A BIM-based model to study wayfinding signage using virtual reality

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Abstract. Wayfinding signage is essential in a large building to find one's way. Unfortunately, there are no methodologies and standards for designing signage. A good sign system therefore depends on the experience of the signage company. Getting lost in public infrastructures might be disorienting or cause anxiety. Designing an efficient signage system is challenging as the building needs to communicate a lot of information in a minimum of space. In this paper, we propose a model to study wayfinding signage based on BIM models and the BIM open library, which allows the integration of signage design into a BIM model to perform analyses and comparisons. The study of signage is based on the user's perception, and virtual reality is a tool that best approximates this today. Our model helps to perform signage analysis in building design and to compare objectively the wayfinding signage in a BIM model using virtual reality.

1. Introduction

Signage guides us in cities, airports, buildings, or even roads. Signs come in different forms and representations, whether they are placed indoors, freestanding, or building-mounted. They can be mobile in space and be dynamic like screens. They may include a combination of letters, words, graphics, and symbols composed of different colours, materials, textures, and lighting. They give essential visual communication for wayfinding, no matter their composition [1]. More and more smart devices, such as smartphones, smart glasses, or smartwatches, are used as navigation aids and thus become signage elements. During the design of a building, signage systems, which consist of a set of signs, are mostly designed late in the project or even at the end. Furthermore, they are not tested or simulated before being implemented. The science of signage is neglected. However, the orientation in airports is well adapted. The first visit to an airport can be confusing, but subsequent visits will be easier because the problem of orientation is the same all over the world. The traveller must get on the right plane following a single path in a minimum of time. In contrast, on a university campus, for example, the visitor has several possible paths to reach his/her destination. One of the most complex cases regarding signage is healthcare facilities. They are subject to multiple restrictions because they have to transmit a lot of information in a small and regulated space. Wayfinding in a hospital is a complicated matter due to the specific terms to be transmitted as well as the number of new visitors who come every day to visit for the first time [2,3]. All public buildings need to communicate and guide their users through signage. Therefore, there is a need to simulate signage, to put engineering back at the heart of signage as it is for the design of buildings today.

The design of a complex building is increasingly carried out in the Building Information Modelling (BIM) process. BIM technology can simultaneously store geometric information and rich semantic information of the building model, as well as the relationship between them, and support the sharing of building model data [4]. It is an intelligent process used to obtain a digital copy of a construction project. Unfortunately, signage is not at present integrated into this process. It is set aside and often seen only at the end of the building design.

In the field of Architecture, Engineering, Construction, and Operations (AECO), there is an enthusiasm for virtual reality to visualise BIM projects [5]. The value of VR in AECO is the interaction with the BIM model, enabling the user to be immersed in the building and navigate while interacting with its environment. Since signs are related to human senses, such as sight, or touch for the visually impaired, virtual reality technology can make use of these senses, and it can be an interesting tool to simulate the signage and to get results.

In this paper, we propose a model to study wayfinding signage based on BIM models. This will allow us to perform signage analysis in building design and help us to make objective comparisons of different types of signage. Furthermore, it helps to design and experiment with signage projects in virtual reality for any future building users. The work that we present in this article concerns the AECO domain in general, although in the examples and the validations, we will refer to the healthcare domain and in particular hospitals, for the good reason of the complexity that they exhibit.

2. Literature Review

As we saw in the introduction, we first need to detail the state of the art to show the shortcomings of the study of wayfinding signage. To do this, we will explain what wayfinding signage is and its impacts. Then we will present the studies carried out so far on signage in connection with BIM. To finish, we will define what virtual reality is and its use related to signage.

In the context of architecture, the user experience of orientation and choosing a path is known as wayfinding. Kevin Lynch defined wayfinding as "a consistent use and organization of definite sensory cues from the external environment." [6]. A wayfinding system is most commonly composed of four types of signs: directional, informational, identification and regulatory [7]. It is not restricted to signs, but also uses architecture, landmarks, colours, lighting or technologies. A poorly designed wayfinding system can, conversely, communicate the wrong information. Furthermore, wayfinding problems can have a financial impact, for example, at a hospital due to disoriented patients and visitors asking for directions and missing their appointments as a result of confusing displays and building inefficiency [8]. In a review analysing 34 publications about signage recommendations and guidelines [9], all the proposed guidelines and recommendations are specific to the cultural context and there is no standardisation for signage designs in AECO, so there remains a need to standardise signage design.

