status. In this case, the display can become a focal point for making decisions, for example, on which car park to go to depending on current availability.

The community dimension contemplates how a display can become a reflection of the community that shares the place in which it is deployed. The display can be somehow open to the community and the situatedness emerges from the strong potential for engagement of content that is locally generated, selected or published. This way, the predominant users of place and their interests become a defining element of the display content.

Place identity represents the connection between the display design and the perceived identity of the place. This includes displays that try to contribute towards building a specific place identity or the ones that are designed to reflect identity elements of the place where they are deployed [8].

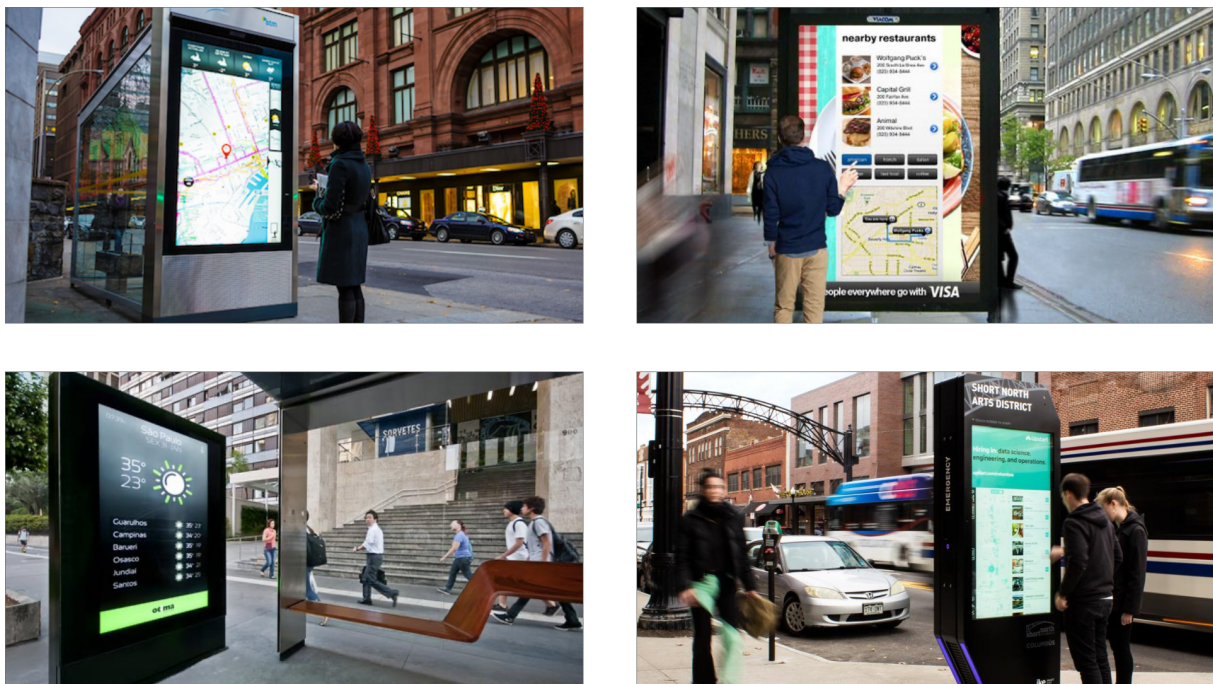


Figure 2.6: Examples of situatedness

It is known that situatedness in digital displays can not be grounded in the exact same assumptions as nondigital ones and we can't simply do a direct translation between them. Therefore, the goal is to find new processes that were not previously supported by nondigital displays but are supported by digital ones, as these are more dynamic, more prone to being interactive and more adaptive to different situations around them.

Despite the amount of research done in the field, a structured framework on how to approach situatedness for digital displays is still needed. In the meantime, while developing content for them, we need to take into consideration these dimensions in order to make sure that the displays are useful in the environment and culture they are deployed in.

2.2.2 Content scheduling

Content scheduling is the art of knowing when and where to show a particular content item. It is a challenging question: it is necessary to understand the context of displays and viewers and it is not an easy task to select content items and choose the right schedule for them in the individual display and across the entire display network [16].

Mikusz et al. [17] developed research to understand the usefulness of a deployed display network. To generate traces of individual view mobility they used a simulator that generated synthetic traces. This allowed taking a few conclusions about the number of times viewers see the same content in different displays or miss important pieces of it, which is crucial to improve content scheduling and placement.

In traditional display deployments, scheduling is performed manually. However, the use of fixed times is likely to become redundant since they are not focused on showing content when specific users are present. Recent research is starting to demonstrate the feasibility of new forms of scheduling that focus on creating schedules that are oriented toward viewers. For example, such systems would be able to support scheduling of content across a network of displays in such a way that users see the maximum number of unique content items, see content items in a specific order or see newest content first [17].

Typical scheduling systems are limited regarding changing the content schedule based on external factors at the same time that large sets of requirements and constraints need to be taken into account. Thus, the creation of scalable, automated scheduling systems, that determine which content should be shown based on the audience, location, and other contextual information, is one of the most important challenges for future display environments [16].

2.2.3 Human-display interaction

When creating content and design for public displays, guaranteeing utility, usability and likability is not enough. Displays need to grab the attention of passers-by, motivate citizens to interact with them and tackle the issues of interaction in public [10]. The reason for this, is that interaction with public displays does not start with the interaction itself. The viewer is just passing by and its interaction needs to be attracted.

Interaction can be divided into two types: implicit interaction and explicit interaction. The implicit one provides a “zero-click” model, where displays react to users passing by. In explicit interaction, users

decide to interact with the content that is being currently displayed. It includes several techniques, like mediated (through a mobile phone, for example) and direct interaction (like a touch screen) [15].

Michelis et al. [1] modeled interaction focusing on audience behavior and called it "The Audience Funnel". The model starts with people just passing by (1) and is followed by them looking at the display and/or reacting to it (2). Then, a subtle interaction happens, only when it is possible to interact (3). After this, a more direct interaction occurs (4, 5). Finally, people can take follow up actions, like taking pictures, for example (6).

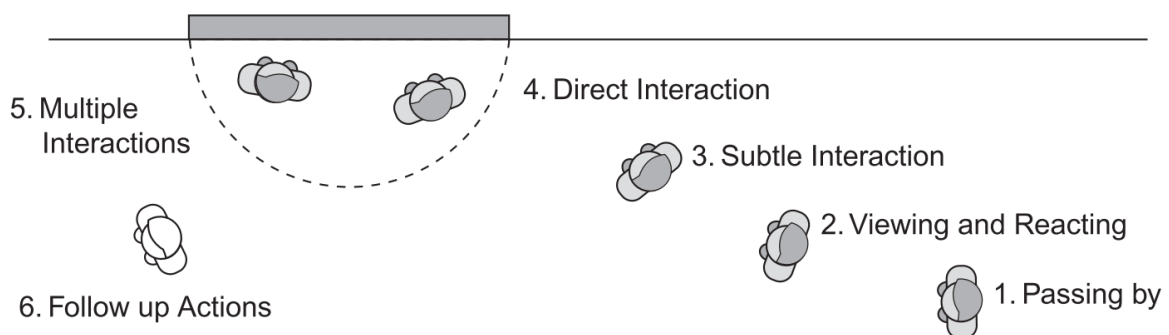


Figure 2.7: The Audience Funnel [1]

The major challenge is to overcome the first step: catch the attention of passers-by. In order to overcome the following ones, people must be motivated.

2.2.3.A Attention

Public displays are always fighting for attention and if they fail to attract it, they are not used at all. Attention is the process in which the human brain decides which of the numerous sensory inputs to apply the most computational power to. Visual attention, in particular, is often modeled with a spotlight metaphor, which means that a certain region of the visual field is selected for more detailed processing [10].

Behavioral urgency and Bayesian surprise are two of the models proposed of what attracts attention, and it is also relevant to mention the Honeypot effect as a strong attention attraction [10].

Stimuli that express the need for an immediate action capture attention [18]. Some examples of that stimuli are the abrupt appearance of new objects, certain types of luminance, moving towards the observer and looming stimuli [1]. Taking this into account, behavioral urgency is a useful model to predict how much attention these stimuli will attract. Bayesian surprise is a model that measures the difference between before and after beliefs. The Honeypot effect describes the outcome of a crowd gathered around a display. It is thought that a crowd attracts even more attention and other people are more likely to join and also attend the display [10].

Although attention plays a role for any multimedia system, it plays a crucial role for public displays, because of the strong competition for audience attention in public spaces [10].

2.2.3.B Motivation

People are not out there looking for displays to interact with, therefore, viewers need to be motivated to interact with one when they come across it [10]. Research has been made in order to understand which are the principles for human-computer interaction design. The following principles were identified as motivators for interaction in public space [10]: challenge and control, curiosity and exploration, choice, fantasy, and metaphor and collaboration.

The challenge and control principle is based on the fact that master an interaction while still being challenged, will increase motivation and the person will continue the interaction. In order to the interaction to be a challenge, the outcomes of the behavior should be uncertain, but at a level that the person believes that have a certain level of control.

Curiosity is identified as the most important characteristic of a motivating environment. It is generated through stimuli that are unclear, incomplete or uncertain. These stimuli create certain insecurity what motivates the viewer to search for a possible cause. So we can say that curiosity is a precursor to explorative behavior [10]. However, to have a motivational effect, curiosity needs to be triggered at an optimal level: it can not be too complex or too simple, which means that it should be surprising, but not incomprehensible. Users should have expectations for the outcome of the interaction, but these should not be completely met and should be clear how to attain completeness.

Choice is pointed out as a motivating factor, since according to observations made, motivation in a certain interaction appears to increase if in the process the users can select between several alternatives in behavior. This means that autonomy and control feelings also increase and provoke motivation. On the other hand, these alternatives should be on an optimal level, otherwise, they can have the opposite effect.

In fantasy settings, the constraints of reality are switched off and the user imagines possessing new abilities. Metaphors are used with the purpose of users to comprehend the interaction, which motivates them to receive it.

Opposite to the other motivating factors, collaboration is based on the interaction with other human beings and its motivating effect lays on the fact that an individual can influence the behavior of others. If the efforts on a certain action are valued and the action is rewarded, people are motivated to repeat the behavior. The degree to which collaboration has a motivating effect is influenced by the personal experience of the user, culture and can greatly vary depending on the situation.

2.2.3.C Interaction

As previously explained, interaction can be divided into two types: implicit interaction and explicit interaction. In the implicit one, the displays react to users passing by, and in explicit, users decide to interact with the content that is being currently displayed. It includes several techniques, like mediated (through a mobile phone, for example) and direct interaction (like a touch screen) [15].

One of the issues of public displays is that the interaction happens in public. If the interaction, implicit or explicit, requires movement or the viewer getting out of its comfort zone, that is a problem considering that the majority of people need to have a certain behavior around others and give them a certain impression. Besides that, they do not want to be annoyed or give personal information, or just want to be polite and not bother others [10].

Personalization can also be a type of interaction. The idea behind personalizable displays is to let viewers decide what they want to see and give them the power to change the display content, thus, the display will be more relevant. There are three different usage models for display personalization identified: walk-by personalization, longitudinal personalization and active personalization [19].

Walk-by is the most common form of personalization, where people are just passing by and the display shows content relevant to them. In longitudinal personalization, users express preferences in what they want to see in the digital displays and a shift is made in the programming of a specific area. This ensures that the content viewers see is more representative of their interests. Active personalization consists of interactively engaging with a display to control applications and content.

2.3 Human-data interaction

We already explored how we have moved from a world where computing is specialized, to a world where computing is ubiquitous and present every day and every time. In many, if not most, parts of the world, networked computing is now mundane as both foreground (mobile phones and tablets, for example) and background (road traffic management and financial systems, for example) technologies [11]. An effect of this increasing pervasiveness of networked computation in our environments and our lives is that data are also now ubiquitous and pervasive, influencing our perceptions and actions in ever more areas of individual and social life [20].

In the last few years, research has been made in order to understand how people interact with data. The field of human-data interaction places the human at the center of the data flows, and it is concerned with providing mechanisms for people to interact explicitly with the systems and data. [11]. In order to gain information or knowledge from it, people need to interact with data instead of only passively consuming it. This interaction goes beyond data analysis and includes an interactive exploration of data sets.

Human-data interaction lies on three core principles: legibility, agency and negotiability. Legibility is about making data and analytics comprehensible to users. Agency means managing our data and access to it. Negotiability means enabling the ongoing engagement of users so that they can withdraw from data processing and can derive value from data harvesting for themselves [11].

