A Taxonomy of Augmented Reality Annotations

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Abstract: Annotations have become a major trend in Augmented Reality (AR), as they are a powerful way of offering users more information about the real world surrounding them. There are many contributions showing ad hoc tools for annotation purposes, which make use of this type of virtual information. However, there are very few works that have tried to theorize on this subject to propose a generalized work system that solves the problem of incompatibility between applications. In this work, we propose and develop not only a taxonomy, but also a data model that seek to define the general characteristics that any AR annotation must incorporate. With this, we intend to provide a framework that can be used in the development of any system that makes use of this type of virtual elements.

1 INTRODUCTION

Annotation is an essential interaction method in daily life. Traditionally, people have used handwritten annotations on paper as a tool to summarize and highlight important elements of written texts (using underlined or highlighted words) or to add reminders, translations, explanations or messages for others in shared documents (through side notes, for example). But not only the text or paper-based information is annotated. In general, any physical object in our environment can be annotated (Hansen, 2006), for example: we can paste a Post-it note next to a switch to explain its functionality.

As text became to be digitized, new tools were developed in order to take annotations in (and through) the new computer systems. Subsequently, the hypermedia systems (Grønbæk, Hem, Madsen, & Sloth, 1994) and the advantages of the web (Kahan & Koivunen, 2001) were exploited to enrich the note-taking processes. With the advent of mobile and ubiquitous computing devices, digital annotation has been extended even further. Since the information is virtual and, therefore, is not physically placed on real-world objects through paper notes. Instead, it is stored on servers and different methods are used to identify the physical objects to which each annotation refers.

A step further in the virtualization of annotations has been achieved thanks to the development of Augmented Reality (AR). In fact, annotations are an intrinsic component of this technology. As described before, humans leave notes in the physical world to share information. In parallel, they place texts, images, audios, etc. in digital format to communicate through the virtual world. Thanks to the AR, it is possible to blur the boundary between physical and virtual world so that virtual information can be presented in the same location as the element of the physical world with which it relates.

One of the main advantages of AR is that it has the ability to contextualize and locate virtual information. Annotation is one of the most common uses of AR as it is a powerful way to offer users more information about the world around them (Wither, DiVerdi, & Höllerer, 2009). However, until 2009 this virtual element was not defined in a reasonably general and well-grounded way to be used in the future literature. Most of the published works show applications developed for specific uses and very few have tried to define and categorize AR annotations.

Once we have reviewed the published literature on this subject, we have found it is necessary to complete a study from the point of view of software engineering that results in a generic data model that can be used in any type of application with AR annotations. This generic model attempts to solve the incompatibility problem that currently exists between the different AR annotation systems: annotations made with a specific application can only be seen with the same application.

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In this paper, we define an AR annotation. Subsequently, we analyze the characteristics of this type of virtual element that over the years have been contributed by different authors. Finally, we develop a theoretical model that allows defining any AR annotation.

2 RELATED WORK

Although the term Augmented Reality was not coined until 1992 in (Caudell & Mizell, 1992), in 1981 Tom Furness already developed the *Super Cockpit* system (Furness, 1986), which can be considered as one of the first applications with AR annotations. The system consisted of a see-through head-based display mounted to the user's helmet through which the pilots of an airplane could see their environment augmented with virtual information.

Immediately, studies on applications of AR annotations began to emerge (Feiner, MacIntyre, & Seligmann, 1992; Rekimoto & Nagao, 1995). Today, it is a hot topic and there are numerous publications on this type of development, such as (Bruno et al., 2019; Chang, Nuernberger, Luan, & Höllerer, 2017; García-Pereira, Gimeno, Pérez, Portalés, & Casas, 2018). However, the theorization of the concepts related to AR annotations has been very scarce, since most of the works focus on the development of ad hoc tools in different areas of application. That is why the definition, characterization and categorization of this type of virtual elements is dispersed in the literature.