BIM technology can be defined as an accurate virtual model of a digitally constructed building [10]. BIM is based on a 3D model, which contains information about the installation. The 3D carries a large amount of data that characterises the installation or part of the installation to improve the understanding of design and planning data [4]. Recently, signs were analysed in BIM using agent-based simulation to simulate human behaviour in general wayfinding and emergencies [11,12]. However, signage is not seen as a means of computation but is positioned by hand, as a decorative element. Motamedi and colleagues [13] propose an interesting system to optimise the placement of signage in a BIM model based on the signage's visibility and legibility using a pedestrian model. It integrates the signage as an element of the BIM model, but the information used to perform the simulation is limited to the visibility of the sign. The BIM properties of the geometric model are lost. The newly generated placement of the signs is based on the possible visibility to a human, but no validation is done in an interactive virtual environment.

Virtual reality is defined as "an approach that uses displays, tracking, and other technologies to immerse the user in a Virtual Environment" [14]. In this paper, virtual reality is immersive and interactive, where a 3D interaction is a “human-computer interaction in which the user’s tasks are performed directly in a real or virtual 3D spatial context” [14].

In the domain of the AECO industry, VR is mainly used to show finished projects to prospective clients, presenting complex information in such a way as to allow an easier understanding of the building design. It is also used for training scenarios [15,16]. In a survey, Coppens and colleagues [5] found that there is a demand for the use of VR for architecture, where 75% of the participants indicated that it could be very beneficial to the field. It could involve stakeholders in the design process, even for the designers during the design process, and not only for showcasing the finished product. Furthermore, Sateei and colleagues [17] highlighted that VR provides a better understanding of the project and a spatial understanding in comparison to 2D drawings and 3D models. VR can influence the design outcome of the building depending on the design phase by facilitating the communication and the coordination between the actors involved in the project [18]. In some studies, VR is used to study wayfinding, where horizontal and vertical signage is compared with a virtual environment without signs [19], comparing wayfinding in a VR and a real environment [20], comparing emergency signs in the case of fire evacuation [21] and more general emergency situations [22,23]. These signs studied are used as a visual element and not as a computational model.

In the state of the art, the models we find mainly consider the signage elements under a visual aspect, and do not simultaneously integrate a signage model, the BIM, and an interactive virtual reality experience.

3. Methods

We saw in the literature review that there is a gap in the study of signage in the AECO field. In our work, we want to automatically analyse and generate signage in the BIM process (or building design). To this end, it is necessary to create a signage model based on a signage typology. Our model aims to provide access to signage information in the BIM process. This information is useful to perform computation and analyses on the signage elements. Our model simplifies the integration of signage in virtual environments by characterising the types of signs and establishing a formalism for the implementation of signs. The workflow of the model is described in section 3.1, the signage typology and the signage model are developed in sections 3.2 and 3.3 respectively, then in section 3.4, we present the use of our model.

3.1. General Workflow

Our model is based on the IFC format. It communicates with the BIM model and its parameters. Figure 1 shows the general process in which the signage model is designed. The signage model retrieves the BIM model and uses it as support. It can also use any other geometric model. We can build multiple tools and algorithms around the signage model to work with signage elements and the BIM model, for example, a set of tools that helps in the placement of signs thanks to a list of proposals based on the typology of the signage. Afterwards, the 3D model can be exported in IFC format to be part of the BIM process.

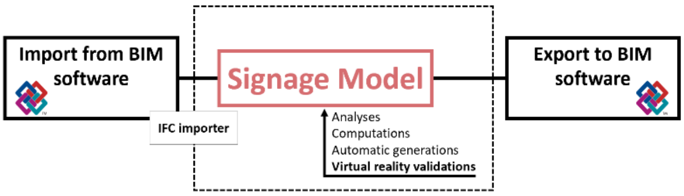

Figure 1. The general workflow using the signage model.

Virtual reality integrates naturally with our model to visualise a BIM model with a more realistic perception than the 3D visualisation on a screen. This allows stakeholders to make a first validation of the implementation of the signage. VR effectively facilitates the coordination and communication between the actors involved in a project and provides an immersive experience on a scale of 1:1 [17]. Some use cases are illustrated in section 4.