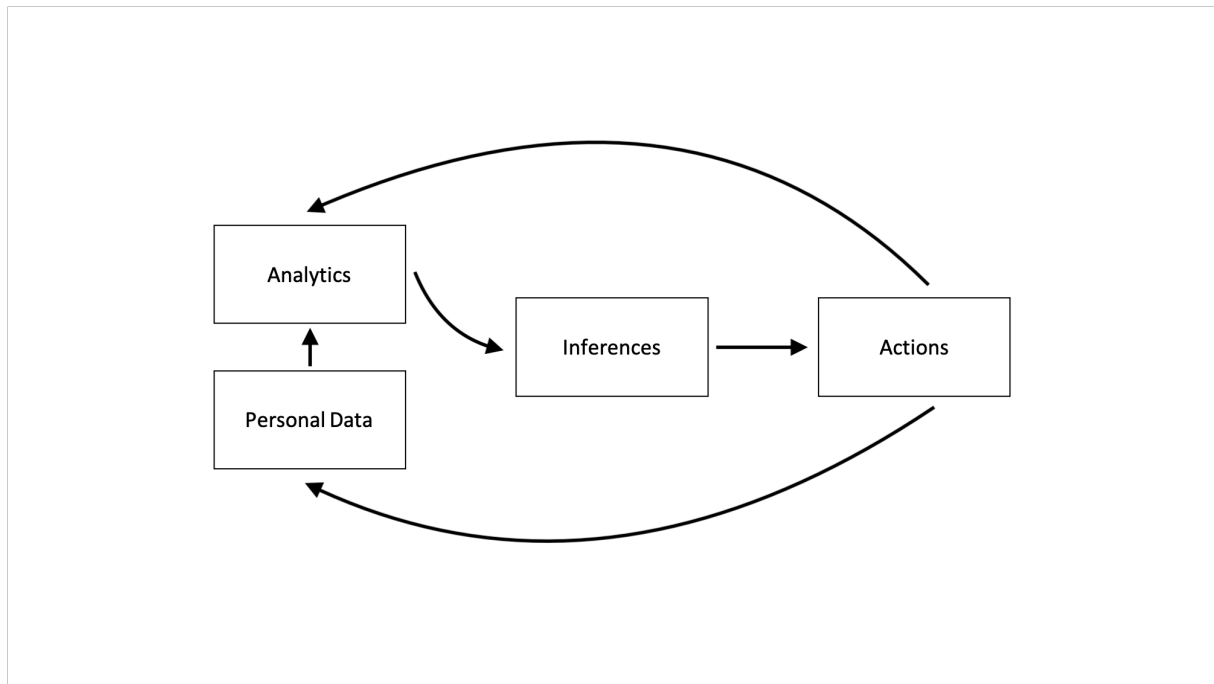


Figure 2.8: Data flow in the human data interaction

In figure 2.8 are represented the data flows in the human-data interaction model. We generate data, which is analyzed to produce inferences. These inferences in turn are fed back, affecting our behavior and becoming themselves the subject of further analysis.

2.4 Examples

In order to better understand the state of the art in terms of ubiquitous analytics and public displays, in the following subsections, we will present relevant systems and analyze their main goals.

2.4.1 Tacita

Personalization systems raise major privacy and consent concerns. Tacita was designed to address user's privacy issues, while it still delivers personalized content through public displays. Tacita relies on proximity detection technology that is capable of detecting the user's presence near a certain display. Then, viewers need to start a trust relationship with a cloud-based content provider [17]. So, instead of

having to trust an unlimited number of display providers and disclose their identity to them, users create a relationship with that cloud-based content provider [15]. Figure 2.9 illustrates Tacita's architecture.

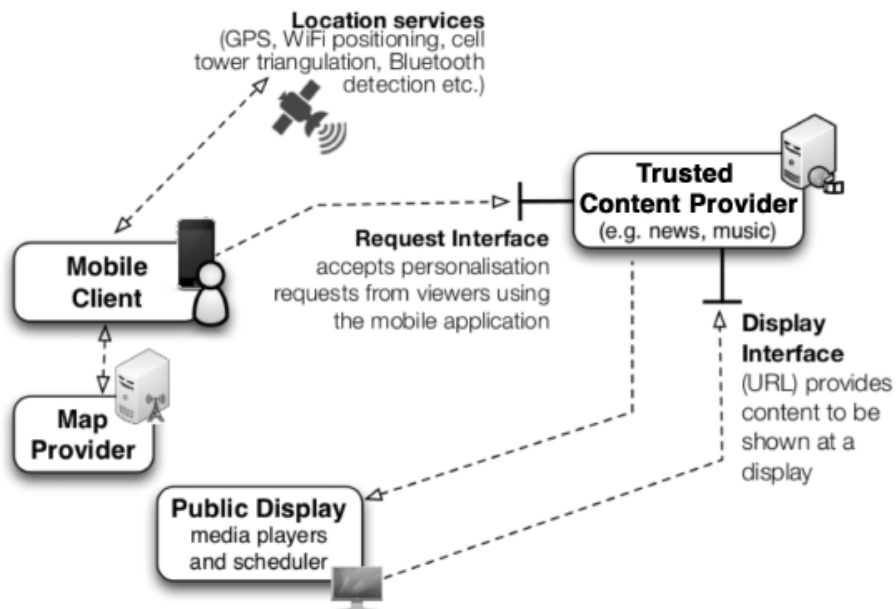


Figure 2.9: Tacita's architecture [2]

From the user's perspective, they need to install Tacita's mobile client and choose to activate the applications that correspond to the content they want to personalize. Once a display is detected, a request is made to the activated application and that makes a request to the display, so the content can be changed [2].

In figure 2.10 is a public display personalized using Tacita.



Figure 2.10: Personalized public display

2.4.2 TOMI

TOMI³ is an interactive urban solution that delivers relevant information about the place where it is deployed. TOMI's goal is to bring cities closer to people who live, work and travel in them. It is very innovative, user-friendly and a unique way to promote multiple activities and points of interest such as touristic, cultural, local commerce, public services among others.

It consists of public displays deployed in different cities around the world with which users can interact through touch, and discover urban information that matters to people at a micro-local level.

³<https://tomiworld.com/>



Figure 2.11: TOMI

2.4.3 Munin

Munin is a software framework for building visualizations and analytics environments, consisting of multiple input and output surfaces, such as tabletop displays, wall-mounted displays, and mobile devices. These environments require managing distribution of data, computation, visual representations, and interaction between participating devices [3].

Munin utilizes a service-based model where each device provides one or more services for input, display, or computation. Using a peer-to-peer model for communication, it leverages IP multicast to replicate the shared state among the peers. Input is handled through a shared event channel that lets input and output devices be fully decoupled. It also provides a data-driven scene graph to delegate rendering to peers, thus creating a robust, fault-tolerant, decentralized system [3].

The Munin framework is similar in scope and goals to many existing middleware solutions for ubiquitous and distributed user interfaces, but Munin is tailored specifically for high-performance data visualization.

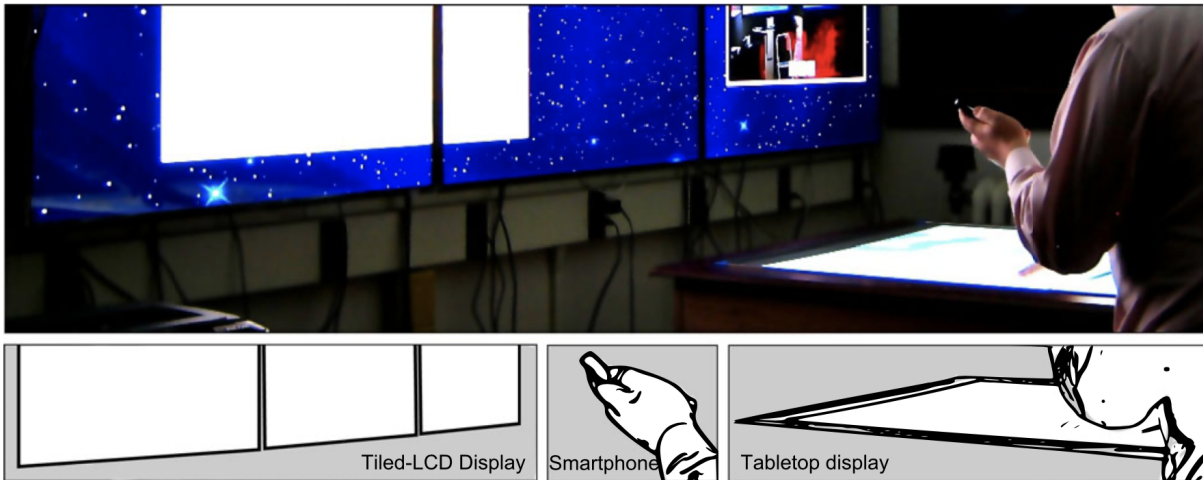


Figure 2.12: Example of a ubiquitous analytics space using the Munin toolkit [3]

2.4.4 Vistrates

Data visualization is an integral part of the analytical pipeline including many activities from data exploration to presentation. It often requires people with different areas of expertise working together. Collaboration among these highly specialized people is a key factor to success, with tools allowing to work anytime and anywhere cross-device [4].

Vistrates is a literate computing platform for developing, assembling, and sharing visualization components. It allows realizing component model design for data visualization to promote modular designs of visualization tools that enhance their analytical scope and supports unification [4].

From a visualization perspective, Vistrates features cross-cutting components for visual representations, interaction, collaboration, and device responsiveness maintained in a component repository. From a development perspective, Vistrates offers a collaborative programming environment where everyone can compose component pipelines for specific analytical activities [4].

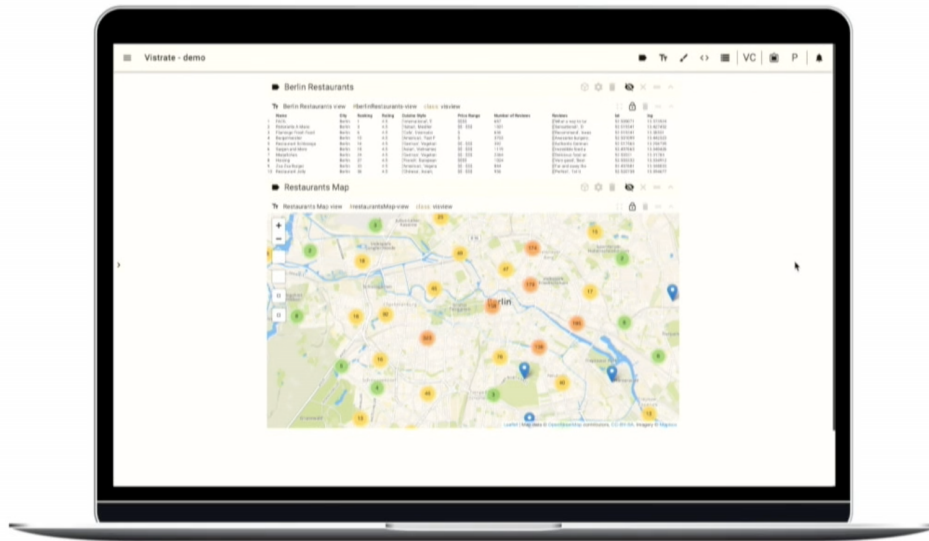


Figure 2.13: Example of Vistrates [4]

2.4.5 Valletto

People increasingly like to access data of interest whenever and wherever they want. Therefore, interfaces for visual analytics require a paradigm shift.

Valletto is a prototypical tablet app that is structured into four tabs, as illustrated in figure 2.14: the first shows for each available data attribute its corresponding histogram as well as standard statistical values, the second implement the multimodal visual analytics, the third shows history, and the fourth contains the user's meta information [5].

To allow the user to interact with the data and analytics, with more data-specific intents (generate include/exclude data attributes, filter, for example) the interaction is done through speech. In the case of adjusting the visual encoding, it is easier and faster to use gestures to search for a suitable visual encoding.

