# Augmenting the Reality of Situated Visualization


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***Abstract* — Situated Visualization (SV), encompassing all the visualizations that change their appearance based on context, by considering the visualizations that are relevant to the physical context in which they are displayed [1], has been recognized as a method with potential in many situations, as is the case of supporting decision making [2]. Augmented and Mixed Reality (AR/MR) are well suited to assist in such scenarios, given its ability to display additional data regarding the real-world context and be supported by context-driven visualization techniques [3]. Though some perspectives on the SV model have been proposed, such as space, time, place, activity and community, an appropriate systematization, covering the main definitions and perspectives has yet to be established. Hence, there is an urge to obtain a more comprehensive description. The work presented in this paper characterizes the SV model, within the scope of AR/MR, shows a critical analysis of the existing knowledge, expanding the SV model and in turn hoping to elicit discussion within the research community.**



***Keywords — Augmented and Mixed Reality, Situated Visualization, Situated Visualization Conceptual Model, Situated Visualization Perspectives***


## I. Introduction

One of the great advantages that Augmented and Mixed Reality (AR/MR) systems have is that digital information related to what the user sees in the real world can be visualized and explored directly in that world [3]. Situated Visualization (SV), an emerging research concept introduced by White in [1], is entirely about that advantage. It includes all the visualizations that change their appearance based on context, by considering visualizations that are relevant to the physical context in which they are displayed [1]. In other words, SV happens when data is visualized in the places, or in situ, where it is relevant to people. This means that visualization of the virtual information is innately related/connected to its environment, giving more meaning to White's words "*through the combination of the visualization and the relationship between the visualization and the environment*" [1]. The definition of SV can be broader or more specific, depending on the authors or the areas of research. However, according to Bressa et al., in [4], its wide range of use has led to inconsistent adoption of the concept and terminology. This article follows the two predominant definitions of SV, the White [1] and Willett et al.'s [5]. The words "*perspective*" [4], "*dimension*" [2] or "*property*" [7] [8] are used whenever it is intended to refer to some SV characteristics, showing the stated broader use of concepts. This paper uses "*perspective*".

According to Moere et al., in [6], SV must have the following characteristics: contextual, local, and social. Contextual because the visualization takes into account the distinctive features of its physical location, in terms of both its explicit and implicit meaning. Local because the presented data has a direct and instant association to the surrounding context. This usually means that information is learned within the physical environment that the user can sense or that it has been processed to reflect the particular circumstances of entities, structures or activities in that environment. Finally, social since the visualization reflects on issues that are pertinent to the social-cultural reality in its vicinity.

Compared with other visualizations, SV offers high adaptability, usefulness, and intuitiveness by contextualizing the relevant information, leading to more informed decisions. For example, it is very helpful and perceptive for the users to know where the places to eat are because the virtual information presented regards their location. On the other hand, in other types of visualization, these places are shown regarding a larger zone (like a city, for instance). That is why White says, in [1], that "*tasks, such as inspection/comparison, spatial learning, and in-situ pattern-seeking and discovery can benefit from enhanced cognition through situated visualizations compared to alternatives*".

According to the SV definition, the visualization is not defined as situated due to the type of data to be displayed nor is it linked to a specific technology. It is also important to know that not all visualizations in AR/MR are situated, as it is the case when the displayed virtual elements are not linked to the real-world (the physical background has no meaningful relationship to the visualization, because each of the AR/MR applications could be executed in different environments and the result would still be the same) [7].

To avoid inconsistent adoption of the SV concepts and terminology, and as SV gains interest in the research community, held by AR/MR, a new effort to generate harmonization of viewpoints must be conducted to create a common ground for analysis, hoping to elicit discussion within the stated community. This is the proposal of this paper. The main contribution of this paper is the extension of the SV model, including a new perspective and updated concepts, aimed at alerting SV designers to the need of placing the users and their needs at the centre of the design process.

The paper is organized as follows: Section II characterizes the SV model, within the scope of AR/MR, based on existing knowledge. Section III presents a critical analysis of the visualization perspectives (space, time, place, activity and community) and their situatedness, expanding their concepts and generating novel insights. The term situatedness, adapted from the situated analytics, is used to describe a characteristic of the visualization perspective that could change on a continuum [8]. Section IV illustrates the SV characteristics with a practical case. Finally, concluding remarks and future research opportunities are drawn in Section V.