3.2. Signage typology

A signage element can have different names that allow them to be grouped into categories. We need to categorise the elements of signage to classify and compare signs based on their internal characteristics. Figure 2 below shows a general overview of the signage typology with every element that describes a sign. A sign can be found inside or outside, it can give either a direction or information, it can be static or dynamic, it can be fixed or mobile. Our signage model must consider all these possibilities of representation, which leads us to the expression of a typology. The signage typology groups the key characteristics that can be used to describe a sign.

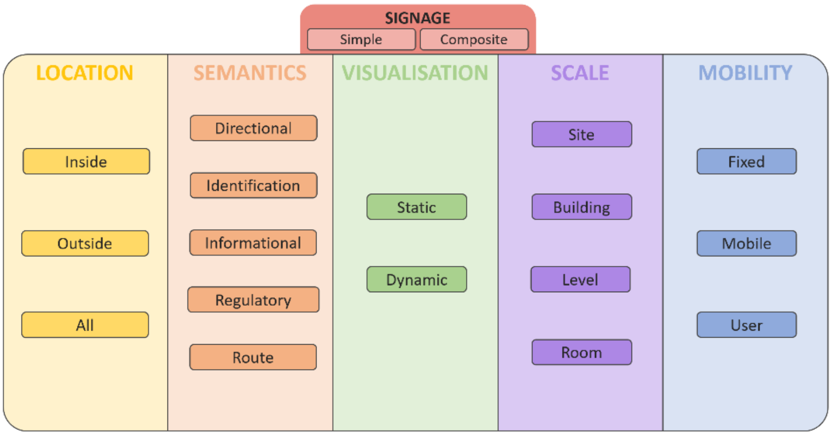

Figure 2. A general overview of the signage typology. A sign is described by different characteristics and can be simple or composite (aggregation of signs).

A sign is linked by its **Location**, which can be *Inside* or *Outside.* In some cases, the sign is mobile and can be moved both inside and outside, referred to here as *All*.
Every sign has a purpose, defined by its **Semantics,** i.e., what type of information does the sign convey? What does the object want to transmit in terms of information and how does it transmit it:

- *Directional* signs help people get to their destination by orienting and guiding them step by step. They are typically found at intersections or anywhere one might look for directions. Continuity is essential for directional signage. If you get lost between two points, you are forced to retrace your steps or just rely on chance.
- *Identification* signage identifies a place. It indicates when a visitor has arrived at his or her destination. It also serves as a point of interest for orientation. Its absence can also indicate that we are not in the right place.
- *Informational* signage provides general information about the entire facility. Information signs are more about completing the journey with useful information along the way rather than moving toward a destination.
  It is usually present in large, widely exposed spaces: lobbies, waiting rooms, or building entrances. It should answer questions before they are asked, such as: Is this the bathroom? What does this door open to? Is there an elevator?
- *Regulatory* signage addresses safety and liability issues. It serves to establish and reinforce the rules, safety standards and privacy expectations of the facility. Regulatory signage is usually big and bold, giving a clear, concise, and prominent message. It should leave no room for ambiguity, such as a request to wear Personal Protective Equipment, rules and regulations (no smoking), access control (reserved for employees, professionals).

- *Route* signage typically uses icons, alphanumeric or voice text, and is capable of adapting in real-time to traffic or route changes. Unlike directional signage, on-board signage is considered continuous direction along the route rather than sequenced at key points. A smart device like a smartphone or goggles that help the user to navigate the building are types of route signage.

Visualisation answers the question, how is the information perceived? It can be *Static*, where the information perceived does not change, or it can be *Dynamic* and adapt to its environment. A dynamic sign can be a television showing slides giving several types of information. It also includes all digital signage.

The **Scale** determines the space encompassed by the sign. Is it related to the entire *Site*, the *Building*, a *Level* or a *Room*? A directional sign on the first floor indicating a room on the same floor is related to a *Level* of the building.

The last characteristic is **Mobility**. The sign can be *Fixed*, *Mobile* in space, or a particular case of mobility where the signage element represents a navigational aid that is used by the *User*, like a mobile device with a wayfinding application.

Each type of signage should not be used on its own, but they should work together. Regulatory signs should prevent people from entering prohibited areas while they are following directional signs to their destination. Informational signage, in conjunction with regulatory signage, should set expectations for behaviour in the building.