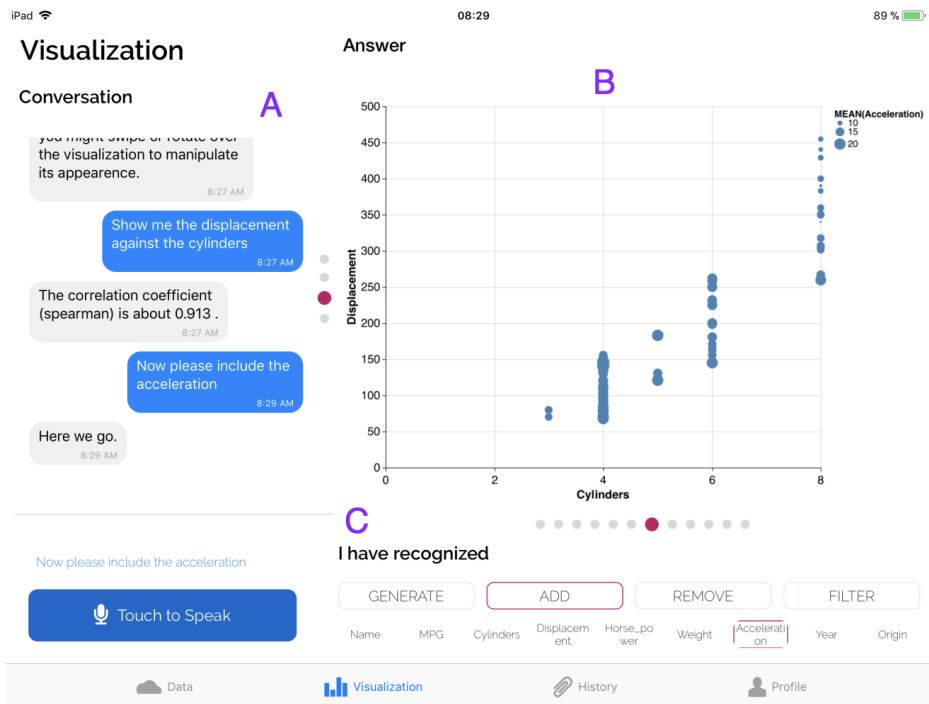


Figure 2.14: Valletto [5]

2.5 Discussion

As already mentioned, one of the most important points of this work is that the dashboard that we develop should be part of the environment where it will be deployed, not only reflecting the activities, mobility, population and culture of the place, but also adding something to the community, giving useful and relevant information for viewers.

Considering the moment in history that we are in where ubiquitous computing is a reality and when, in developed countries, almost everyone has a smartphone, we have the opportunity to create something that is an extension of the viewers who are close to the public display and allow people to contribute to the content directly. Similar to one of the examples presented previously, the Munin framework, each display will have several inputs, the viewers' mobile phones and the information stored on the display itself, and each display will then generate an output that will be shown on it.

Although video format is the one viewers find more attractive, this would limit user customization, content diversity and scheduling. This way, similar to what happens in the TOMI display example, we believe that the content should be dynamic, be it text, graphics, or images, with movement, to attract attention. That will also allow the content to appear and disappear when it makes sense.

In addition to people's contributions, we also believe that we have the opportunity to include other

dimensions as a source of situatedness. Good options are a location map, which is a location dimension source, or the events that will happen in the surroundings or buses that will pass on that place, which support the activity dimension.

To conclude, as in the field of human-data interaction, we intend to place the viewer at the center of the system flows, providing mechanisms for people to interact with it.

3

Dashboard System

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Public displays aim to become the backbone of a new global communication medium in a world of ubiquitous computing. While they should disappear in the background and be perceived as part of our environment, they should also stand out enough to be used for their intended purpose.

Our goal was to develop a dashboard to be deployed on displays around cities that give passers-by, locals or tourists, relevant information about the place. Through the research presented before, where we were able to understand the state of the art in the area of public displays and the interaction between them, data and viewers, we were capable to identify the main points we need to focus on when developing such a system.

In this section, we will present the requirements for the project, as well as how the conclusions of our research shaped the final solution. After that, we will give a brief overview of the functionalities of the system and how you can interact with it. Lastly, the architecture and technologies used for developing the dashboard will be presented.

3.1 Requirements

The starting premise of this work was to create a dashboard with ubiquitous data that the viewers can interact with, in a way that the dashboard and its analytics are part of their environment. That dashboard will be deployed on public displays scattered around the Madeira Islands.

The data being displayed was collected as part of a previous project, using a non-intrusive positioning system. The goal of that work was to analyze and understand the movement and behavior of people around town, which can be useful for urban planning, tourist tracking or passer-by counters [21]. Our project builds on this previous work done in the context of the Beanstalk¹ project. Beanstalk is a multidisciplinary project with the aim of designing and delivering a product to the board of the Tourism of Madeira that allows them to analyze trends in tourism and marketing, that can stimulate the local economy.

Based on the project objectives and the research conducted, we can summarize the requirements in the following points.

- Viewers find video more attractive but are more likely to spend time looking at physical signage. This is explained by the fact that, although digital signage is more attractive and dynamic, viewers prefer to have control over what they want to see at the moment. Thus, the dynamic of the content is important to catch attention, but viewers need to be able to see the information they consider important in order to carry out the interaction with the display. The key to this question is personalization. The display should give the power to change its content to viewers. In our case, the model we are using for personalization is active personalization.

¹ <https://beanstalk.arditi.pt/>

- In order to achieve this relevant communication between the passers-by and the display, each viewer should be able to connect with the display that it is in his/her surroundings. That communication should be conducted through the viewer's mobile phone, since we expect, based on the numbers presented before, the majority of the people to have a mobile phone.
- This personalization described requires handling personal information. That leads to a few concerns regarding privacy and security. The development of the system and the personalization of the dashboard has to be developed in a way that does not disclose revealing content or personal identity.
- The displays industry is still lacking a scheduling system that changes the content based on external factors. Our dashboard should have a system that delivers the content that is required by the viewers at a time where it is still relevant. Besides that, the scheduling system needs to be scalable and be able to make decisions when it has several contradictory external factors.
- The dashboard should reflect the environment and the people in the environment where the display will be deployed in. In our case, the Madeira Islands.

After having these requirements defined, we can then start designing a prototype that meets them.

This work was developed following an iterative and incremental methodology. This allows the team to take advantage of what is being learned during the development of earlier versions of the system. Key steps in the process were to start with a simple implementation of a subset of the software requirements and iteratively enhance the evolving sequence of versions until the full system is implemented. At each iteration, design modifications are made along with adding new functional capabilities [22].

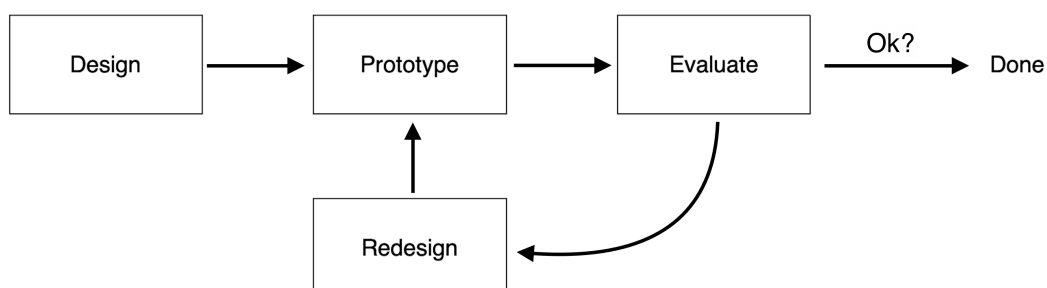


Figure 3.1: Development methodology used

3.2 Data

As previously stated, the data that we will be using was collected as part of research to understand the flow and dynamics of tourism in Madeira Islands, in the context of the Beanstalk project. The data was gathered through a Wi-Fi monitoring infrastructure, with routers placed in different locations in Madeira in order to be able to capture how many people passed by that specific location [21].

To populate the dashboards we consume data from the endpoints made available to access that data. To make this possible, every screen is linked to its nearest router. The information captured by that router is the one that will be displayed on that screen. Besides the router, every screen has also a location name and POI identifier, which are also used as reference points. POI stands for point of interest.

The data available as well as the endpoints we use to get it are described in the table below. These data can also be visualized in the ViTFlow Dashboard².

/get-routers	routers in the system
/get-active-routers	active routers in the last minutes
/get-place-count/router_id	daily count for the selected router within dates
/get-place-count-detailed/router_id	daily count with specification of locals, tourists, random for the selected router within dates
/get-hourly-place-count-detailed/router_id	hourly count with specification of locals, tourists, random for the selected router within dates
/get-hourly-count/router_id	hourly count for the selected router within the dates
/get-flow	number of leaps IN and OUT of each location
/get-events	Madeira's events
/get-curr-events	Madeira's current events
/get-mac-groups	mac address group combinations
/get-port-transit	get port foreign ships transit within dates
/get-bus-route	buses routes
/get-bus-stop-times	bus route with stops, theoretical times and weekdays
/get-poi	points of interest as reference points
/get-social-media	daily post/review counts from instagram, twitter, flickr, airbnb, tripadvisor
/meteo/get-prediction/location_name	daily meteorology prediction for the selected location

Table 3.1: Data endpoints

²<http://vitflow.m-iti.org/>

3.3 Low and High Fidelity Prototyping

We started the development of this work by prototyping. Prototyping provides a communication basis for discussions among all the groups involved in the development process. Prototypes help in identifying difficulties, clarifying problems, and arriving at design decisions, before too many resources are used [23].

The first step to handle was the low-fidelity prototype. We decided to use the paper prototyping technique since it allows us to demonstrate the behavior of an interface very early in development and test designs with real users. It is a technique that can dramatically increase quality. It is fast, it brings results early in development (when it is relatively cheap to make changes), and allows a team to try far more ideas than they could with high-fidelity prototypes [24].

In 3.2 is the low-fidelity prototype developed for this work that allowed us to check if the design fulfilled the requirements and in what ways we could visualize the data we had. The designs were developed taking into account the data that we had, that was gathered previously.



Figure 3.2: Low-fidelity prototype developed for the project

As we can see on figure 3.2, the main screen contains a map, which gives the display a location dimension as source of situatedness. Also on main page, we have information regarding buses and

events, that represent an activity dimension, contributing to situatedness also.

The flow between the several pages will be defined by the interaction with the viewers. That interaction will be explicit, the viewers are just passing by and they are the ones that decide to interact with the display, and will be mediated through their mobile phones. This interaction will work as content scheduler: the content is changed based on the preferences that the views communicate to the public display.

Since the visual component of this project is crucial for its success, after validating the LFP, the team developed the high-fidelity prototype (HFP), which is shown on figure 3.3.

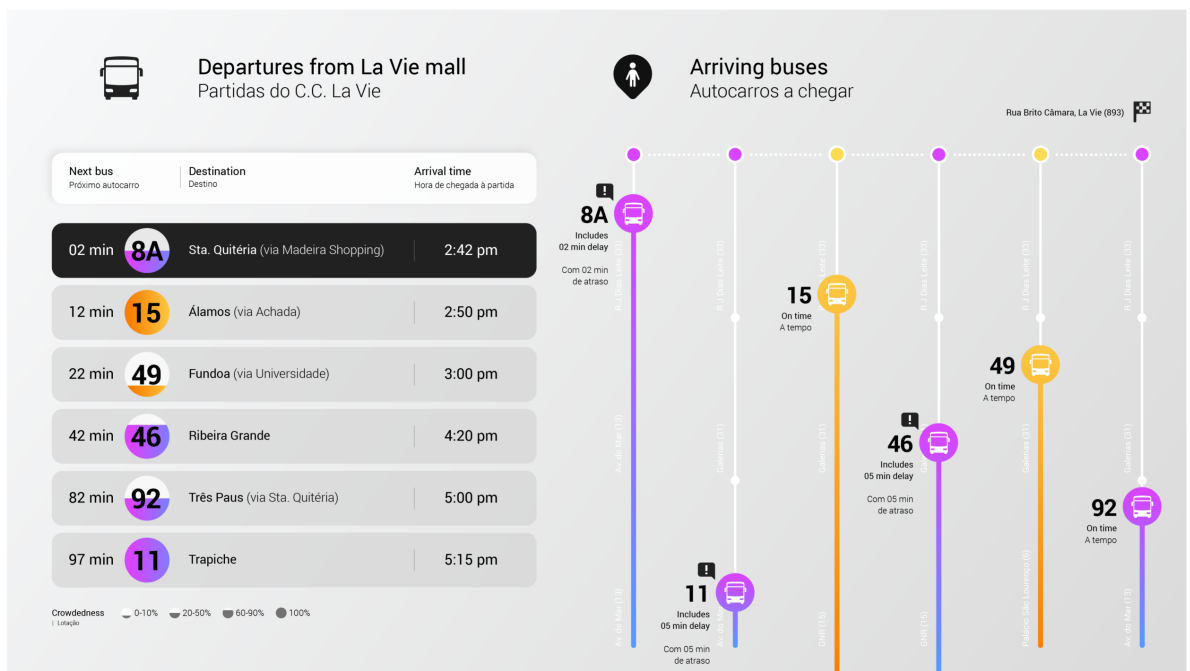
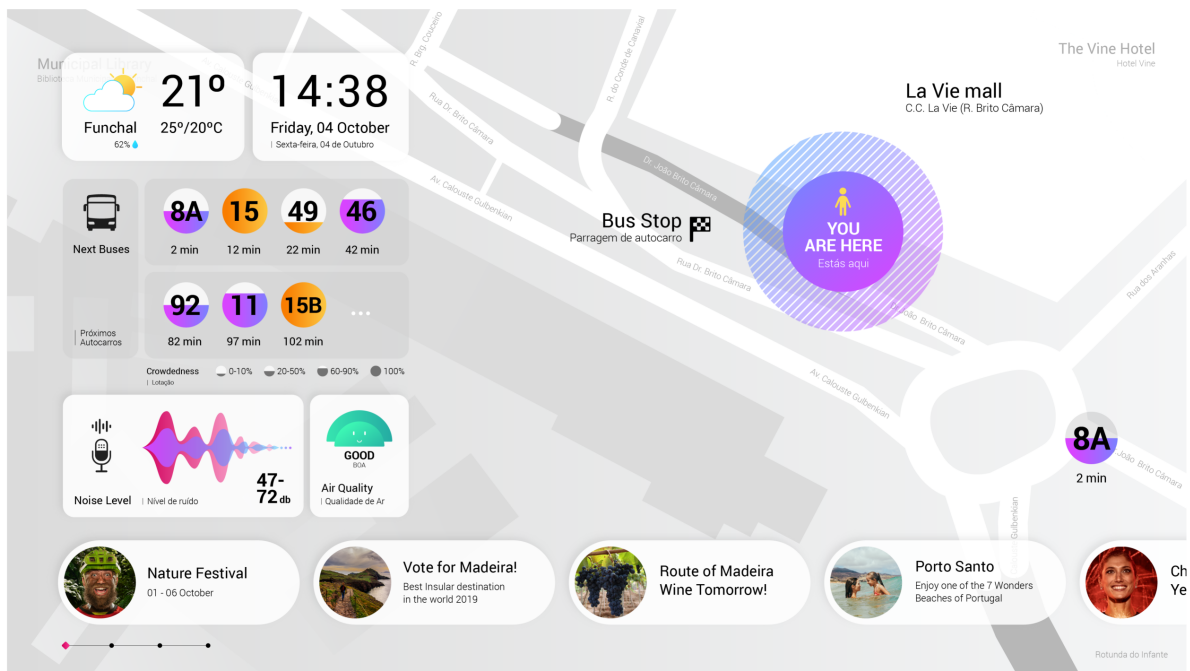