One of the first authors to theorize about AR annotations was Hansen in (Hansen, 2006), who analyzes the annotation techniques of different systems, such as: open hypermedia, Web based, mobile and augmented reality. This aims to illustrate different approaches to the central challenges that ubiquitous annotation systems have to deal with. Subsequently, Wither et al. defined in (Wither et al., 2009) the concept of annotation in the context of AR. In their paper, they propose a taxonomy for this type of virtual elements. Although this work is one of the most complete to date, in the last decade there have been new studies that analyze some aspects that were not contemplated by Wither et al. One of them is (Tönnis, Plecher, & Klinker, 2013), where the authors present the main dimensions that cover the principles of representation of virtual information in relation to a physical environment through AR. These dimensions are perfectly applicable to AR annotations, as we will see later. In (Keil, Schmitt, Engelke, Graf, & Olbrich, 2018), the authors describe and categorize the visual elements of AR based on their level of mediation between the physical and the virtual world. Again, their concepts can be used to classify AR annotations.

In this paper, we analyze the contributions made to date on AR annotations (or on virtual elements applicable to annotations) with the aim of unifying them in a data model capable of supporting any type of AR annotation.

3 DEFINITION OF AR ANNOTATION

Wither et al. defined in (Wither et al., 2009) the concept of AR annotation. Theirs objective was to cover a wide range of uses, so it is a fairly general definition: *"An augmented reality annotation is virtual information that describes in some way, and is registered to, an existing object"*.

As the authors explain, this definition allows that virtual information can adopt different formats (texts, images, sounds, 3D models...). Also, the relationship between virtual information and the object annotated can be defined indirectly. This second point presents discrepancy in the existing literature, since some authors, such as (Hansen, 2006), consider that an AR annotation must necessarily be in or next to the object annotated and clearly related to it. For example: an arrow that directs a user to a destination is linked to the final destination, which is the object annotated, but does not appear next to it or with a clear visual relationship, so Hansen does not consider it as an annotation as opposed to Wither et al. In this work, we use the Wither's point of view since it encompasses many uses of AR annotations that would otherwise not be analyzed.

From the definition of Wither et al., we can extract four basic elements that must be defined when designing an AR annotation:

1) Virtual information
2) Object annotated
3) Spatial relationship between 1) and 2)
4) What kind of description does 1) of 2)

To clearly differentiate what an annotation is from what is not, the authors define two essential components that every AR annotation must necessarily have: a spatially dependent component and a spatially independent component. The first one must link the virtual information with the object that is being annotated, so it is a relationship between the virtual world and the physical world. This means that any annotation must be registered to a particular existing object and not only to a point in the coordinate system. The spatially independent component implies that there must be some difference between virtual content and what the user sees from the physical world. For example, a perfect 3D model of an object that is used to make occlusions is not an annotation, even if it was spatially dependent. Instead, if the same 3D model has some modification in relation to its physical homonym (it changes a texture, for example), it would already be considered an annotation since it adds information and modifies the user's perception of the physical world.

Figure 1 shows a graphic representation of the definition given by Wither et al. for an AR annotation and all the concepts associated.

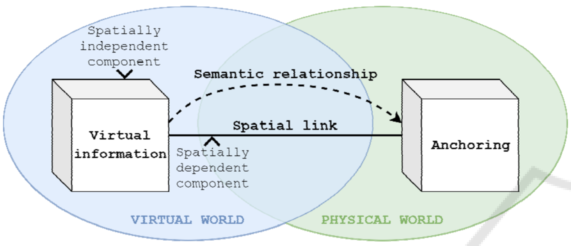

Figure 1: Components of an AR annotation.

4 CHARACTERISTICS OF AR ANNOTATIONS

As explained in the previous section, some studies present taxonomies to characterize the AR virtual elements or, more specifically, the AR annotations. The different visions of each author are explained below in order to synthesize their contributions later.