A sign can be *simple* or *composite*, where a composite sign is the aggregation of multiple signs. A simple Directional sign and a simple Informative screen aggregate to form a composite sign with both characteristics.

We have described in this section an abstract model of our signage typology. We will see next how to integrate it concretely in section 3.3.

3.3. Signage model

The signage model characterises types of signs and helps the integration of the signs in a BIM model. Figure 3 shows how the signage model operates. The *Signage Object* is our sign in the virtual environment. It represents the implementation of the signage classification. These are not restricted to interacting with other objects, but can also have links with the *environment* and the *users*. For example, in a wayfinding case, each panel (*Signage Object*) shows the same destination. In a more complex situation, a lost person will use his smartphone (*Signage Object*) to ask for orientation information to find his/her way in a city or a building (shown in section 4).

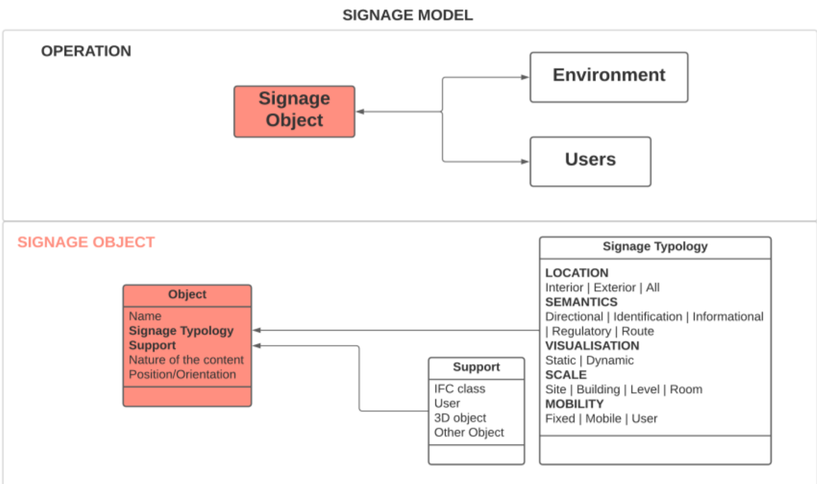

Figure 3. Representation of the signage model. (Up) describe the operation of the model. (Bottom) details the composition of a signage object.

To give more details on the *Signage Object* in Figure 3, it is defined by what follows:

- The **Signage Typology** refers mainly to the *Signage Typology* described above in section 3.2. It describes how the object transmits the information and what is transmitted.
- The **Support** represents the element on which the object is placed. It can be directly attached to an IFC class. A sign on a wall will be attached to the corresponding IfcWall. The object can also be attached to any other object, 3D or not, or the user himself.
- The **Nature of the content** allows the detailed elements contained on the sign to be specified. We represent it as a list of visible elements on the sign. For example, a panel could have text, an arrow, and a pictogram. For a screen, the nature of the content can specify what is displayed.
- The **Position/Orientation** specifies the spatial characteristics.

Our signage model is extensible and generic, so new typologies and signage elements can be easily added.

3.4. A model to allow computations and analyses

The properties contained in the signage model integrated in the BIM model give the possibility to access and analyse the entire building, and different queries can be made on this BIM model. The sign can be located in the building, knowing in which room on which floor it is located.
Our signage model gives properties to the signage elements to perform analysis in the BIM model.
The study of signage can lead to the need for algorithms. We want to have a tool that allows us to edit the signage and link it to the architecture. To do this, we can have a library containing a list of signage elements that can be enriched. To test a specific sign, an architect or designer may want to design a visual of a future sign to integrate it into the building. These elements can be placed in the building to be validated in a generated virtual reality application. The software Unity3D[1] allows us to fully integrate our model and to add an interactive interface to interact more intuitively with our signage model. Figure 4 shows the Signage Data Editor listing presets for the signage.