Figure 3.3: High-fidelity prototype developed for the project

3.4 Functional Prototype

The last step was to develop a functional prototype, which is a prototype much similar to the final product, that captures both its appearance and functionality. Throughout this section, we will describe the steps necessary to follow when deploying the dashboard on a certain public display, the different pages of the dashboard, what information we can find in them and how it is possible to interact with the dashboard and personalize it.

3.4.1 Setup

As previously mentioned, the goal of the dashboard is to be deployed on different public displays scattered around Madeira Islands. As such, the information that each one of the displays will be presenting will be related to the place where the display is situated. To achieve this, we need to complete a list of steps so the dashboard can get the right information for the place it is at.

Firstly, we need to create a CSV with the displays' latitude and longitude, as shown in figure 3.4 as an example. Each line represents the exact location of a different display. When the file is ready, we can run a task that will create these displays on the database, give each one of them an identifier and associate them with the closest router, the name of the location and the POI identifier of the place they are deployed at.

```
1  "{:latitude=>32.6593933, :longitude=>-16.9259481}"
2  "{:latitude=>32.6940941, :longitude=>-16.7748073}"
3  "{:latitude=>32.6480984, :longitude=>-16.9069047}"
4  "{:latitude=>32.6471827, :longitude=>-16.9113031}"
5  "{:latitude=>32.6497724, :longitude=>-16.9086465}"
```

Figure 3.4: CSV with screens locations

Then, another task should be run in order to import the data of the buses to the database and associate each bus stop to the nearest displays. The data for the buses is consumed from the endpoints mentioned above. It is being imported to the database and not used directly from the endpoint, unlike the rest of the data, because there is too much of it and would take a long time to process in the runtime. Storing it in the database, the relations between the displays and the corresponding bus stops are previously created, and much faster to get at the moment that are needed. Every time the bus routes are updated on the islands we can rerun this task to update the schedule that we have stored.

The setup is now complete. To find the dashboard of a certain display, we need to add the display identifier after the dashboard URL, as shown in figure 3.5. In this case, we are seeing display number 4.

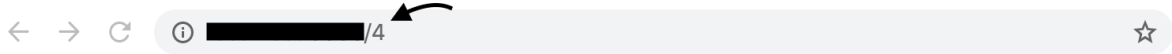


Figure 3.5: Public display identifier

3.4.2 Main page

When we access the dashboard URL, we are presented with the main page of the dashboard, which contains analytics for that display environment. The background of the main page is composed of a map of the screen localization.

When we first render the dashboard, the data that is needed for the system to run is all loaded. This happens so we avoid repeated requests, once that the data that is used for all the other pages is the same as the one that is shown on the main page, only on the main page is summarized. Besides that, this way, the data is always synchronized and updated when necessary, and we do not have to wait for the requests to end when we change pages.

The main page is composed of a few different widgets, with different types of information. In the next sections, we will describe each one of them and the different variations they can take depending on the data.

In the future, more widgets can be easily added without compromising the proper functioning of the dashboard.

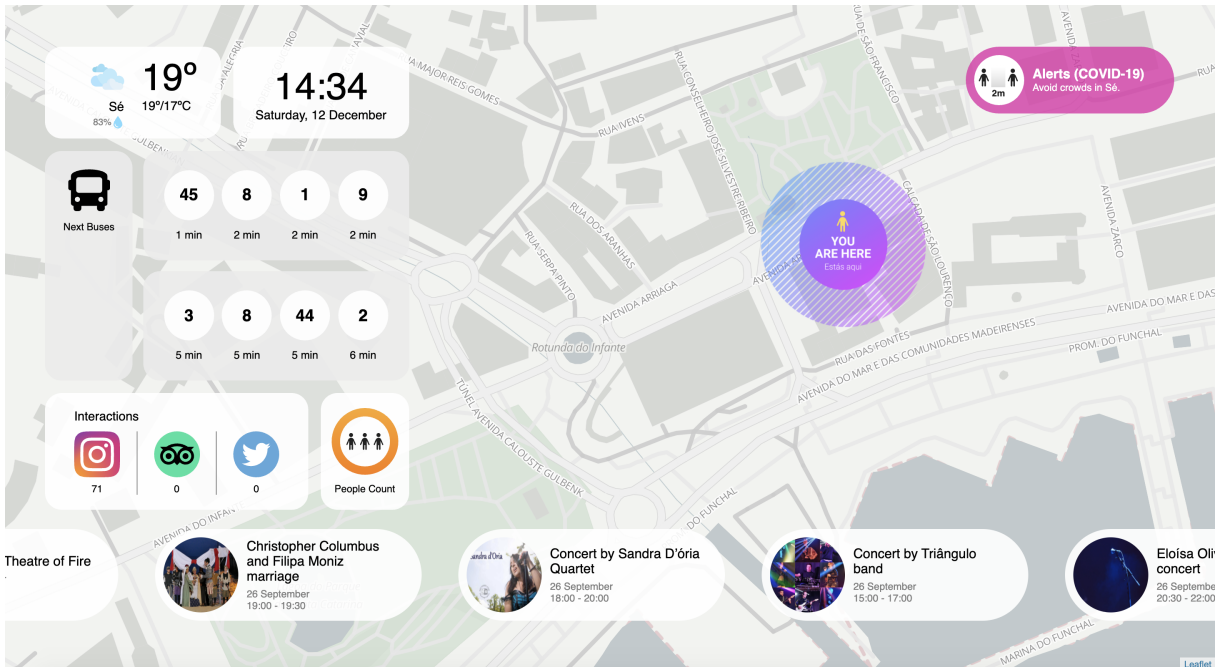


Figure 3.6: Dashboard's main page

3.4.2.A Position marker

The marker represented on figure 3.7 sign the exact place where the public display is located, which means, where we are on the map. The coordinates used for this position are the ones we introduced on the CSV.

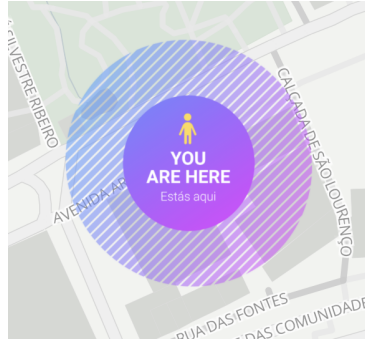


Figure 3.7: Public display position

3.4.2.B Meteorology

The first widget on the top left corner is meteorology. To populate this widget we are using /meteo/get-prediction endpoint, where we can get the meteorology for a certain location name and for a certain date range. It is refreshed every hour. An example of the JSON returned by the endpoint is illustrated in figure 3.8.

```
1  {
2  {
3    "datetime": "2020-12-12T00:00:00.000Z",
4    "date": "2020-12-12T00:00:00.000Z",
5    "hour": 0,
6    "temp": 18,
7    "humid": 85,
8    "rain": 0,
9    "cloud": 41,
10   "wind_speed": 4,
11   "wind_direction": 310,
12   "key_name": "FUNCHAL",
13   "lat": 32.649337,
14   "long": -16.986994,
15   "id_poi": 232
16  },
17  ...
18  {
19    "datetime": "2020-12-12T23:00:00.000Z",
20    "date": "2020-12-12T00:00:00.000Z",
21    "hour": 23,
22    "temp": 18,
23    "humid": 78,
24    "rain": 0,
25    "cloud": 97,
26    "wind_speed": 6,
27    "wind_direction": 253,
28    "key_name": "FUNCHAL",
29    "lat": 32.649337,
30    "long": -16.986994,
31    "id_poi": 232
32  }
33 }
```

Figure 3.8: Meteorology endpoint response

We have several meteorology related info on this widget. Looking at figure 3.9, on number 1 we can

find the current temperature in Celsius degrees, which is updated every hour. On number 2 we have the maximum and minimum temperature, respectively, for the day. On 3 we have the current humidity, which is also updated every hour. On 4 is the location name where the display is at. On number 5 we can find a small image representative of the climate right now. This can take several states represented in figure 3.10.

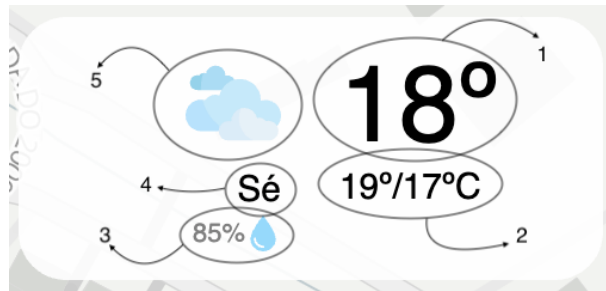


Figure 3.9: Meteorology widget

The icon on (a) represents the night and is shown from 8 pm to 6 am. During the day, from 6 am to 8 pm, we have four different options. If the 'rain parameter' that is returned by the endpoint is more than zero, (b) is shown. If the 'cloud parameter' is more than 50 we show (c) and if it's between 25 and 50 we show (d). If none of the above is true, (e) is shown.



Figure 3.10: Meteorology icon states

3.4.2.C Time and date

This widget simply showcases the current time and date for the timezone the public display is in.



Figure 3.11: Time and date widget

3.4.2.D Next buses

Next buses displays how much time is left for the next buses that are linked to this display to pass. Each display has links to the nearest bus stops, and those bus stops are part of different bus routes. On this widget, we can find eight circles, that represent the next eight buses that are going to stop around this public display. Inside the circle is their route number - so it is possible to identify them - and under it is how much time is left for the next bus from that route.

The information used to populate this widget is stored in the database, as previously explained. All the buses for a day are loaded and stored at the front end and refreshed at the beginning of every day.

The next buses are updated every minute, so the buses that have a time left less than zero, which means they already passed, disappear, the other ones are updated and new routes appear at the end.

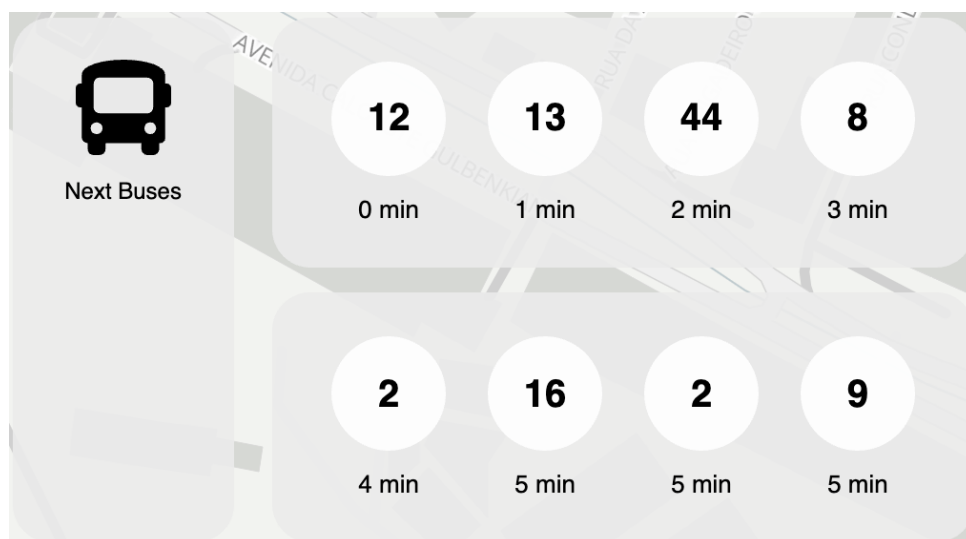


Figure 3.12: Next buses widget

3.4.2.E Interactions

On interactions widget, we can find three numbers related to the interactions of the people with the Madeira Islands in social media. From left to right, we first have the number of Instagram posts related to Madeira that were published today, the number of TripAdvisor reviews of places in the islands, and lastly the number of tweets.