## II. The Situated Visualization Model

In the current section it will be described the existing visualization perspectives (space, time, place, activity and community) and their concepts.

### A. Space

The characterization of SV must start with the dominant spatial understanding of what it means for data visualization to be spatially situated. According to Thomas et al., in [8], a "*visualization is **spatially situated** if its physical presentation is close to the data's physical referent*". A physical referent is "*a physical object or physical space to which the data refers*" [8]. A physical presentation is "*the physical object or apparatus that makes the visualization observable*" [9]. For a typical visualization system, the physical presentation consists of a physical display on which the visualization appears and can take many forms, such as any device with displays, paper, 3D prints or light. A typical AR/MR visualization system usually exploits mobile devices (or handheld displays), see-through-based devices (e.g., head-mounted displays), and projection-based devices (or spatial displays). Finally, the term "*close*" is left vague on purpose because the situatedness is lying on a continuum. For example, a visualization projected on a physical object is spatially more situated than one viewed on a mobile device near the object.

For a better explanation, [8] presents a **theoretical model of a spatially SV**, mainly based on the model from Willett et al., in [5], which covers both logical and physical worlds, as can be seen in Fig. 1(a). The physical world is the real 3D scenario. The logical world, created by a computer, produces the visualization (information that will be added to the physical world). The raw data is the information that comes from the physical world and the one made in the logical world, to be used in the visualizations. To obtain an intelligible visual representation for the user (the rendered images), the raw data must pass through the visualization pipeline (**A→B**), as can be seen in Fig. 1(a). As stated previously, the only way the user can see the rendered images is with a physical presentation, as represented through link **C** in Fig. 1(a). The visualization pipeline, formed by a sequence of geometric transformation matrices, only requires the logical world, but the existence of a physical world is necessary for SV since data visualizations are intertwined with the physical environment. Thus, another way to tie the logical and the physical world, as can be seen in Fig. 1(a), is through link **D**, between the raw data and the data's physical referent. This theoretical connection means that raw data can come from several referents [8]. It can often be useful to consider several individual referents, rather than the set of all of them [5]. Link **E**, in Fig. 1(a), between the physical referent and the physical presentation, represents the distance (or the "*close*"ness) among them. If the physical referent and the physical presentation share the same space, both can be seen by the user, at the same time, and the visualization is called spatially situated. Finally, the link **F**, between the physical referent and the user, in Fig. 1(a), represents the possibility of the referents to be visible to the user. To **exemplify** all that was mentioned above, let us assume that a maintenance technician needs to inspect several machines. The raw data is, for instance, the model of the machines to be checked and their respective location. The visualization pipeline creates an image with the map of the machines' location. A physical presentation can be the map shown on any kind of screen or on a piece of paper, which turns the rendered image observable on the physical world. Selecting a certain machine model, the raw data related to it could refer to several machines to maintain. These referents could be in different places of the physical world. They may also be or not, visible to the technician from his location. If that technician is looking at the information of the selected machine through his mobile phone, away from the machines, he will not be able to physically see the machine that interests him. In this case, the distance between the physical referent and the physical presentation will be too far apart for the technician to be see both simultaneously and the visualization will not be spatially situated. On the other hand, if the technician, in the factory that has the selected machine, is looking at the machine's information on a tablet, as can be seen in Fig. 1(b), then the distance between the machine's data and the real machine could be such that both might be seen, representing a **spatially SV**. This means that spatially situated or non-situated cases are related to the physical presentation and not to the visualization per se, even if it is seen on the same device.

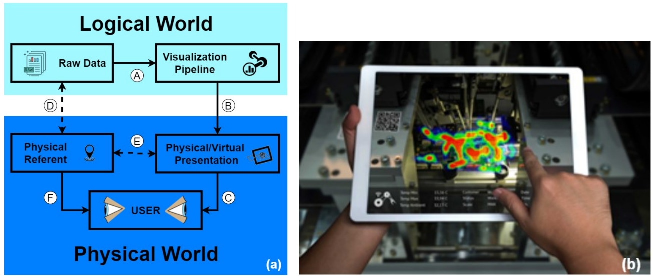


Fig. 1. (a) Classic theoretical model of a spatially SV, adapted from [8]. (b) spatially SV example, from Agro & Chemistry[1].