Wither et al. present in (Wither et al., 2009) six orthogonal dimensions that serve to describe and classify the annotations in a more concrete way:

- **Location Complexity:** The obligation to have some spatially dependent component means that all annotations have an associated location in the physical world. However, the complexity of this location can vary greatly from one annotation to another, from a single 3D point to a 2D or 3D region or even a 3D model.
- **Location Movement:** of the virtual part of the annotation (not of the physical element annotated or of the animations contained in the virtual information). The freedom of movement of virtual information and the allowed distance from its anchoring depend on the application and, where appropriate, on the user's preferences.
- **Semantic Relevance:** Indicates how the virtual information of a given annotation and anchoring are related. The descriptors that provide more direct information about the annotated element and have a greater semantic relevance are those that name or describe it. On the contrary, those descriptors that add information, modify the annotated physical element or guide the user usually provide information that is not directly related to the anchoring and have less semantic relevance.
- **Content Complexity:** This dimension can vary greatly from one annotation to another: from those that are a single point that marks an object of interest to that whose content is an animated 3D model with sound. The complexity of the content can be determined both by the amount of information transmitted by the annotation to the user and by the visual complexity of the annotation itself.
- **Interactivity:** Wither et al. differentiate between four levels of interactivity: annotations that the user can only view but without interacting with them, annotations with which the user can interact but without editing or adding information, annotations whose content can be modified and annotations that the user can create when using the system.
- **Annotation Permanence:** An annotation does not always has to be visible to the user, as in cases where you want to avoid information overload. To control the permanence of an annotation, the authors list five basic strategies: permanent annotations, time-controlled permanence, user-controlled permanence, permanence based on the user's location and filtered annotations based on the information and current status of the application and the user.

Wither et al. compare their six dimensions of AR annotations with the four challenges for ubiquitous annotations described in (Hansen, 2006), which are:

- **Anchoring:** The linking of the virtual information with the annotated physical object is essential and the precision with which it is carried out is decisive in achieving a communication objective.
- **Structure:** The data model used by the identification technologies to link the virtual information with the annotated elements must be general enough to: 1) allow any object that has been identified to be annotated and linked and 2) to be able to use different anchoring techniques.
- **Presentation:** Hansen differentiates between three types of virtual information presentation: presented in the annotated object, separated from the annotated object but in its environment and completely separated from the annotated object.
- **Editing:** Providing the user with the ability to edit the annotations displayed or generate new ones is very desirable in certain scenarios, therefore developers should not limit themselves to annotation

systems that only allow the user to consult the information previously loaded into the system.

As Wither et al. point out, the Anchor, Structure and Presentation challenges defined by Hansen describe how and where an annotation is placed in relation to the object that it annotates, so they are directly related to what they call Location complexity and Location movement. For its part, Hansen's challenge of Editing is directly linked to the Interactivity dimension of Wither et al. Hansen's work does not take into account the information contained in the annotations, only its relation to the annotated objects and with the user. Wither et al., instead, adds the dimensions of Semantic relevance, Content complexity and Annotation permanence in order to evaluate the content of the annotation and its temporal dimension.

As a complement to the six orthogonal dimensions of Wither et al., the work of (Tönnis et al., 2013) presents five other dimensions that cover the representation principles of virtual information in AR related to the physical environment. Therefore, the authors do not speak specifically of annotations but their classification complements that of Wither et al. and can be extrapolated to the scope that concerns us. These dimensions are:

- **Temporality:** It depends on the existence of the virtual information, regardless of whether it is within the field of vision or not. The authors differentiate between permanently represented information and information that occasionally exists in the augmented world, as it depends on specific events.
- **Dimensionality:** Methods used to visualize and integrate virtual information in the physical environment: 2D or 3D.
- **Viewpoint Reference Frame:** Method to represent the virtual information in relation to the point of view of both the user and the virtual camera of the system. They differentiate between: egocentric (first person), exocentric (third person) and egomotion (displaced).
- **Mounting and Registration:** Spatial relationship between virtual information and the physical world. Mounting refers to what virtual information is linked to (user, environment, world or multiple). Registration is the technical part of the mounting, that is: how to accurately determine a location in the physical world (the anchoring) to place the virtual information.
- **Type of Reference:** The extent to which a virtual object refers to an element of the physical world. This dimension depends on the visibility of physical objects. The authors differentiate three types of references: direct (physical objects and their augmented information are visible to the user), indirect (virtual information reveals hidden physical objects) and pure (virtual objects provide references to physical objects that are not in the field of view).