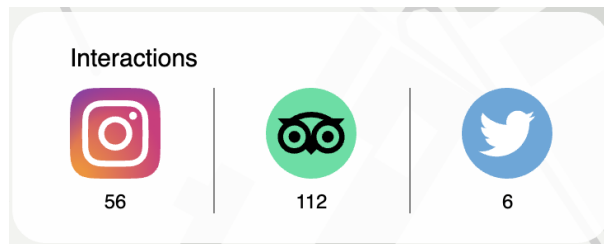


Figure 3.13: Interactions widget

To populate this widget we are using /get-social-media endpoint which response is illustrated in figure 3.14, as an example.

```
1 {
2   {
3     "district_name": "Calheta",
4     "parish_name": "Arco da Calheta",
5     "id_POI": 10,
6     "name_POI": "Arco da Calheta",
7     "latitude": 32.71463165,
8     "longitude": -17.14913075,
9     "date": "2016-12-31T00:00:00.000Z",
10    "count": null,
11    "count_without_random": null,
12    "count_locals": null,
13    "count_visitors": null,
14    "count_random": null,
15    "estimated_people": null,
16    "estimated_locals": null,
17    "estimated_visitors": null,
18    "in_move_count": null,
19    "in_leap_count": null,
20    "out_move_count": null,
21    "out_leap_count": null,
22    "insta_posts": 2,
23    "tweet_count": null,
24    "count_insta_comments": 0,
25    "count_insta_likes": 52,
26    "tripad_reviews": null,
27    "tripad_avg_rating": null,
28    "flickr_count": null,
29    "airbnb_count": 8,
30    "airbnb_avg_rating": 4.7,
31    "airbnb_comment_count": 5,
32    "min_temp": 16,
33    "max_temp": 17,
34    "avg_temp": 16,
35    "min_humid": 61,
36    "max_humid": 95,
37    "avg_humid": 85,
38    "min_rain": 0,
39    "max_rain": 0,
40    "avg_rain": 0,
41    "min_cloud": 24,
42    "max_cloud": 100,
43    "avg_cloud": 77,
44    "min_wind_speed": 29,
45    "max_wind_speed": 42,
46    "avg_wind_speed": 37
47  }
48  ...
49 }
```

Figure 3.14: Interactions endpoint response

The parameters that are being used are 'insta_posts', 'tripad_reviews' and 'tweet_count'.

These values are referent to a day and are refreshed every hour to make sure that are as much up to date as possible.

3.4.2.F People Count

People count is the last widget in the vertical structure. This widget showcases the number of people that are around the public display at a given time.

To populate it we are using /get-hourly-count endpoint, which returns the number of the people around a certain router (the public display closest router), at every hour of the day. The endpoint response is illustrated in figure 3.15.

```
1  [
2    {
3      "router_id": 6,
4      "hour": 7,
5      "count": 14
6    },
7    ...
8    {
9      "router_id": 6,
10     "hour": 17,
11     "count": 79
12   }
13 ]
```

Figure 3.15: People count endpoint response

This information is refreshed hourly.

Depending on the number of people around, the widget takes different forms. If we have less than 50 people the widget is green (a). If we have more than 50 but less than 200, the widget changes to orange (b). If there are more than 200 people around, the widget is red, as in (c).



Figure 3.16: People count states

To make this widget more accurate, some further work could be done. The calculations for how many people is too many people could be done taking into account some other factors regarding the place, such as the area, if it is indoors/outdoors, etc.

3.4.2.G Events



Figure 3.17: Events widget

At the bottom of main page we have a carousel always moving with the events that are happening in Madeira this month. The data for this is consumed from the /get-curr-events endpoint. Although the information is for a month, it is refreshed daily just to make sure that is updated and there are not any new events. The endpoint's response is on figure 3.18.

```

1  [
2  {
3    "id": "3784",
4    "post_content": "<!-- wp:paragraph -->\n<p>Bordal presents a collection of
5    "trimmed_content": "Bordal presents a collection of original tapestries, in
6    "post_title": "A journey through Madeira Tapestries"",
7    "post_excerpt": "",
8    "perma": "a-journey-through-madeira-tapestries",
9    "post_guid": "https://eventsmadeira.com/?post_type=event&#038;p=3784",
10   "post_type": "event",
11   "post_status": "publish",
12   "comment_count": "0",
13   "post_modified": "2020-09-09 12:26:11",
14   "img_guid": "https://eventsmadeira.com/wp-content/uploads/2020/08/2-e153139
15   "start_date": "2020-09-03",
16   "start_time": "10:00",
17   "end_date": "2020-09-27",
18   "end_time": "18:00",
19   "repeat_times_raw": null,
20   "photo": "default",
21   "lat": "32.647103",
22   "lon": "-16.908100",
23   "thumbnail_id": "2733",
24   "venue_data": "a:1:{i:3782;i:3782;}",
25   "venue_id": "3782",
26   "venue_title": "Assembleia Legislativa da Madeira",
27   "venue_perma": "assembleia-legislativa-da-madeira",
28   "venue_content": "<!-- wp:paragraph -->\n<p>Bordal presents a collection of
29   "venue_guid": "https://eventsmadeira.com/?post_type=venue&#038;p=3782",
30   "thumbnail_guid": "https://eventsmadeira.com/wp-content/uploads/2020/08/2-e
31   "cats": [],
32   "tags": [],
33   "cats_id": [],
34   "tags_id": [],
35   "post_title_pt": ""Viagem pelas Tapeçarias da Madeira"",
36   "post_content_pt": "<!-- wp:paragraph {\"translatedWithWPMLTM\": \"1\"} -->\n
37   "post_id_pt": "3786",
38   "photo_gallery_ids": null,
39   "photo_gallery": [],
40   "repeat_times": []
41 }
42 ...
43 ]

```

Figure 3.18: Events endpoint response

Each card, illustrated on figure 3.19, represents an event and is part of the carousel. On 1 we have the name of the event, which is truncated if it has more than 70 characters. On number 2 it is the date of the beginning and finishing, if different, of the event. On 3 we have the beginning and finishing hours. On 4 it is an image representative of the event, that also comes from the endpoint.



Figure 3.19: Events widget card

3.4.3 Other pages

Besides the main page, the system also has three more pages with more detailed information. As previously explained, all the data necessary for the system to run is loaded at the beginning and the same data that is used for the widgets is also used for the pages. The difference relies in the detail of the information presented, the one on the pages being much more extensive. Being the data the same means that is consumed from the same place that the widgets and is updated at the same time.

Right now we have three more pages: next buses page, events page, and people count page. As the names suggest, they extend the information that the widgets with the same name present.

The idea is to add more pages in the future, with different kinds of information. That would be done easily, without threatening the proper functioning of the dashboard.

3.4.3.A Next buses page

On the next buses page, we have the same information that we have on the widget: the number of the route of the bus (on 2) and the time that is left for that same bus (on 1). Besides that, we also have information about the destination of that bus (on 3) and the time that the bus is supposed to arrive at the stop we are at (on 4). On 5 we can see the name of the public display that we are consulting and where we will hop on the bus.

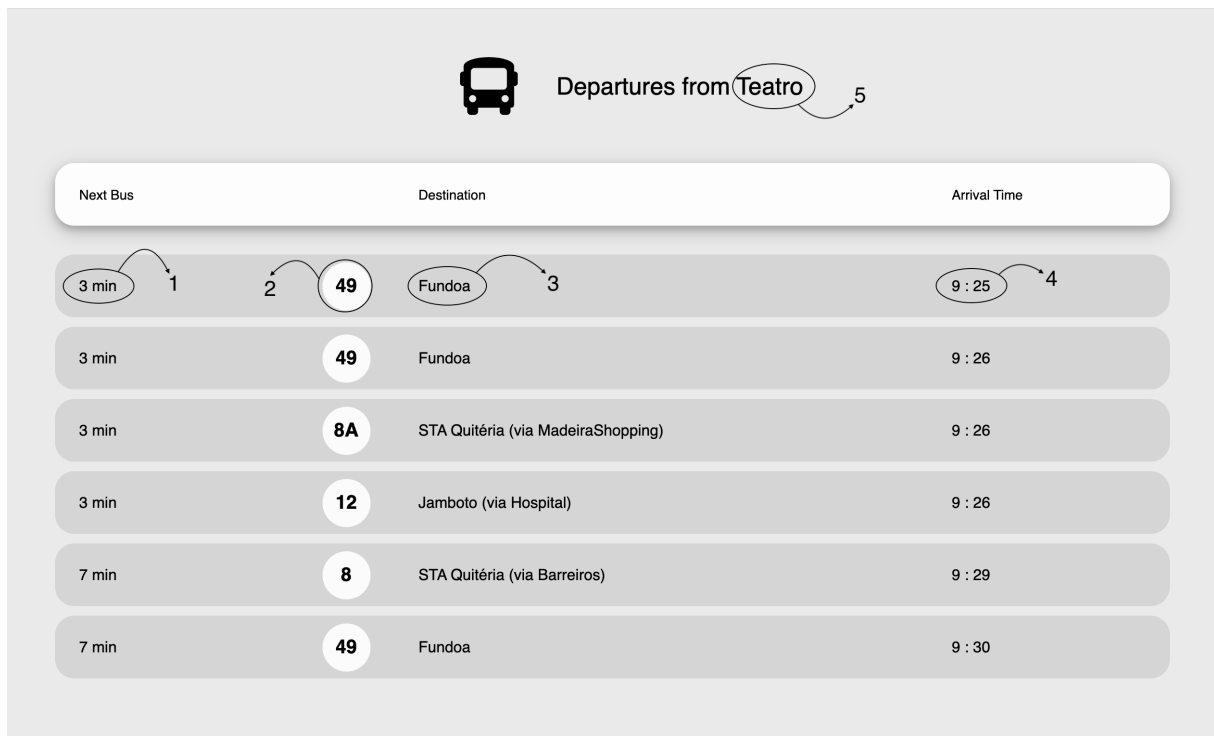


Figure 3.20: Next buses page

3.4.3.B Events page

The events page consists of a carousel that moves every few seconds and shows detailed information about the several events that are happening this month in the Madeira Islands. Each carousel item has the size of the screen, as we can see in figure 3.21.

At the top, we have an image relevant to the event and the respective title (on 1). On the right side of the page, we have the starting time and date (on 2), the ending time and date (on 3), and the location where is going to take place (on 4). On number 5 we have a small description of the event. Lastly, on 6, we can have one or more categories that were assigned to the event.

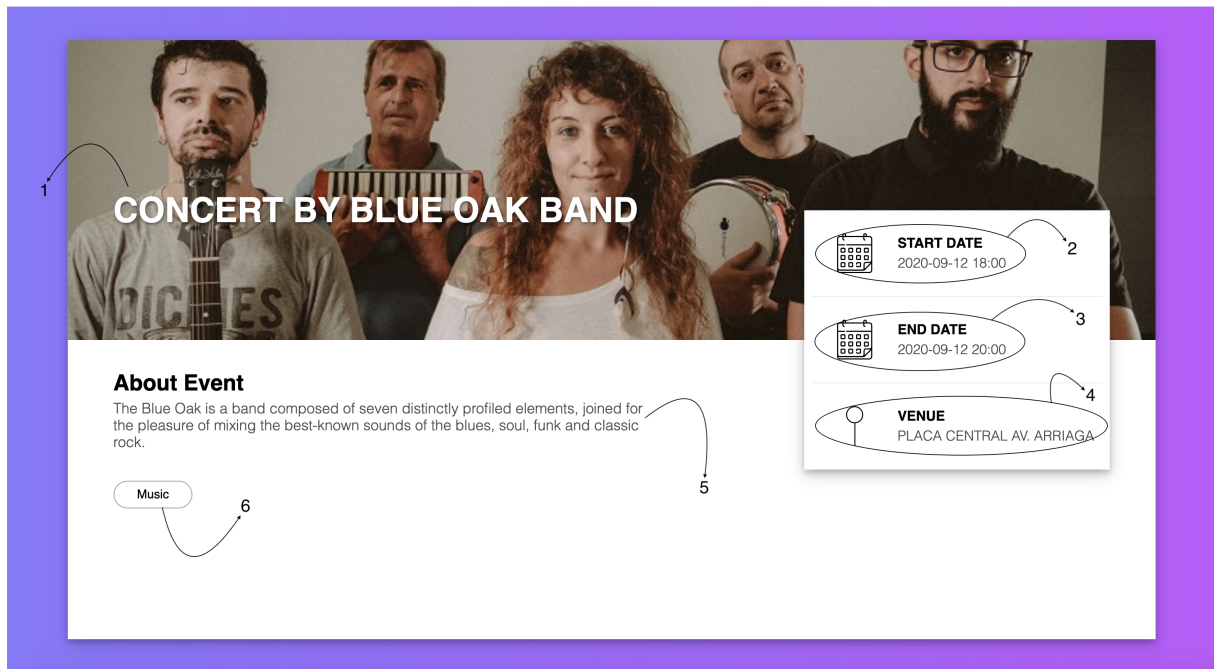


Figure 3.21: Events page item

3.4.3.C People count page

The people count page's goal is to show off where are the most crowded places in the neighborhood. Having this information available is not only useful in the pandemic situation we are living in at the time of the writing of this work, but will also allow us in the future to know what places are more crowded.