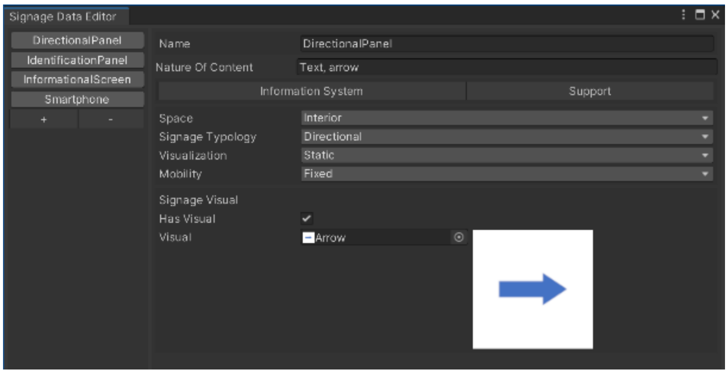

Figure 4. The Signage Data Editor, listing presets of signage.

Another type of result is to propose algorithms that automatically compute the type and position of signage elements from the model directly. For example, the algorithm could compute, from the patient flows applied to it, the complete signage for a complete building. Having all the users' flows from the architect allows us to generate the signage associated with all the paths from the users' flows.
To better understand the interest of our model, we will show in section 4 how we describe a sign with the model and examples of use we implemented.

[1] Unity3D game engine, https://unity3d.com/

3 Model Validation

With a computer-implemented model, we have a model with computational capabilities. Thanks to this, we can build verification algorithms before running simulations and perform simulations at any time during the design of a building. This means that we do not have to wait until the end of the building design to start the design of the signage. This may have a positive impact both on the design of the building and on the science of the signage.

To better understand the organisation of the model, we can represent three simple signage elements: a Directional panel, an Informational screen, and a Smartphone.

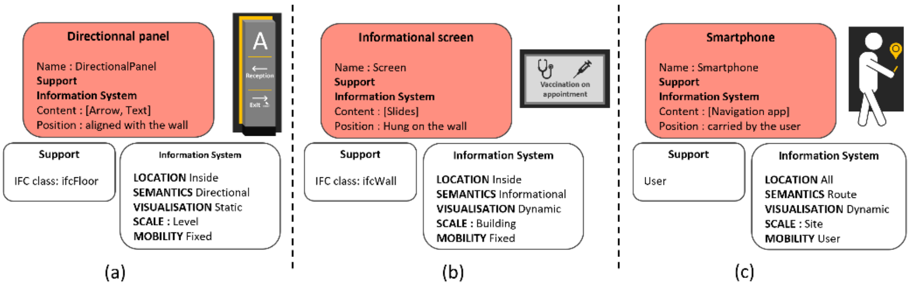

Figure 5. Three representations of signage objects described by the model:
(a) Directional panel, (b) Informational screen, (c) Smartphone.

The three signage elements are shown in Figure 5 in the same layout as the Signage Object in Figure 3 for a better view. The Directional panel is a panel with an *arrow* and a *text*. The panel is placed on the floor on the IFC class *ifcFloor*. The information contained in the panel is *Inside* the building, containing *directional* information with a *Static* image on a *Fixed* panel to the visitors at the current *Level.* In slightly more complicated signage, an Informational screen shows *informational slides on a screen hung on the wall*, which is no more complicated to describe than the directional panel. The main change is that the sign contains *informational* information with a *Dynamic* screen. A more complicated example is the Smartphone, which is a *Navigation device carried by the user*. The information contained is used by the *User* as a navigational aid through *All* the buildings and *Sites* (inside and outside), showing continuous direction along the *Route* on the *Dynamic* screen of the device.

To validate our signage model, Unity3D is used for its integration and the development of some examples of use. As an example, a portion of a hospital designed in Autodesk Revit[2] is imported into Unity3D. All the BIM parameters are contained in the 3D model in Unity3D. From this, algorithms can work with the signage model and the BIM model. For this validation, we use the BIM model of the outpatient unit corresponding to a real hospital project under construction. We also have the patient flows for the outpatient which represent the main paths between the different units studied by the architect.

One of the needs expressed in section 3.4 was to be able to generate the signage associated with the patient flows. We retrieved the real patient flows from the outpatient department for this example. Figure 6 shows the top view of the model in Unity3D separated in main room by the green areas. In the patient flow, the patient arrives at the reception desk for his/her appointment, then has to go to the locker room to drop off his/her belongings before going to the waiting room, where he/she will be redirected to the right module for the day (https://youtu.be/3NpZnHGaUAs).

[2] Autodesk Revit, https://www.autodesk.fr/products/revit/

Figure 6. (left) Top view of the model waiting for path selection before generating signs. **(right)**The blue directional sign and the orange identification sign are generated according to the respective doors.