According to [4], the three types of spatial placement are: entity-centric, activity-centric and space-centric. These types reflect space beyond physical distance between the referents of interest and the visualization, noticing that, for instance, user's activities and context are important to consider [4].

#### 1) Visualization phisically and perceptually situated

It is common knowledge that distance could be perceived in a relative way. Therefore, to avoid the vagueness of the definition of spatially SV, [8] suggests two definitions. One is "*a visualization is **physically situated** in space if its physical presentation is physically close to the data's physical referent*". The other is "a *visualization is **perceptually situated** in space if its percept (physical or virtual presentation) appears to be close to the percept of the data's physical referent*". Thus, perceptually SV can be related to virtual presentations, therefore it must be included in Fig. 1(a).

#### 2) Embedded visualization

Another physical perspective in the characterization of SV is the embedded visualization (EV). In [5], Willett et al., say that EV "*is the use of visual and physical representations of data that are deeply integrated with the physical spaces, objects, and entities to which the data refers*". In [8], **embedded visualization** happens "*if each of its physical sub-presentations is close to its corresponding physical sub-referent*", assuming that each sub-presentation is aligned with its corresponding sub-referent. The behaviour of each sub-presentation and sub-referent are, respectively, the same as the presentation and referent. This differentiates the SV cases, in which the data is displayed close to data referents, from EV, which displays data so that it spatially coincides with data referents. However, SV can be embedded or non-embedded.

[1] https://www.agro-chemistry.com/agenda/embracing-industry-4-0/, accessed on 03/03/2022

For example, if the user's water consumption is presented on a unique visualization placed next to the house, the visualization will be merely situated. On the other hand, if the water consumption's graphs were just from the house kitchen and bathrooms, the visualization, aligned with them, would become **embedded**. Finally, [5] introduces highly embedded data representation, a special case in EV. This happens when a set of small-scaled data presentations is considered together.

### *B. Time*

According to Thomas et al., in [8], the characterization of SV can be seen beyond the spatial, physical and perceptual location of the representations. They argue that data can be thought of as referring to an actual region in time [8] and, thus, SV may have another perspective, when the data is linked to time. In their definition, a visualization is "***temporally situated*** *if the data's temporal referent is close to the moment in time the physical presentation is observed*" [8]. This perspective is about the connection between when data is presented and when it is recorded. To have a temporally SV, visualizations should minimize the temporal indirection (i.e. display data as it is seized), if a linear time-flow is assumed [4]. Since it is impossible to go back in time, traces or aggregate information is usually shown instead. The time perspective, also, lies on a continuum and has different levels of situatedness.

Still regarding the time perspective, Bressa et al., in [4] introduce another consideration on temporal situatedness, the **social time**, which allows to take into account several temporalities relating to activities linked to a location (specifically, when there are requirements of coordination), cultural conventions, and habits of the community (such as eating breaks in the working day). Thus, temporal situatedness is based on the interactions between persons and the manner that information bonds them through time [4].

### *C. Place – Activity – Community*

Going beyond the dominant understanding of SV, Bressa et al., in [4], added three new visualization perspectives, in line with [6], namely, place, activity and community. Founded in the theoretical considerations on place in Human-Computer Interaction, in [10], [4] presents the **place perspective** as more than a location or a context for an activity. Visualizations become situated if they embody not only relevant information, but also the characteristics of the place, such as identity, history, and socio-cultural meaning. Based on activity theory ideas proposed in [11], the **activity perspective** situatedness, in [4], implies that visualizations are embedded and associated to a broader set of tasks, exceeding space and time aspects and having significant impact on the suitability of different spatial layouts. For [4], **community perspective**, an underdeveloped perspective at a certain point, but implicit in the literature, brings the focus on the authors/viewers of the visualizations and complements place and activity perspectives.

## III. EXTENDING THE SITUATED VISUALIZATION MODEL

This section presents the critical analysis outcomes of the visualization perspectives situatedness, in the form of updated existing concepts and novel insights.