This is the only page that has different information comparing the page and the widget. While in the widget we show data about the number of people around the nearest router of the public display, we here present information from several routers that are within a radius of some meters of the public display. Each bubble is centered on one of those routers, and its size and color depend on how many people are passing that router, as stated in the legend. The diameter of the bubbles is calculated using a logarithmic function. In the bottom bar, we can also find the names of the places where the routers are, which are the center of each bubble.

This bubble map chart was built with the Leaflet library, as the main page. As the widget, the accuracy of this page could be improved with some more information about the places, which would allow us to understand how crowded it is, but that was not in the scope of this work.

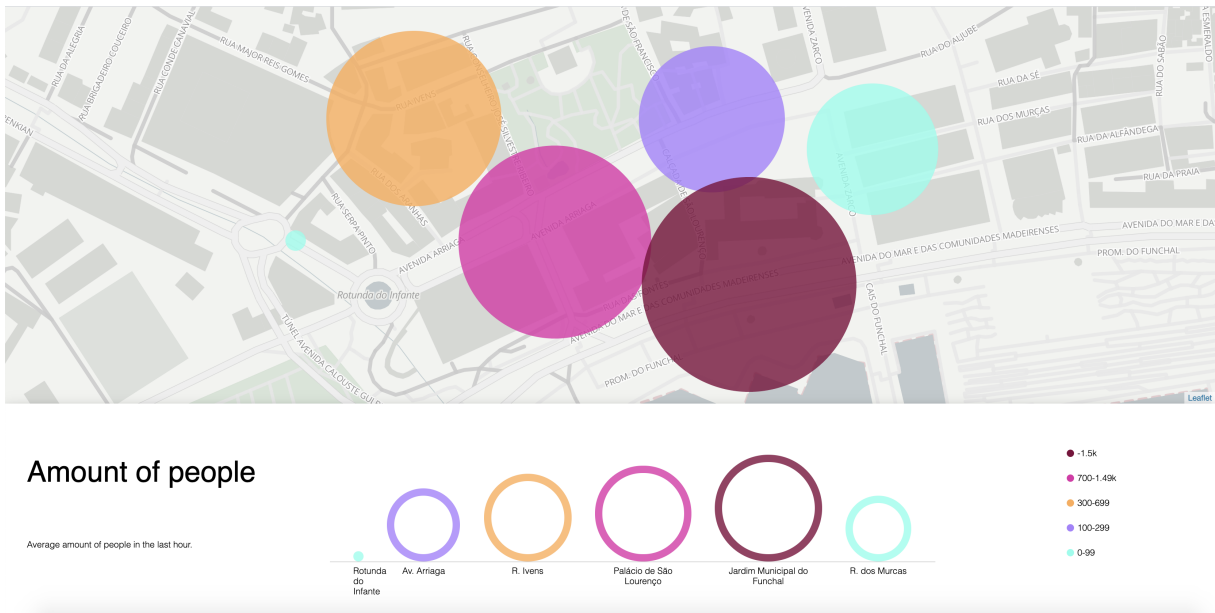


Figure 3.22: People count page

3.4.4 Notification

Besides the widgets and the pages, we have one more component: the notification. The notification is a component with a structure as represented in figure 3.23, that appears at the top right corner of the dashboard and can highlight varied information. It appears every other minute, lasting one on the screen.

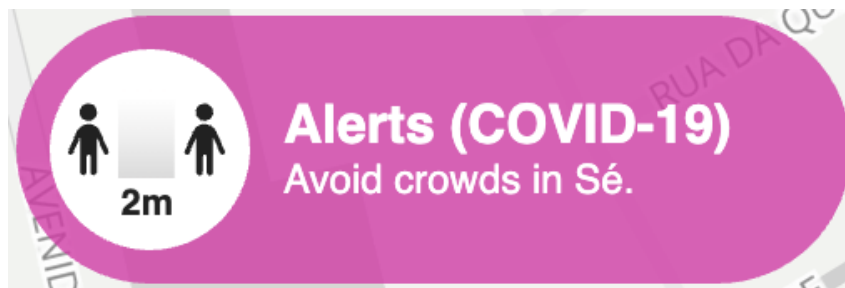


Figure 3.23: Notification

As of now, the purpose of the notification is to draw attention to viewers to respect the social distancing, showing off what are the most crowded places at the moment. That way, people can keep away from those places, avoiding clusters.

As explained on the people count page subsection, we collect information about the number of people from several routers that are within a radius of some meters of the public display. If there are two or more places that count more than 200 people around, the notification shows the names of the two that are more crowded. If only one of the routers captures more than 200 people, the notification only

showcases that one place. If none of the routers detect more than 200 people around, the notification does not show up.

The notification is independent of the other pages, can appear in front of any of them.

3.4.5 Personalization

When we access the dashboard URL, with the public display identification, we are presented with the main page. The way we navigate to the other ones is the key to the personalization component of the dashboard.

One of the requirements of this work was for the dashboard to be personalizable through the mobile phones of passers-by. The authentication of the user and access to the communication with the public display is not on the scope of this work, so in the project and description we assume that the user is authorized to communicate its preferences to the display.

In figure 3.24 we have a scheme of how personalization works. It starts with the viewer having on its mobile phone an application that allows choosing what kind of information he/she wants to see in the public display that he/she has around. The development of that application is not in the scope of this work. When the viewer has a display in his/her surroundings, he/she can send, through that application, what he/she wants to see in more detail. The preferences of the viewers are saved.

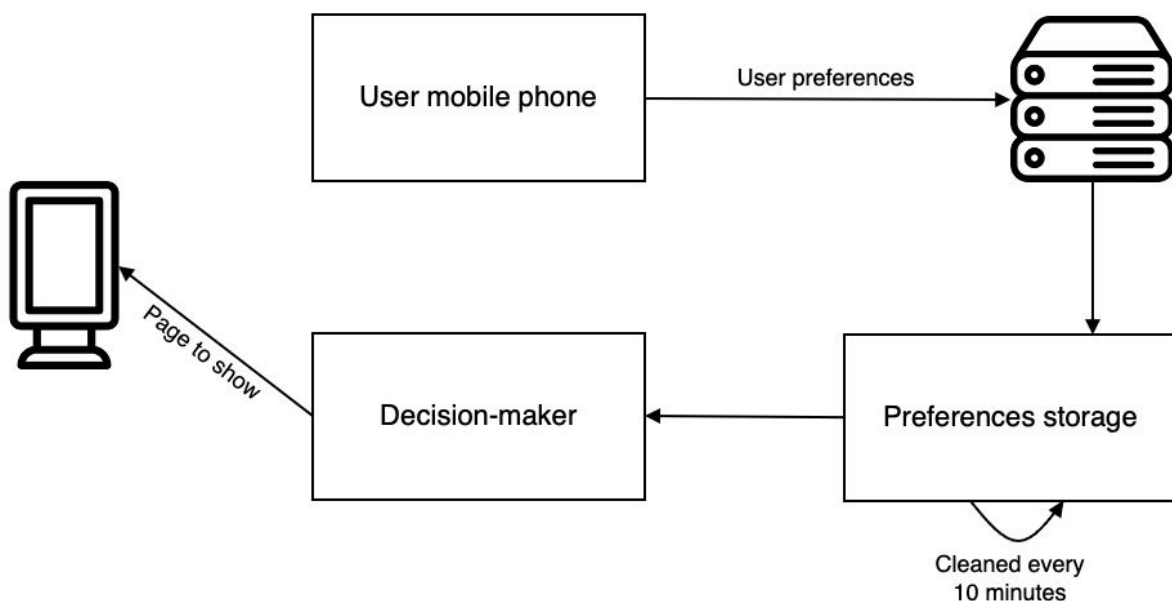


Figure 3.24: Personalization flow

Every minute, some criteria are evaluated in order to understand which page should be shown next. For the time being, we have two criteria: how many viewers prefer to see each page, and how many rounds there have been since the last time each page was shown. There are some exceptions but

briefly, this means that if a user expresses a preference on two different pages, the one that is shown is the one that was shown lastly more rounds ago. If no user expresses a preference, the main page is shown. The decision making process is explained in detail in the next section.

3.5 Architecture

To develop the project we used a layered architecture pattern. This pattern, as the name says, is organized into horizontal layers and each layer performs a specific role and responsibility within the application (in this case, presentation, business, database) [25], as we can see in figure 3.25. This pattern supports the incremental methodology and creates abstraction and isolation around each layer.

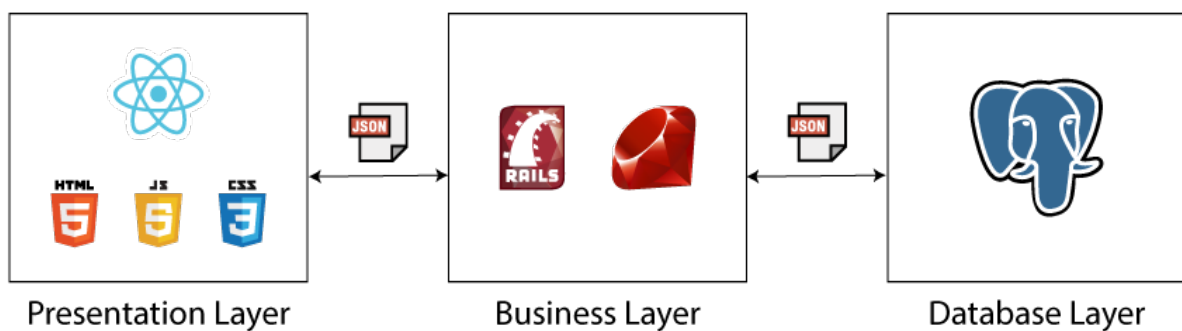


Figure 3.25: System architecture

Our application has three layers: presentation layer, business layer, and database layer. They communicate with each other through JSON files. A JSON file is a file that stores simple data structures and is a standard data interchange format.

3.5.1 Database layer

The database layer is responsible for managing and storing the local data that is used in the system, the one that is not directly consumed from the previously presented external endpoints at runtime.

We started by creating the entity-relationship model in order to understand which entities and relationships we needed. As presented in figure 3.26, our database is going to be very simple since the rest of the data is going to be consumed directly from the external endpoints. For accessing the external endpoints, we use the screen identifier to get the router_id, location_key_name and poi_id, depending on the endpoint.

The database was developed in PostgreSQL. PostgreSQL is an object-relational database system that uses and extends the SQL language combined with many features that safely store and scale the most complicated data workloads. Some of the advantages pointed are its proven architecture, reliability,

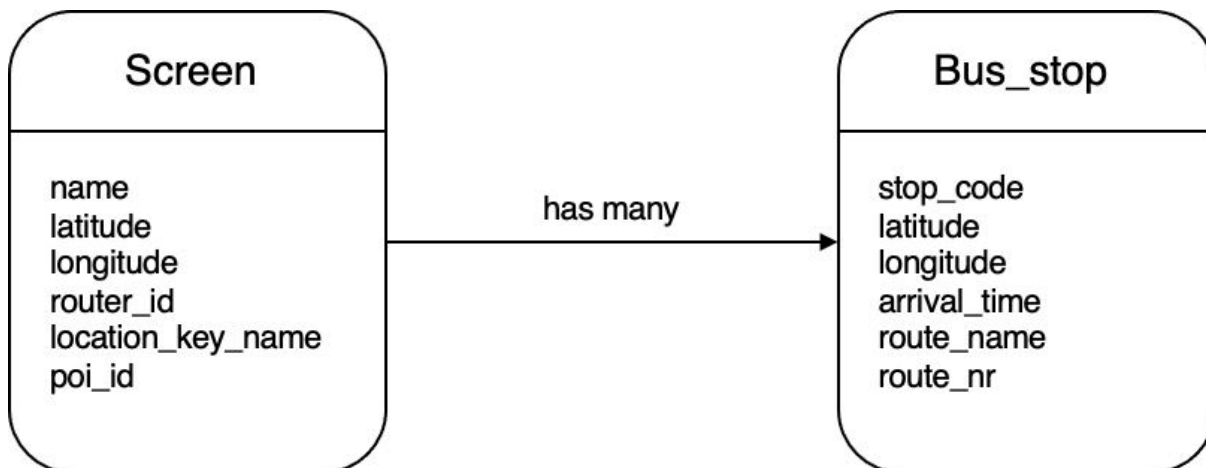


Figure 3.26: Entity-relationship model

data integrity, robust feature set, extensibility, and the dedication of the open-source community³.