From this top view of Figure 6, in the application we select a starting point and an end point that will automatically create a red path. The red path is created with Unity's internal navigation system. Once created, the algorithm will analyse this path and retrieve the positions of the doors, which are recognised thanks to the properties contained in the BIM model. On this path, there are three doors, two in the corridor and one for the lockers. Blue *directional signs* are generated above the doors on the selected path and an orange *identification sign* is above the door of the lockers as shown in the right part of Figure 6. We can then validate in virtual reality if the placement, the size, or the colour are correct. The path algorithm is run iteratively for all the destinations and that therefore at each iteration, on each door the destination indication and the arrows are cumulated to make a global panel. To go a little further, we experimented with virtual reality navigation using a virtual smartphone in the virtual environment of the hospital (see Figure 7). The smartphone indicates the direction with the help of four arrows to the specified destination. The arrows light up in turn to indicate whether the user should go straight ahead or turn at the next intersection. If the user takes a wrong turn, the smartphone indicates a downward arrow to signal to turn back. The smartphone is described by our model, queries can be made between it and other generated signs.

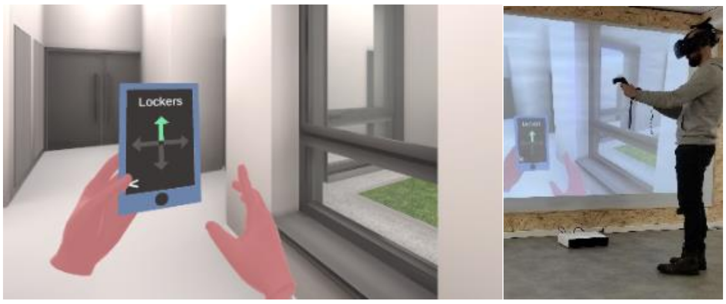

Figure 7. VR navigation with a smartphone indicating the lockers.

The combination of our signage model and virtual reality gives the possibility to realise different scenarios related to signage. We were able to integrate what could be the future of signage within a BIM model and provide the ability to carry out analysis.

4 Discussion

The literature review showed that signs are mainly studied as visual elements and not as computational elements. It also showed that VR want to be more and more used in AECO and provides a better understanding of the project and a spatial understanding in comparison to 2D drawings and 3D models. The BIM process allows today to embed a set of data directly into the 3D model. We want the signage design to be part of this process and therefore we propose a signage model that allows data to be integrated directly into the 3D sign. The model is based on a sign typology with different characteristics to describe a sign. Once the data is accessible, analysis and calculations can be carried out in different use cases. This was presented in the Validation section with two examples of the use of our model. The first example is inspired by the literature studies with pedestrian models to analyse a signage in a BIM model. The data embedded in the sign make it a computational element bringing more possibilities in signage study. The second one is a scenario of wayfinding using a virtual smartphone described by our model. The user uses a simplified smartphone which propose several destinations. Once the destination is selected with the virtual hand, arrows on the screen guide the user to the destination. Since the smartphone guides the user in a building, it is considered as a signage element by our model. So, we can make queries between the different signage elements and this smartphone and imagine the future of signage.

We would like to conduct an acceptability study with architects and designers to confirm that our model can be used and have an expert validity. Then, we will conduct a user experiment to determine the wayfinding differences between virtual reality and real-life orientation. We propose a model and a tool for signage designers to make proposals for users of a building. The starting point of the work is to propose a model and then to verify that in VR we have user behaviours similar to what happens in real-life. Otherwise, if we do not have something coherent, all the designs we make in virtual will be meaningless.

5 Conclusions and Further Research

Designing signage for a building may require some prototyping in real life for validation, but each building is unique and has its own specific purposes. A signage system that is adapted for one building will not necessarily be suitable for another building. One of the interests of virtual reality is that, as each building is unique, we can quickly prototype and validate the result using the virtual representation of the building in its environment. This allows us to speed up the verification process.
This paper presents a signage model and its open library that allows the integration of signage design into a BIM model to perform analyses, comparisons, and applies computational algorithms to signage elements and their surroundings. Furthermore, it helps to design and experiment with signage projects in virtual reality, either by the architect, designer, or any users the project is aimed for. This model aims to put engineering back at the heart of signage science.

For future work, we would like to improve our model to make it more accessible and closer to being ready for use by designers.

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