### *A. Updating the SV theoretical model*

Fig. 2 presents an extended theoretical SV model, accommodating all the perspectives that characterize the SV (mentioned in the literature as well as proposed in this work), for better understanding. In this inclusive representation, as previously mentioned, the raw data belongs to both worlds and not only to the logical one, as illustrated in Fig. 1(a), because some of its information come from the sensors within the physical world. Another new addition to Fig. 2, based on Card et al.'s information visualization reference model [12], details the visualization pipeline. As stated, it is useful to consider several individual referents, rather than the set of all of those. So, according to Willett et al.'s words, "*data representations are made up of multiple physical presentations that each independently display data related to their respective physical referent*" [5], Fig. 2 shows various sub-referents of different kinds and several physical and virtual sub-presentations. Technological advances and the increasing society's demand for information are making visualization more complex, and thus the integration of multiple referents and presentations are more common. In Fig. 2, the referents associated with space, time, place, activity, community and content perspectives are, respectively, denoted as physical, temporal, local, activity, communal and content.

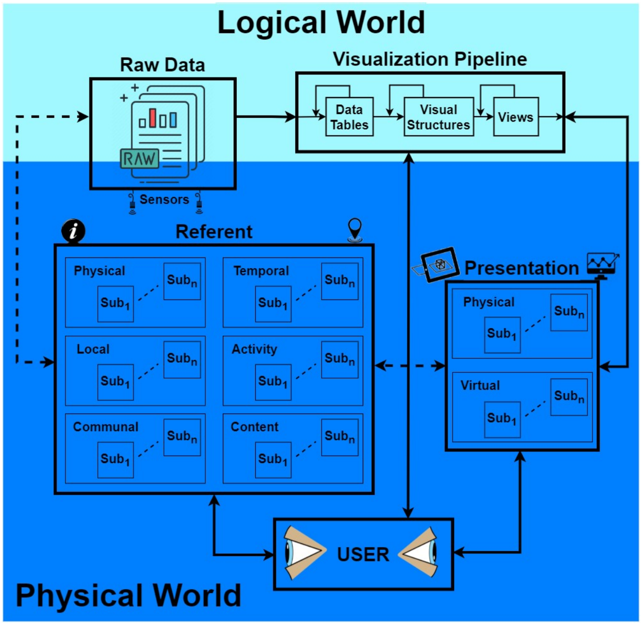


Fig. 2. Proposed extended SV theoretical model, with information on the use of sensors to obtain raw data, the visualization pipeline and the referents (spatial, temporal, local, activity, communal and content) linked to all the identified visualization perspectives (space, time, place, activity, community and content), where it is possible to have sub-presentations and sub-referents.

The Card's model postulates that visualization can be altered by the user. This alteration happens when the user interacts with the SV system. So, a global representation of the theoretical model of SV integrates all possible interactions between a user and a SV system. In Fig. 2, both the user's interactions that arrive at the visualization pipeline could belong to any interactive visualization system (situated or not). More specifically, one way to alter the visualization is when the information that flows from the user to the visualization pipeline is about operations that modify the pipeline. Examples of such operations are selecting, filtering or highlighting data, changing the visual representations, and altering the camera's parameters [9]. To accomplish these interactions, data from sensors (illustrated in Fig. 2) must be collected and combined with software to recognise the user's actions. Altering the physical presentation is another way to modify the visualization. The reorganisation of the physical elements (by moving it or moving around it), according to [9], can give the user new perceptions of the physical presentation and expand the possibilities of interactions, overcoming the limitations of the previous way. The reason for having an arrow linking the physical presentation to the visualization pipeline, in Fig. 2, is because some of the user's physical interactions could affect the visualization pipeline. When the information that flows from the user passes through any kind of referent, as stated, the visualization is situated, and yet another way of interaction appears. It, also, makes some referents visible and, usually, manageable [5]. If the user interacts with a SV system, analysis and actions can be interlaced and actions could be taken forthwith, including modifying the raw data, if the referent is the real-time data source (link between the referent and the raw data in Fig. 2).

### B. *Critical analysis outcomes*

Before describing the results of the critical analysis and to prepare the reader, Fig. 3 presents a summary of the obtained outcomes, in the form of a diagram with a representation of all the identified visualization perspectives (space, time, place, activity, community and content), and their own categories and particular cases. Each of the referents enclosed in Fig. 2 are closely linked with each of the visualization perspectives shown in Fig. 3 (and marked in grey).