The database will be populated when we do the setup through tasks that will process data from CSV files or the endpoints available, creating its instances and relationships between them. A task is the basic unit of work in a Rakefile and has associated actions and a list of prerequisites. When invoked, a task will first ensure that all of its prerequisites have an opportunity to run, and then it will execute its own actions.

3.5.2 Business layer

Since our application will not have complex business logic, its architecture only has three layers, and the business and persistence layers are combined into a single business layer. This layer is responsible for, not only all the business logic that will be necessary but also for making the connection between the presentation layer and the database, having an API role.

The technology used to develop this layer was Ruby and Ruby on Rails. Ruby on Rails is a web application framework written in Ruby. It is designed to make programming web applications easier. The Rails philosophy includes two major guiding principles: don't repeat yourself and convention over configuration⁴. This allows for more productivity compared to other languages. Summarizing, one of the biggest advantages of Ruby on Rails is the fact that it abstracts and simplifies common, repetitive tasks.

It is on the business layer that we do the requests to the external endpoints and processes their responses. As shown before, the responses given by the endpoints often have more information or in a different format than we need. We receive the requests by the front end with some parameters, the

³<https://www.postgresql.org/about/>

⁴<https://guides.rubyonrails.org/>

business layer does a request to the external endpoints with those parameters, and then processes that data in order to send to the front-end the information filtered and ready to use. The front-end will receive the information and just displays it.

The personalization is also taken care of by the business layer. Assuming that the viewer is authorized to interact with the public display, the viewer can send its preferences to the system through a WebSocket. The WebSocket was integrated with this Rails application using Action Cable. Action Cable is a full-stack offering that provides both a client-side JavaScript framework and a server-side Ruby framework⁵.

The client of a WebSocket connection is called the consumer. In Action Cable the consumer is created by the client-side JavaScript framework. When we create a subscription for the instance of the consumer to a given channel, the consumer becomes a subscriber. The consumer is the entity that is receiving data from a channel. Incoming messages are then routed to these channel subscriptions based on an identifier sent by the cable consumer.

The viewer preferences are stored in the browser `sessionStorage`. The `sessionStorage` allows saving key/value pairs in a web browser for one session. We are using `sessionStorage` because the viewers' preferences are irrelevant some time after they were done since the viewers are expected to be in movement and not to be waiting for the public display response. Besides the viewers' preferences, we also store how many rounds ago each page was shown last.

To send preferences to the system you need to broadcast the requests with the format shown in figure 3.27. The number is the public display identifier, that the application is expected to know from the authentication process. The function `broadcasting` allows streaming the message to the channel indicated.

```
2.5.7 :001 > ActionCable.server.broadcast "preferences_channel_4", preferences: ["buses", "events"].to_json
[ActionCable] Broadcasting to preferences_channel_4: {:preferences=>["\buses\","\events\"]}
=> 1
2.5.7 :002 > █
```

Figure 3.27: Broadcast preferences to public display with identifier 4

Whenever a message comes in through the channel the `received` method is called. In the `received` method we format and add the new preferences to the `sessionStorage`. An example of what is stored in the `sessionStorage` is shown in the figure below.

⁵https://guides.rubyonrails.org/action_cable_overview.html

Key	Value
previousPreferences	[{"screens":{"buses":1,"events":1,"covid":0},"time":1608487477966}, {"screens":{"buses":0,"events":0,"covid":1},"time":16084877970...}
rounds	[{"buses":2,"events":3,"covid":1}]
<pre> ▼ [{"screens": {"buses": 1, "events": 1, "covid": 0}, "time": 1608487477966}, ...] ▶ 0: {"screens": {"buses": 1, "events": 1, "covid": 0}, "time": 1608487477966} ▶ 1: {"screens": {"buses": 0, "events": 0, "covid": 1}, "time": 1608487797003} ▶ 2: {"screens": {"buses": 0, "events": 1, "covid": 0}, "time": 1608487802856} </pre>	

Figure 3.28: Example of sessionStorage state

Every minute we get was is stored in the sessionStorage and send it to the decision-maker, implemented in Ruby on Rails.

3.5.2.A Decision-maker

What page should we show next? This represents a multiple-criteria evaluation problem since our question has a finite number of alternatives, explicitly known at the beginning of the solution process. What we aim for is to build a decision-maker that finds the best alternative.

Since this is a single-dimensional problem, we opted to use a simple weighted sum model. The weighted sum model (WSM) states that, if there are m alternatives and n criteria then, the best alternative, is the one that satisfies (in the maximization case) the following expression [26]:

$$A_{WSM-score}^* = \max_i \sum_{j=1}^n a_{ij} w_j, \quad for \quad i = 1, 2, 3, \dots, m.$$

where: $A_{WSM-score}^*$ is the WSM score of the best alternative, n is the number of decision criteria, a_{ij} is the actual value of the i -th alternative in terms of the j -th criterion, and w_j is the weight of importance of the j -th criterion.

Our algorithm starts by checking if there are any preferences that were got from the sessionStorage and sent to the decision-maker. If not, the main page is shown and the evaluation stops. If there are, we apply the weighted sum model to find the best option. To apply the WSM to our concrete problem, we generate a matrix similar to the following one, with the data we got from sessionStorage.

Page	Number of preferences	How many rounds ago
	(0.50)	(0.50)
Buses	10	2
Events	3	8
People count	8	5

Table 3.2: Decision matrix for the WSM

Each criterion has a weight, in our case the two criteria weight 0.50. We multiply each cell by the respective weight and then add every value of each row. When the formula is applied to the previous data, the scores of the three alternatives are:

$$Buses_{WSM-score} = 10 \times 0.50 + 2 \times 0.50 = 6$$

$$Events_{WSM-score} = 3 \times 0.50 + 8 \times 0.50 = 5.5$$

$$People_{WSM-score} = 8 \times 0.50 + 5 \times 0.50 = 6.5$$

If the biggest value has zero votes (there are not any viewer that signed it as a preference), meaning that only won because it is was not shown for a long time, or if the biggest value was shown one round ago, which means that was the last page shown, we show the main page. Otherwise, we show the page with the biggest WSM-score.

Every time a page is shown the count of how many rounds ago the page appeared lastly is changed to one, while we add one to the count of the other pages. After ten minutes of a particular preferences request, that request is deleted, since we expect the viewer who done the request to not be in the surroundings of the public display anymore. That is why the preferences are stored with a timestamp.

In figure 3.29 we can find a scheme where the decision-maker is summarized.

3.5.3 Presentation layer

The presentation layer corresponds to the front-end of the platform. It is responsible for creating and displaying the user interface and handling user interaction. Data that is shown on the front-end is fetched from the business layer.

This layer was developed using React, HTML, CSS and JavaScript. React is a Javascript library for building user interfaces. It makes possible to design simple views, using HTML and CSS, and React efficiently updates and renders the right components when data changes.

For maps, we used Leaflet⁶. Leaflet is a JavaScript library for creating interactive maps. It works efficiently across all major desktop and mobile platforms and can be extended with lots of plugins.

Each of the widgets previously presented is a React component. This way, we can add and remove components without compromising the good functioning of the dashboard. The main page, and the other pages, are also each one a component. The page that is selected to be shown, is the one that is rendered.

⁶<https://leafletjs.com/>

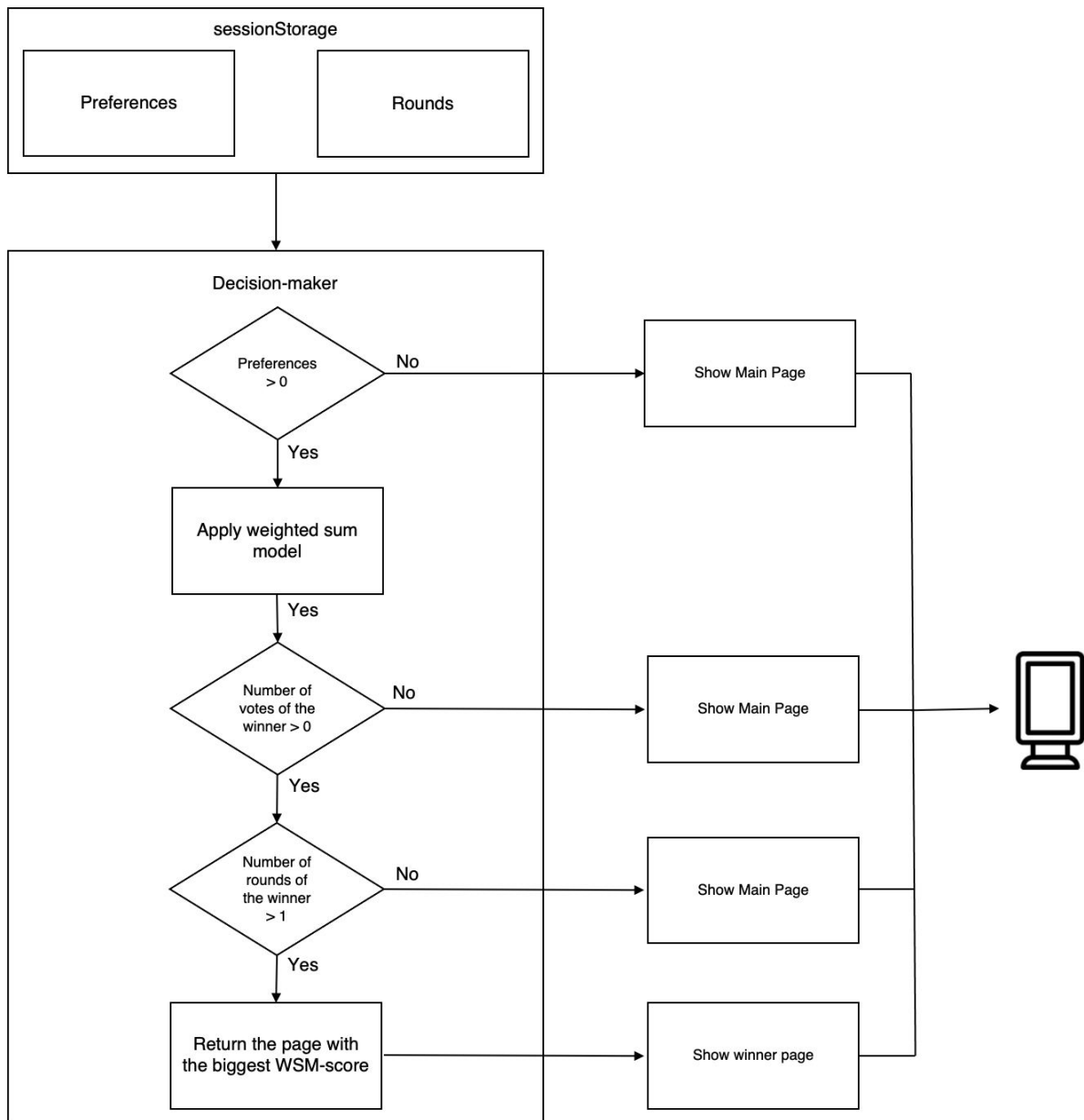


Figure 3.29: Decision-maker algorithm

4

Evaluation

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After we have completed the development of the functional prototype, we started to think in a better way to find if our system met the needs of users - people can gather useful information at the same time that they feel that the system is part of the environment.

Considering that this part of our project occurred during a pandemic situation, we had to adapt our tests and give priority to remote tests and, consequently, guide our study for quantitative and qualitative usability metrics. In this section, we will start by explaining our approach and methodology, followed by the description of the tasks we proposed to our users - and what we wanted to see answered with them -, the characterization of those users, and, finally, our conclusions from the analysis of test results.

4.1 Methodology

The approach that we always have had in mind was to test the users in two moments. The first moment with observation, where we put a public display in a public place and, in a hidden way, try to understand the impact of our system in the people behavior that passes in front of it. We would try to see if factors such as the location of the screen, different types of information, or even different types of interfaces and content (colors, shapes, etc.), changed the way how public displays interfered with the person's routine. The second moment was related to the usability of the system and find out if the users were able to understand the different kinds of information in the best way possible.