Tönis et al. compare their dimensions with those of Wither et al. The authors relate their dimension of Temporality with that Wither et al. call Annotation permanence. However, we believe that, although they are related concepts, it is interesting to study them separately because the Wither et al. classification is based on the fact that an annotation does not always have to be visible to the user while that of Tönis et al. depends on the existence of the annotation, regardless of whether it is within the field of vision or not. Moreover, Tönis et al. relate their dimension of Dimensionality to the Semantic Relevance and Content complexity of Wither et al. However, Tönis et al. differentiate between 2D and 3D information objects while the Wither's classification is much more detailed. The Viewpoint reference frame dimension is exclusive to Tönis et al. since it is a generic concept of AR. For its part, the Type of reference dimension is described by Tönis et al. as a sub concept within the Semantic relevance dimension of Wither et al., so it might be interesting to study these two dimensions separately (Wither et al. focus more on how the content of the annotation contributes to the object annotated while Tönis et al. focus more on the relationship between them). Finally, the dimension of Mounting and registration are related to the dimensions of Location complexity and Location movement but, again, Wither et al. granulate the problem much more.

To complete the dimensions presented by Wither et al. and Tönis et al., it is also important to analyze the recent work of (Müller, 2019). His study focuses on how to represent information with AR to support manual procedure tasks. Although his work speaks, in general, of information and focuses on a very specific use of AR, its definitions and classifications can be applied to the specific case of AR annotations. Müller describes seven characteristics:

- **Spatial Relation:** Virtual information is spatially related and located in the physical world, which implies a link between physical and virtual objects and the registration of virtual information in specific coordinates of space.
- **Connectedness:** Virtual information is connected to the physical world not only spatially but also semantically.
- **Discrete Change:** Virtual information may be subject to change over time.
- **Manipulability:** It is possible to interact and edit virtual information through software. However, it

should be borne in mind that this may cause a loss of relevant spatial information.
- **Combination:** The combined view that the user has of the virtual information and the environment varies depending on their own point of view and, therefore, is not always controllable. In the same way, the environment can change making the perception of information objects not as precise as intended.
- **Fluctuation:** The difficulties in achieving a precise and stable alignment of the physical world with the virtual world mean that the combination of virtual information, the environment and the point of view is affected by uncontrollable fluctuations.
- **Reference Systems:** Virtual information can be placed and oriented using a different reference system than the one used to locate its anchoring. The authors differentiate two basic types of reference systems: world and spectator coordinate systems.

The characteristics described by Müller are much more generic and less detailed than the dimensions presented by Wither et al. and Tönis et al., although they are related and can give us new nuances at certain points, as will be seen in the next section.

The generic definitions and categorizations described above contrast with other works that perform classifications at a lower level, as is the case of (Keil et al., 2018). The objective of this work is to describe, categorize and organize the visual elements of AR to later discuss the level of mediation achieved by each of them and their suitability according to their context of use. The visual elements identified by Keil et al. in this work are the following:
- **Annotations and Labels:** In this category, the authors include 1) labels connected to the anchoring by means of a line and whose position can be relative to the element annotated or fixed on the screen and 2) elements such as icons that are always placed in the anchoring, oriented towards the user and that they can behave as objects that trigger events or display more information once they are activated. Thus, the authors group under this category the elements that extend the physical world by adding information even if they do not visually fit the augmented object.
- **Highlights:** Zones, objects or parts of objects that are visually highlighted through the use of its shape (for example: a table drawer is illuminated to attract the user's attention to it). The purpose of this type of elements is emphasize the physical world.
- **Aids, Guides and Visual Indicators:** Complementary visual elements, such as arrows or other markers, guiding elements or metaphorical indicators, such as light effects. They are usually 2D or 3D sprites or geometries, animated or not, that are anchored to particular points of interest. They emphasize caution and attention to certain details that would otherwise go unnoticed by the user.
- **X-ray:** Additive elements that show hidden, occluded or imperceptible structures. The illusion is created by artificially removing the occlusive parts of the objects of the physical world. These visual elements reveal spatial and semantic relationships between hidden and visible objects.
- **Explosion Diagrams:** Additive elements that show the relationship or the order of assembly of several parts of an object. Like the previous ones, it can be seen as an additional layer that enriches the current scene. It is necessary to ensure that the virtual element coexists in a consistent way with its physical homonym, without disorder, ambiguity or occlusion.
- **Transmedia Material:** Audiovisual material that can take any form, from sprites to video sequences. These elements overlap in the user's view and align with a real object and its viewing context.