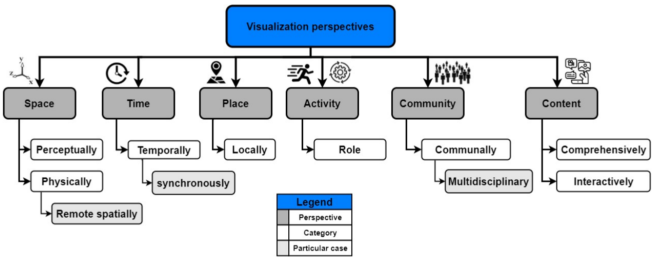


Fig. 3. Systematization of all visualization perspectives (space, time, place, acitivity, community and content), their own categories, and particular cases.

#### 1) *Space*

Taking into account the previous definitions regarding the SV space perspective, and to avoid ambiguity, focusing on AR/MR, the following ones are suggested:

- A visualization is physically situated in space if at least one of its physical sub-presentations is physically close and aligned to its corresponding data's physical sub-referent (i.e., the matching pairs share the same space and are seen at the same time);
- A visualization is perceptually situated in space if at least one of its percept (physical or virtual sub-presentations) appears to be close to the percept of its matching and aligned data's physical sub-referent (i.e., the matching pairs are seen at the same time).

The next contribute, in the light of the spatially SV definition, appeared from the effort to answer the question "is it possible to have situated visualization for activities made in hazardous environments or involving connected equipment not placed in the same physical location?". It is obvious that these activities make it difficult for the physical presentation to be close to its corresponding data's physical referents, even with the term "*close*" lying on a continuum. However, telepresence allows people to be in one place, yet, be able to perceive and act as if they were present in a different place [13]. This line of thought follows Milgram's virtuality continuum idea [14], where "*the term virtuality essentially separates what something is from and what the essence of that thing is, that is, it possesses the characteristics of something but lacks its physical embodiment*" [13]. The relationship of AR/MR with telepresence is the same as it is with the non-augmented world [13]. Therefore, in terms of acquiring information, there is no difference between being present in a place and seeing it remotely. Thus, in terms of visualization, feeding a physical presentation with video images of a physical referent that the users cannot see from their location can be considered similar to the user being close to that referent, visualizing, also, the aligned data's physical presentation. From the preceding a new particular case of the physically SV category appears, the remote spatially SV, with the following definition:

- A visualization is remote spatially situated if at least one of its physical sub-referents cannot be seen from the user's current location, but its data is seen aligned with its corresponding physical sub-presentation (i.e., the corresponding pairs do not share the same space but are seen at the same time).

This new particular case in the characterization of SV is, also, represented in Fig. 2 by the dashed link between the physical referent and the physical presentation. It is important to state that remote spatially SV should not be confused with perceptually SV, because the understanding, by the user, of the location of the physical referent and the physical presentation is always known and not perceived. Finally, taking into account the aforementioned, the user's physical world is extended from the physical scenario "where the user is" to the ones where the user is either physically or remotely.

#### 2) *Time*

Regarding the time perspective, avoiding vagueness and focusing on AR/MR, the subsequent definitions are proposed:

- A temporal referent is any period of time, social temporality or moment to which the data refers;
- A visualization is temporally situated if at least one of its data's temporal sub-referents is close to the period of time, the social temporality, or the moment its corresponding and aligned physical sub-presentation is observed or recorded.

The remote spatially situated case is the reason why the first temporally situated visualization definition, in [8], needed the insertion of the word "recorded".

The prior remote spatially SV can be extended to time. An example of this happens when an assembly line is stopped due to a malfunction and the user must understand what caused it and see the past surveillance image feed with its virtual augmentations. The definition for this particular case is:

- A visualization is asynchronously situated if at least one of its temporal sub-referents cannot be seen from the user's current time, but its data is seen aligned with its corresponding physical sub-presentation (i.e. the corresponding pairs do not share the user's current time but are seen at the same time).

In theory, knowing that there is a latency to send the video feed from where the physical referent is to the location of the user and the physical presentation, the remote spatially SV is also asynchronously SV. In practice, the latency time is so small that the observation is referred to as in real-time. Thus, when the user is observing the feed of the augmented data's temporal sub-referent, via physical sub-presentation, in real time, the matching pair is **highly temporally situated** (more than close). This is similar to EV in the space perspective.