Bearing in mind that because of COVID-19 the movement flows of people are totally unregulated, and also due to limitations in the time of the project, it would be difficult to make the first moment of the tests in a correct and interesting way for our study. For this reason, we opted to just do the second moment of the tests in the best conditions we can.

This evaluation has as the main function to evaluate the best and worst aspects of the functional prototype and to check that a standard was upheld, a process known as summative evaluation [27]. Users are presented with a list of tasks, and their performance is evaluated through quantitative measures: the time it takes the user to do the task, the number of errors made (if any), and the level of satisfaction while doing such tasks.

To perform these tests we used 10 users, with no special age, background, or technological literacy filtering because we used a sampling technique called Convenience Sampling, which means that our users were selected because of their convenient accessibility and proximity to us.

4.2 Protocol

To maintain the consistency of the tests, we developed a protocol to ensure that all users went through the same process.

The protocol was divided into the following parts:

1. A profiling survey was used to collect key demographic information about our users, such as gender, the range of age, education, birth country and if the users had a smartphone.
2. A contextualization of our project and evaluation method. We followed a prepared script to ensure that we did not forget to explain anything and to ensure every user had the same information.
3. The execution of a list of 5 tasks to be performed one at a time and without any help. The users were asked to inform us when the task started to start the timer. In order to provide more comfort to users, they were informed that what was being tested was the system and not them.
4. A second survey to understand the users' level of satisfaction while doing the tasks. For this we used the System Usability Scale (SUS) - a simple, ten-item scale that gives a global view of subjective assessments of usability [28] about the user experience with our system. We followed the guidelines established by Brooke [28]: each question had a degree of disagreement or agreement, with a range from Strongly Disagree (1) to Strongly Agree (5) respectively, from which the user could choose. Users were asked to answer each question with their true opinion, but we recommend them to not think too much about it, and if undecided to pick the middle score of the presented scale.
5. Final thoughts and offer of cookies to tested users as thank.

For the tasks to be done by the users, we tried to choose some that covered the maximum points of the system to make sure that we would discover the maximum possible problems.

The five tasks to be performed by users were:

1. How many publications are there on TripAdvisor for this area today?
2. Where will the Floral Carpets event take place?
3. What is the destination of the next bus?
4. What are and how much time is left for the next 3 buses?
5. What are the places with more than 300 people?

4.3 Results

4.3.1 Demographic Analysis

Through the demographic surveys carried out, we obtained the results illustrated in table 4.1. Demographic questions in a survey allow us to gain background information about our users. These questions

provide context for the collected survey data, allowing us to describe participants and better analyze the data.

Table 4.1: Users' demographics

Item	Demographic	Frequency	Percentage (%)
Gender	Female	6	60%
	Male	4	40%
Age	18-24 years old	3	30%
	45-54 years old	3	30%
	Under 18 years old	2	20%
	25-34 years old	1	10%
	35-44 years old	1	10%
Country	Portugal	9	90%
	France	1	10%
Education	Master's Degree	3	30%
	Basic Education	3	30%
	Bachelor's Degree	2	20%
	High School	2	20%

10 users participated in our test sessions. Most of these users were female (6 out of 10 users). In terms of age, we had users from different age groups, with 3 users between 18 and 24 years old, 3 between 45 and 54 years old, 2 under 18, only 1 between 25 and 34 and 1 between 35 and 44. In terms of nationality, the overwhelming majority of users were Portuguese nationals, with only 1 out of 10 having French nationality. Regarding the level of education, we also had a wide spectrum of different types of users. 3 of the users replied that they had a Master's degree, 3 had only basic education, 2 of them said they had a Bachelor's degree, and 2 finished high-school. As for the question of whether users had smartphones, they all replied that they did.

As we can see we have a wide spectrum of different users with different characteristics. Taking into account our study, this fact turns out to be positive because our application, being in public places, catches all types of users.

4.3.2 Statistical Analysis

As previously mentioned, we chose to do a statistical analysis of the tests. For this analysis, metrics were measured, such as response times and the number of errors for each task. Table 4.2 and 4.3 summarize some of these results and for each of them, we calculated Min, Max, Average, Standard Deviation and 95% Confidence Interval.

Table 4.2: Response time for each question

Duration (seconds)					
Users	Questions				
	T1	T2	T3	T4	T5
U01	5	36	18	15	22
U02	5	40	22	11	30
U03	3	37	16	11	31
U04	46	33	16	20	23
U05	45	48	30	21	32
U06	1	73	25	30	39
U07	2	38	23	67	30
U08	1	54	20	19	24
U09	16	57	14	29	39
U10	1	27	20	3	23
Statistics					
Min	1	27	14	3	22
Max	46	73	30	67	39
Average	12,50	44,30	20,40	22,60	29,30
Standard Deviation	17,95	13,74	4,81	17,63	6,32
Confidence Interval (95%)	35,59	27,25	9,54	34,97	12,54

Table 4.3: Number of errors for each question

Number of Errors					
Users	Questions				
	T1	T2	T3	T4	T5
U01	0	0	0	1	0
U02	0	0	0	0	0
U03	0	0	0	0	0
U04	1	0	0	1	0
U05	1	1	0	1	0
U06	0	1	0	1	0
U07	0	0	0	1	0
U08	0	1	0	1	0
U09	1	1	0	1	0
U10	0	1	0	0	1
Statistics					
Min	0	0	0	0	0
Max	1	1	0	1	1
Average	0,30	0,50	0	0,70	0,10
Standard Deviation	0,48	0,52	0	0,48	0,31
Confidence Interval (95%)	0,95	1,04	0	0,95	0,62

Analyzing the tables we can make some conclusions from each of the tasks and relate them to some of the feedback obtained from users.

- **Task 1** - As we can see in the response time table, this task has a relatively high standard deviation. This is related to the fact that some of the users do not recognize the TripAdvisor logo, which took them more time to complete the task and also leads them to make mistakes. In fact, if we analyze both tables we realize that the users who took an above-average time were the same users who made mistakes.
- **Task 2** - In this task, we have again a relatively high standard deviation in the response time table. The first justification for these results is that some of the users tried to see the location of the event in the events widget of the main page (which only has the name of the events). The second justification is that some of the users, when entering the events menu, felt that the carousel that demonstrates the various events, was running too fast, not giving them enough time to analyze all the information related to the event (including location).
- **Task 3** - In this task, the vast majority of users completed the task without any hiccups or doubts, as we can see from the task response time and the zero number of errors.
- **Task 4** - We again had a relatively high standard deviation in terms of response time and it was the task that had the most mistakes of all. The reason for this is that most users had difficulty identifying buses by their number, therefore, they had difficulties in realizing that the number inside the circle shown on the interface referred to the identification of the bus.
- **Task 5** - In this task we had very satisfactory and consistent results, having only one error related to the fact that the legend and the information do not appear in the same order.

4.3.3 System Usability Scale (SUS)

The last step in our testing guide was asking users to fill a SUS Survey. We used this tool because it allows us to quickly measure the usability of the system. Although we are aware of the limitations that this type of measure may have, it was the one that seemed to us to have a better cost-benefit compromise taking into account the test limitations mentioned above.

Table 4.4: System Usability Scale (SUS) score from each user

Item Rating (1 to 5)											
Users	Questions										Final score
	Q01	Q02	Q03	Q04	Q05	Q06	Q07	Q08	Q09	Q10	
U01	3	1	5	1	5	1	5	1	3	1	90,0
U02	4	1	4	1	4	1	4	2	4	1	85,0
U03	5	2	5	1	5	1	4	1	5	1	95,0
U04	3	2	5	1	3	3	5	1	3	3	72,5
U05	5	1	4	1	5	2	5	1	5	1	95,0
U06	4	3	2	1	5	2	4	1	3	1	75,0
U07	4	2	4	2	4	1	4	2	3	2	75,0
U08	4	3	4	3	3	1	3	1	5	2	72,5
U09	3	1	4	1	4	1	4	1	5	1	87,5
U10	4	1	4	1	5	2	5	2	5	1	90,0
Statistics											
Min	3	1	2	1	3	1	3	1	3	1	72,5
Max	5	3	5	3	5	3	5	2	5	3	95
Average	3,9	1,7	4,1	1,3	4,3	1,5	4,3	1,3	4,1	1,4	83,75

Following the guidelines of John Brooke [28] and as we can see in table 4.4, our system obtained a score of 83.75 points, which means that according to this measurement tool the system is considered 'Excellent' in terms of usability on a scale between 'Worst Imaginable', 'Awful', 'Poor', 'OK', 'Good' and 'Excellent' or 'Best Imaginable'.

4.3.4 Discussion

From the results of the usability tests, we can assume that our system has a good acceptance and usability rate.

Although we were unable to carry out the tests in the way we envisioned at the beginning of this project, good commitments were made in order to be able to quantify and validate our system in some way. Even though we were not able to cover all the points of the system in tests, we managed to identify some points of improvement to make our project more refined, which was what we wanted.

Some problems and the targets for improvement were raised in carrying out the tasks. Social networks should be identified not only with the logo but also the name, the various carousels of the system should have a lower speed so that users who read more slowly can do so. On the events page, since each event has a lot of information in text, some design options could be rethought and prioritized so the user can read the information faster. On the bus page, the number that identifies each bus should be clearer for the user.

Two points of improvement were detected during the tests, but not directly related to the various

tasks. The first was the language, which we realized that in a real system you should have the option of the language of the country where the system is being used. The second was related to the font size of the whole system, which should be a little bigger so that users do not have reading difficulties.

After the tests are finished, we can say that the system ends up meeting our initial objectives and ends up corresponding to the needs of our target audience.

5

Conclusion

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We live in a time where the idea of ubiquitous computing was achieved: we live surrounded by computers, not only to work or communicate with, but to help us with day-to-day tasks. They are so embedded in our routine that we don't even remember anymore that they are there.

Public displays are examples of these computers: present in many of the places where we pass, either with advertising, news or as a guide. These public displays promise to be the backbone of a new medium of communication, but with the number of stimuli that we have everywhere, public displays are often ignored.

In this work, we started by analyzing the research done in the fields of the relationship of humans and public displays and human-data interaction, in order to understand what are the main points of focus to prevent the displays from going unnoticed while delivering understandable and relevant information for users. After a few steps, we developed the functional prototype presented earlier.

The main objective of this work was to build a dashboard to be deployed in public displays scattered across the Madeira Islands. The data to be presented are related to the movements, meteorology and culture of various locations on the islands, and were collected in a previous project. Our goal was to create clearer and relevant visualizations for these data, in order to deliver useful information to passers-by, locals or tourists, in the places where the public displays will be present. For this, a dashboard with several pages was developed, the main page and additional pages. The additional pages allow seeing the information present in the main in more detail. The scheduling system between these various pages is the key to personalization. For that, a decision machine was built that allows choosing which page should be shown at each moment, allowing viewers to interact with the public display and making it more relevant, since this communication will allow the display to be the image of the viewers' preferences.

After developing this prototype we tested the system. The tests carried out did not allow verifying the effectiveness of the dashboard to capture the attention of passers-by, but it did verify the effectiveness and usability of the various visualizations and the satisfaction of the viewers. For this, we developed usability tests with 10 viewers, where we took note of the time needed to complete 5 different and isolated tasks and the number of errors in each one. Finally, we asked users about their satisfaction with using the system through the SUS.

After developing and testing the functional prototype, we can conclude that, in general, the goals set out in Chapter 1 and the requirements defined in Chapter 3 have been achieved. The dashboard presents the data that it should, allowing users to interact with it through their mobile phones and choose the page they want to see next. The system, when there are conflicting requests by several viewers, chooses the one that is the best option taking into account the criteria chosen. This does not question the user's privacy or disclose its entity.

In conclusion, the Dashboard for Ubiquitous Analytics could be deployed on public displays on the Madeira Islands and is prepared to deliver the already existing information to people.

5.1 Future Work

Besides the small improvements already mentioned in Chapter 4 as a consequence of the tests of the system, there are also other features that could be added and some improvements that could be made to the already existing ones.

Starting with improvements to the features that we already have, we could add data to our data sets about the places where the routers are implanted so, that away, we could take those into consideration when calculating how many people is too many people in a place.

Besides that, the system could be deployed in other places of the world other than Madeira without any change if the endpoints used for data consumption were the same. If not, the system can be adapted in order to work for other cities.

Regarding the decision-maker machine, more criteria can be added easily, or change of the criteria weight, in order to refine the page chosen, trying more and more that the chosen page is the ideal one.

More widgets can always be easily added to the dashboard, it is only necessary to develop the new widget, collect the necessary data and add it to the dashboard. The same for the pages, in which case it would be necessary to add the page to the decision machine.

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