As can be seen, all these virtual elements described by Keil et al. fit the definition given by Wither et al. for annotations, provided they have a spatially dependent component and a spatially independent component. Therefore, if we call the first classification of Keil et al. "Icons and labels" (instead of "Annotations and labels"), we can use this taxonomy to categorize more accurately the annotations described generically by Wither et al.

Besides, Keil et al. define three basic objectives that can be achieved thanks to them: **extending**, **emphasizing** or **enriching** the physical world. These objectives are closely related to the Semantic relevance dimension of Wither et al.

5 DATA MODEL

Once analyzed the most relevant contributions on the characteristics of the AR virtual elements and, specifically, of the AR annotations, it is essential to obtain a unique model that brings together all this information. As described in the previous section, the proposals analyzed complement each other but often the information is overlapped and repeated. The next step is to decide which characteristics are selected, which are combined and which are discarded. As a result of this synthesis task, a data model capable of characterizing any type of AR annotation has been obtained. With this, it is intended that the design of AR annotation systems will be much more transversal than the ad hoc tools developed to date.

All the conceptual connections that exist between the works analyzed in the previous section (Hansen, 2006; Keil et al., 2018; Müller, 2019; Tönnis et al., 2013; Wither et al., 2009) are reflected in Figure 2a. It shows the characteristics and dimensions described by each author and how they interrelate with each other. From the analysis of all these interrelations, all characteristics have been classified based on the type of information they provide about the AR annotations. In Figure 2 the characteristics have been marked in different colors according to the category to which they belong, leaving without color those that do not contribute any new concept and, therefore, are included in what other authors have already explained. The blue characteristics refer to concepts related to the content of the annotations, the green ones have to do with the spatial dimension, the yellow ones with the temporal dimension and the red ones with the interactivity. These four axes are explained later. The three characteristics marked in purple are generic concepts of AR, so they will not be included as specific to the annotations. Finally, those that have been marked in dark green have more to do with the technical part than with the conceptual part of the annotations, so they will not be discussed here.

Once all the characteristics have been classified and analyzed, those that are redundant or that can be included in more generic ones have been eliminated. In addition, some interrelations have been modified to identify which characteristics are going to be treated together and which are separately. The result of this analysis is shown in Figure 2b.

Based on this analysis and the result obtained in Figure 2b, the essential characteristics that must be defined during the design of an AR annotation are presented below. These characteristics are grouped around four axes: the content, the location (both of the anchoring and of the virtual information), the temporality and interaction allowed to the user.

To design the **content** of an annotation, it is essential to define, on the one hand, its functionality (extend, emphasize or enrich the physical world) in order to choose between annotations that name, describe, add, modify or direct. On the other hand, it is necessary to determine the degree of complexity that it will have, taking into account the amount of information and its visual composition. Once these two aspects are delimited, it is necessary to choose what type of annotation will be developed (labels, icons, highlights, aids, indicators, X-rays, explosion diagrams or transmedia material).

In addition to the content, it is essential to make a good design of the **spatial dimension** of the annotation. To do this, the location of the anchoring and the location of the virtual information must be defined. Both must have a reference system that they do not necessarily have to share, for example: the anchoring of an annotation can use the coordinate system of the world while virtual information can use the one of the user and move following him or her. In addition, virtual information can use a reference system for position and a different one for orientation, for example: a label that is located at a fixed point in the world but is always user-oriented. The possible reference systems are: user, physical object and world. Besides the reference system, the degree of complexity of the anchoring location must be