*3) Place*

The literature has not provided a structured definition regarding the SV place perspective. Thus, to fulfil that gap, focusing on AR/MR, the following ones are suggested:

- A local referent is any characteristic or characteristics of the place to which the data refers;
- A visualization is locally situated if at least one of its physical sub-presentations provides information that closely embodies the identity, history or socio-cultural meaning of its corresponding and aligned data's local sub-referent.

Another result obtained from the critical analysis was that the category "*locally*" of the SV should comprise an additional characteristic of the identity of the place, the surroundings. This characteristic is about the livelihood of the place. In terms of visualization there is a difference between a dynamic place (where many things are happening) and a static one. The surroundings have a strong bond with the activity perspective.

*4) Activity*

As prior, there was no organised definition for the SV activity perspective. Thus, centring on AR/MR, the following is proposed:

- An activity referent is the activity to which the data refers;
- A visualization is situated regarding the activity if at least one of its physical sub-presentations provides information that is closely related with its matching and aligned data's activity sub-referent;

One more conclusion of the critical analysis was that the activity perspective of the SV lacks a more comprehensive description of its situatedness. According to [15] there are six related components that form an activity, namely, object (something to be transformed and always treated as the centre/focus of the activity), subject (the transformer, or the activity's team), tools (all the means used by the subject to alter the object), rules (norms to obey within a community), community (the people who share knowledge, interests, stakes, and goals to accomplish the activity and the physical place where the activity happens) and division of labour (fixed by the object) [15]. The components subject and community already exist in the stated place and community perspectives. Based on that, the situatedness of the activity perspective of the SV should integrate the category "*role*", which focuses on the activities that each intervenient has to play. It comprises rules, division of labour, instructions, advice or guidelines. As mentioned, this category exceeds spatial and time aspects and has a profound impact on the suitability of different spatial layouts. For this situation, the next definition is proposed:

- A visualization is situated regarding the activity's role if at least one of its physical sub-presentations provides information about the playing part of the activity's intervenient that is closely related to its matching and aligned data's activity sub-referent.

*5) Community*

Following the last two sub-sections, to provide definitions for the SV community perspective, focusing on AR/MR, the following definitions are recommended:

- A communal referent is the person or group of persons associated to a space, a time, a place, an activity, or a content to which the data refers;
- A visualization is communally situated if at least one of its physical sub-presentations provides data that is closely related with its corresponding and aligned data's communal sub-referents.

The critical analysis, also, highlights that a particular case, the multidisciplinary, appears from the communally SV. This particular case is about the different backgrounds and points of view of each individual in the community, which has an obvious direct impact in the visualization. It is indisputable that visualization is for people. Therefore, in terms of background, SV must be for a broad spectrum of user profiles and, thus, the multidisciplinary situatedness goes from extremely simple (for layman users) to very complex (for expert users). The subjective people's points of view are arguable on how they should be considered in the visualization. This particular case is more pertinent when related to activities, and it is in its midst that the points of view of the team members matter. According to Marques, in [16], the multidisciplinary "*pose particular challenges regarding how, e.g., a more elaborate context needs to be provided, communication is supported, or adaptation needs to be available to allow custom discipline specific augmentation*". For this situation, the following definition is proposed:

- A visualization is multidisciplinary situated if at least one of its physical sub-presentations provides information that is closely understood by its corresponding data's communal sub-referents.

*6) Content*

Concerning new visualization perspectives, content is the one that the critical analysis produces. This perspective complements all the other mentioned ones. Similar to other perspectives (space, time, place, activity and community), the content perspective, also, lies on a continuum and has different levels of situatedness. The content perspective integrates the categories comprehensively and interactively. The category "*comprehensively*" is about offering the user all the correct and wholly organised data. Sometimes, the physical sub-presentations cannot handle some types of data or the given information is disorganised, incomplete, incoherent, or erroneous on the screen. These problems are part of the main challenges when using SV combined with real-world [7]. As stated, visualization can be changed by the user's interactions. Thus, the situatedness of the category "*interactively*", as the name implies, is about interaction, and has three aspects. The first one regards the input/output modality (every independent single way, or channel, to obtain or give information). The second aspect concerns the user's actuation ability, that can range from passive-view (which can be on-site or remote) to interacting/exploring (e.g., handling content present in the scene) and to sharing/creating (e.g., adding annotations to the scene or new views or content that others can see) [16]. Finally, [16] refers to the last aspect "*to the possibility of the user or the system to automatically choose/customize or not the most suited channels for output*". The next definitions for the content perspective and its categories are proposed:

- A content referent is any input/output information to which the data refers;

- A visualization is situated regarding the content if at least one of its physical sub-presentations provides data that is closely related with its corresponding and aligned data's content sub-referents;
- A visualization is comprehensively situated if at least one of its physical sub-presentations provides the correct, wholly and organised information that is closely related to its corresponding and aligned data's content sub-referent;
- A visualization is interactively situated if at least one of its physical sub-presentations provides the needed data for a closely understandable interaction with its matching and aligned data's content sub-referent.

## IV. APPLICATION CASE

To clarify all the described perspectives, a practical case in the area of air pollution is described. "Situated Pollution" is a research project about public visualization using AR/MR devices to evaluate the situation of air pollution and to alert and educate the community on that problem. The idea is, for certain areas, to show different kinds of data on air pollution, present possible issues on the users' environment, gather information about the habits of the inhabitants through a survey, and recommend ways to reduce the air pollutants. Thus far, researchers have collected the pollutant levels from two different areas (referred as Zone A and Zone B). A small-scale model of Zone B, with 1.5 meters in diameter was built to test different visual representations of the air pollution data. Another task in progress is the creation of a 3D computer model of these areas to superimpose the collected data in the real world scenario. The project's physical sub-presentations are the mobile phones/tablets or AR glasses of each local user. Next, it is shown in which situations there are SV for each of the mentioned visualization perspectives, their categories and particular cases.

### *A. Space*

When people pass through the areas of study and use the "Situated Pollution" application, they can see, for instance, the air pollution levels that surround them. The specific area, where the pollution is measured, is the data's spatial referent. If the user can see that area, but is not in it, the visualization will be **spatially situated**. On the other hand, if the user is located in that mentioned area, the visualization will be **physically situated**. If the user and the air pollution's measure sensor are located at the same spot, within the area where air pollution is measured, the visualization will be **highly spatially situated**. Furthermore, if it is possible to have the pollutants concentration graphics and annotations, from specific locations within that area, the visualization, aligned with these locations, would become **embedded**. If the used physical presentation to see the air pollution levels is a head mounted display, which merges both real-world images and virtual content and feeds them to the user's eyes at the same time, the user could be led to think that he/she is close to the physical referent, even when he/she is not physically there. According with [8], in this case, the visualization seen by the user is virtual rather than physical. When this happens, the visualization will be **perceptually situated**. Finally, if there is a camera in the area and the user is seeing images from that camera, augmented with the information about the air pollution, from a totally different location, the visualization will be **remote spatially situated**.

### *B. Time*

The "Situated Pollution" project aims to allow the display of air pollutant levels from a specific time. The used period of time is the data's temporal referent. When that happens, the visualization will be **temporally situated**. If the pollution data is seen in real-time, the visualization is considered **highly temporal situated**. Moreover, assuming the existence of a camera in the area of study and a user seeing its feed from, for instance, the day before, augmented with the air pollution data, the visualization will be **asynchronously situated**.

### *C. Place*

Zone B has a building with a particular shape. This characteristic is part of the identity of that zone (data's local referent). Thus, the visualization embodies the identity of that place when it presents, for instance, the issues caused by air pollution to that specific building. When this happens, the visualization will be **locally situated**. Moreover, Zone B was named after a Portuguese singer, which associates the cultural work of that singer to that zone. Thus, a **locally SV** is, also, happening if the air pollution of that place is, for instance, shown with a background music of that singer. Thinking in the **surroundings** characteristic of the place's identity, the visualization must take into account if the area is dynamic or not and, if so, how that livelihood affects the user. Thus, for instance, if there is too much information about the air pollution to follow on the physical sub-presentations, the user could be unable to extract all the information without stopping, jamming the walking flow. If that happens, the visualization is not locally situated.

### *D. Activity*

If the "Situated Pollution" application detects air pollution above a certain level in the area where the user is, it triggers the activity "actions alarm", by showing the user several hints to reduce the air pollution (scientific education). This situation denotes that the visualization is **situated regarding the activity**. The pollution reduction is the data's activity referent. After the presentation of the hints, the application asks the user if he/she really wants to participate in the activity. If the answer is yes, a set of instructions to be followed by the user will be exhibited. If that happens, the visualization will be **situated regarding the activity's role**, because the physical presentation provided information closely related with the stated activity. The term "*closely*" indicates that the directives could go from being exact to being generic. Ideally, but not yet implemented, for each correctly followed instruction the user will gain eco-times, which he/she can spend to plant trees.

### *E. Community*

With the analysis of the results from the pollution data, a public polling about local issues regarding the pollution is planned. Since the obtained data is from Zone A or Zone B, it only makes sense if it is done for and with people who enter either zone (data's communal referent). Therefore, the visualization is **communally situated**, because the questions presented on the passers-by mobile phone, are closely related to them. As mentioned, in the community perspective, the situatedness of the category "*multidisciplinary*" goes from extremely simple to very complex. Thus, in the "Situated Pollution" project, a visualization will be **multidisciplinary situated** if the message "not polluted air in the area" appears on the mobile phone of a layman user profile and the physical presentation of an expert user profile will display: the air quality index, the air pollution level, a 3D model of the pollution data overlaid on the real world images, the existing pollutant substances in the air, and the historic/forecast for the air quality in that specific area.

### *F. Content*

In relation to the situatedness of the category "*comprehensively*", if a physical sub-presentation does not have enough graphic capacity to show the 3D model of the pollution data (the only information to show), the visualization cannot be comprehensively situated, because that information cannot be seen by the user. On the other hand, if the same physical sub-presentation can show, instead, other types of information related with the acquired data of the air pollution, its visualization could already be **comprehensively situated**, because the user can see almost all, or "*closely*" see, the information. Another important point concerns the exhibition of confusing, incomplete or erroneous information. This only happens in the visualization design phase, with a poorly prepared project staff. Therefore, a comprehensively situated visualization is related to the designers of the visualization and not to the end user. One of the goals of the "Situated Pollution" project is the inclusion and accessibility, implying that the input and output of the mobile application should be multimodal (visual and audio) and adaptable to the user's capacities (customizable). In addition, the stated goals involve interaction/exploration regarding the user's actuation. Thus, when these goals are achieved, the project will have a visualization **interactively situated**. The information obtained from the pollution's measure sensor and from the user are the data's context referent. In conclusion, the project will be **SV regarding the content** when its designers produce a comprehensively or interactively situated visualization.

## V. CONCLUDING REMARKS AND FUTURE WORK

As SV, held by AR/MR technologies, gains interest in the research community, new efforts to generate harmonization of perspectives must be conducted to create a common ground for analysis. This may lead to a better understanding of the contributions that AR/MR may bring to this developing research area. In this paper, a critical analysis about the current knowledge characterization of the emerging SV research area, within the AR/MR, is presented. The proposed outcomes allow to establish a common ground for debate and analysis by the research community. This novel suggestion offers an update of existing concepts and definitions, as well as the introduction of new perspectives. One of these, the content, aims at alerting SV designers to the need of placing the users and their needs at the centre of the design process. Although the use of technology is becoming increasingly common, there are still many people who have a very reduced or non-existent knowledge on the handling and use of basic computer applications. So, a concern of SV designers should be, whenever possible and appropriate, to create visualizations and interactions to a broad spectrum of user profiles.

One essential point to note is that our proposal is not intended as a closed work, but should, instead, be taken as the grounds that might enable the community to elaborate, expand, and refine it over time. The work presented in this paper contributes to this high-level goal by providing a sufficiently clear organization for understanding where new categories may be inserted.

As future work, the "Situated Pollution" application must be used as a utility demonstration method, to validate the systematization proposal with experts in the visualization field and to understand the user experience. To accomplish the appealing strategy of democratizing the visualization, the project must develop methods and tools, technological or otherwise, to support non-visualization specialists and make interaction fluent and easy to use, considering the environment, leveraging technological and human modalities. Generically speaking, the community must push forward towards the design of intelligent AR/MR systems for SV scenarios. These may allow a broad spectrum of user profiles to have support for decision making situations [2]. Another opportunity that may be explored, is to consider gamification concepts within the SV domain, which may create greater engagement and awareness by potential users.

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