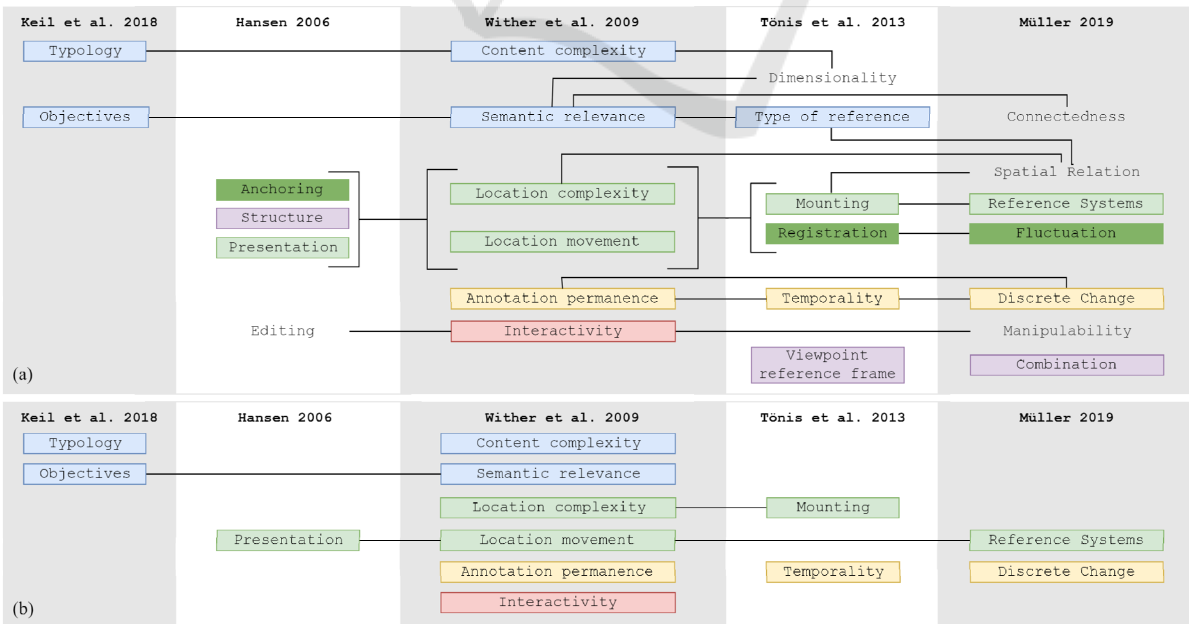

Figure 2: Conceptual relationship, classification (a) and synthesis (b) of the AR annotations characteristics.

determined. On the other hand, the location of the virtual information must have limited both its freedom of movement and the distance to which it can be from its anchoring. Depending on this distance and the characteristics of the application, it may be necessary to draw a line or some type of connector between the virtual information and the anchoring.

In the **temporal dimension** of the application, three aspects must be taken into account. The first one is variability, that is: how virtual information changes over time. The second one is visibility, since an annotation does not have to always be visible to the user. There are five strategies to control the visibility of annotations: fixed (virtual information is always visible), temporary (they are only visible at a specific moment and for a certain time), spatial (they are visible when the user is in a certain location), on demand (it is the user who controls which annotation is visible at each moment) and filtered (the visibility of the annotation depends on the current state of the application and the user). The third one is existence, that is: if virtual information exists constantly (regardless of whether it is always visible or if it is only shown in certain circumstances) or if, on the contrary, only exists as a result of certain events.

Finally, in the design phase of an AR annotation, the **degree of interaction** that is allowed to the user must be determined. For this, it is necessary to choose between: annotations that are created offline and that are static (they can only be viewed but not interact with them); annotations that are interactive but cannot be edited; annotations that can be edited; and annotations that are created online by the users, who choose both the content and the location.

Figure 3 shows the four essential axes that must be defined when designing an AR annotation and the characteristics of each of them. From this taxonomy of the AR annotations, a data model has been designed with the aim of being able to support any type of AR annotation, regardless of its typology, functionality and device in which it is developed and with which it visualized. The simplified class diagram representing this data model is shown in Figure 4.

In our model, the proposed main class is "Annotation", which has as its attributes, among others, an object of the following classes: "Anchoring location", "Virtual information location", "Content" and "Visibility". In addition, annotations that are editable have a collection of "Annotation" objects whose purpose is to store the history of changes. Other important attributes of this class are the author and the creation date. It also has the necessary methods to manage the subscription to certain events of the application. The "Visibility" class allows managing the permanence of the annotation, whether fixed, temporary, spatial, on demand or filtered.

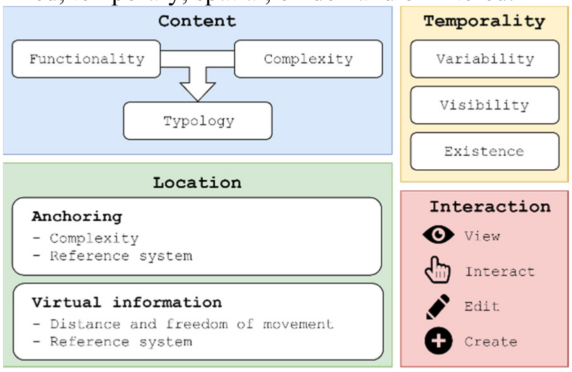

Figure 3: Main characteristics to be defined when designing an AR annotation.

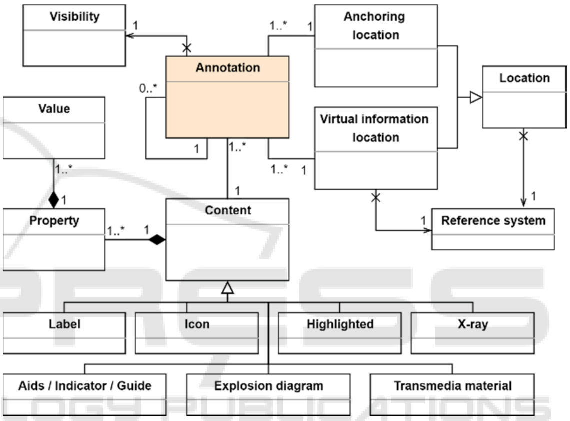

Figure 4: Data model of an AR annotation.

The "Anchoring location" and "Virtual information location" classes inherit their attributes from the "Location" class. One of them is a "Reference system" object for the anchoring position and virtual information respectively. In addition, the "Anchoring location" object has an attribute to store coordinates that allow the anchoring to be positioned correctly based on the chosen reference system. These coordinates can be from a simple point in space to a complex cloud of points. The "Virtual information location" object has an additional attribute of the "Reference system" class to know the orientation of the virtual information. In addition, it has attributes to store the minimum and maximum distance of the virtual information to the anchoring and/or the user, the allowed area where virtual information can be placed and, in the case of existing, the visual union of the virtual information with the anchoring.

Depending on the complexity and functionality of the annotation, designers choose the type of AR annotation to implement. Following the recent work of (Keil et al., 2018), our class diagram differentiates between "Label", "Icon", "Highlighted", "X-ray", "Aids / Indicator / Guide", "Explosion diagram" or "Transmedia material". All these objects inherit from the "Content" class, which requires developers to define a set of key-value pairs. In our data model, this is defined by a set of "Property" objects within the "Content" class. This "Property" class, in addition to the id, name and type attributes, has a set of "Value" objects, with their respective id and value attributes. In this way, any type of annotation can be implemented based on a list of properties.

6 CONCLUSION AND FUTURE WORK

This work presents a study and characterization of AR annotations from the point of view of software engineering. To do this, different works have been analyzed that theorize, in general, on virtual elements in AR or, in particular, on AR annotations. After the analysis of the existing literature, a taxonomy of the AR annotations has been obtained, which proposes to classify the characteristics of these virtual elements around four axes: content, location, temporality and interaction. This has been done based on a generic definition of AR annotation that encompass all virtual element that meets the requirement proposed in (Wither et al., 2009): having a spatially dependent component and a spatially independent component.

This taxonomy has allowed us to propose a data model capable of supporting any type of AR annotation, regardless of the hardware used. After this first model proposal, the next step will be to implement a system based on a more detailed version of the class diagram proposed and perform the relevant tests to perfect it. Thanks to this, we could offer a final solution to the incompatibility problem of AR annotation systems. Due to the increase in applications that make use of AR annotations, we believe that having a common framework is of great importance as it facilitates the work of developers and offers users greater transversality when interacting with different types of AR annotations.

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