# Challenges in Public Display Deployments: A Taxonomy of External Factors

**Ville Mäkelä[1], Sumita Sharma[1], Jaakko Hakulinen[1], Tomi Heimonen[2], Markku Turunen[1]**
[1]University of Tampere, Tampere, Finland
[2]University of Wisconsin - Stevens Point, Wisconsin, USA
{ville.mi.makela, sumita.s.sharma, jaakko.hakulinen, markku.turunen}@sis.uta.fi,
tomi.heimonen@uwsp.edu

**ABSTRACT**
Public display deployments are often subjected to various surprising and unwanted effects. These effects are frequently due to *external factors* – properties and phenomena that are unrelated to the deployment. Therefore, we conducted a literature review within the public display domain to investigate the causes behind the reported issues. This work presents a taxonomy of external factors affecting deployments, consisting of six categories: *weather*, *events*, *surroundings*, *space*, *inhabitants*, and *vandalism*. Apart from a few positive examples, we predominantly found negative effects arising from these factors. We then identified four ways of addressing the effects: *ignoring*, *adapting*, *solving*, and *embracing*. Of these, ignoring and adapting are substantially more frequent responses than solving and embracing – emphasizing the need for researchers to adapt. We present real-world examples and insights on how researchers and practitioners can address the effects to better manage their deployments.

**Author Keywords**
Public displays; pervasive displays; challenges; taxonomy; external factors; deployments; literature review.

**ACM Classification Keywords**
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

## INTRODUCTION

Public displays are actively deployed and studied in various contexts, from shopping and transportation to entertainment. Much of the current focus in public display research is on understanding user behavior and interaction, and on models describing the dynamics of users [10,23,47, 49,69] and the components of the deployment [46]. Although public display applications presented in prior research generally appear to be successful, researchers often experience various surprising challenges.

Some past works provide retrospective guidelines based on subjective experiences with various challenges in public deployments [19,31,62]. However, a large segment of articles describing public deployments are less explicit in their reporting of these challenges. This is in part because the challenges faced are not necessarily vital to the research questions - or the "take-away message" - of their studies. Any experienced challenges are typically mentioned very briefly, for example, to explain why certain research approaches were not possible, or to provide rationale for sub-optimal design decisions that had to be made.

The work presented in this paper is based on the realization that many of these challenges (or *effects*) are due to *external factors*, i.e., they are caused by properties and phenomena that are unrelated to the deployment. The motivation for this work stems from our own experiences with various public display deployments in which we have encountered surprising issues due to external factors that have been difficult to identify and control. We believe there is now enough collective experience within the pervasive display community to shed light on the extent and type of challenges caused by external factors. This led us to conduct a literature review of reported issues to better understand their role in public display deployments. To our knowledge, we are the first to approach challenges with public display deployments from this perspective. This work addresses the following research questions:

- **RQ1:** Which types of external factors affect public deployments?
- **RQ2:** How do researchers react to the effects of external factors?

We identified and collected a set of 61 issues with public deployments caused by external factors (10 issues from our own experiences, and 51 from the literature). Then, using affinity diagramming, we categorized both the causes for the issues as well as the researchers' reactions to the issues. In addressing RQ1, we identified six categories of external factors: *weather, events, surroundings, place, inhabitants*, and *vandalism*. In addressing RQ2, we identified that researchers' reaction to these issues can be categorized as: *embracing, solving, ignoring*, and *adapting*. We found that ignoring (39%) and adapting to (39%.) issues are much more prominent than solving (13%) and embracing (8%).

The experienced issues are rarely fully solved during deployments, which we believe is because external factors are difficult or impossible to control, and their effects are often surprising. Hence, researchers must instead be prepared to adapt to such situations by adjusting the properties of the deployment. The infrequency of embracing, on the other hand, shows that such effects are most often negative, and are difficult to take advantage of. Both conclusions show the importance of recognizing external factors, and being prepared to address them.

By building on the collective experiences of the HCI community working within the public deployments domain, we provide a taxonomy of external factors. We highlight examples of each type of external factors, and provide guidelines for identifying potential factors that could affect their deployments, and describe common approaches for tackling these issues.

The paper is organized as follows. We first discuss the methodology, in which we describe the deployments from which we draw our real-world experiences, and the literature review, and the process of creating the taxonomy of external factors. Following, we present each category of external factors in detail and discuss approaches for addressing each of them. Finally, we discuss the significance of our findings.

## METHODOLOGY

To systematically investigate external factors with public deployments, we gathered issues caused by external factors from our own experiences as well as from existing literature, and categorized the found issues using the affinity diagramming approach.

We only included issues wherein a clear external cause could be identified. Therefore, we did not account for internal issues, that is, issues arising from the deployment itself, due to e.g., poor design solutions.

### Case Deployments

We first gathered issues from two of our own deployments. Since our focus in this paper is on external factors, and not on interaction with the installations, we present the deployments only briefly, primarily describing the deployment locations.

The *Information Wall* is a gesture-controlled public information display. We implemented two different versions, however in both versions, users navigate location-relevant content, such as local events and lunch menus of nearby cafeterias, by using mid-air gestures in front of the display (Figure 1 – B and C). The first Information Wall was deployed at a university campus for one year, from April 2013 to April 2014. The next version was deployed in the same location with identical equipment from October 2014 to April 2015. The deployment setting (Figure 1A) is a large, open space with a high volume of pedestrian traffic. It contains two major landmarks: a cafeteria that students, staff and visitors regularly use, and a large auditorium with several hundred seats. Information Wall was conveniently projected on a wall roughly between these two landmarks with a ceiling-mounted full HD projector.

The second deployment, *EnergyLand*, is a gesture-based system for initiating conversations on novel energy-efficient solutions for smart homes. Users interact with virtual objects in game-like tasks to understand ways to incorporate green energy practices inside their homes (Figure 1D). EnergyLand was a part of a Smart House installation at an annual Finnish housing fair in summer

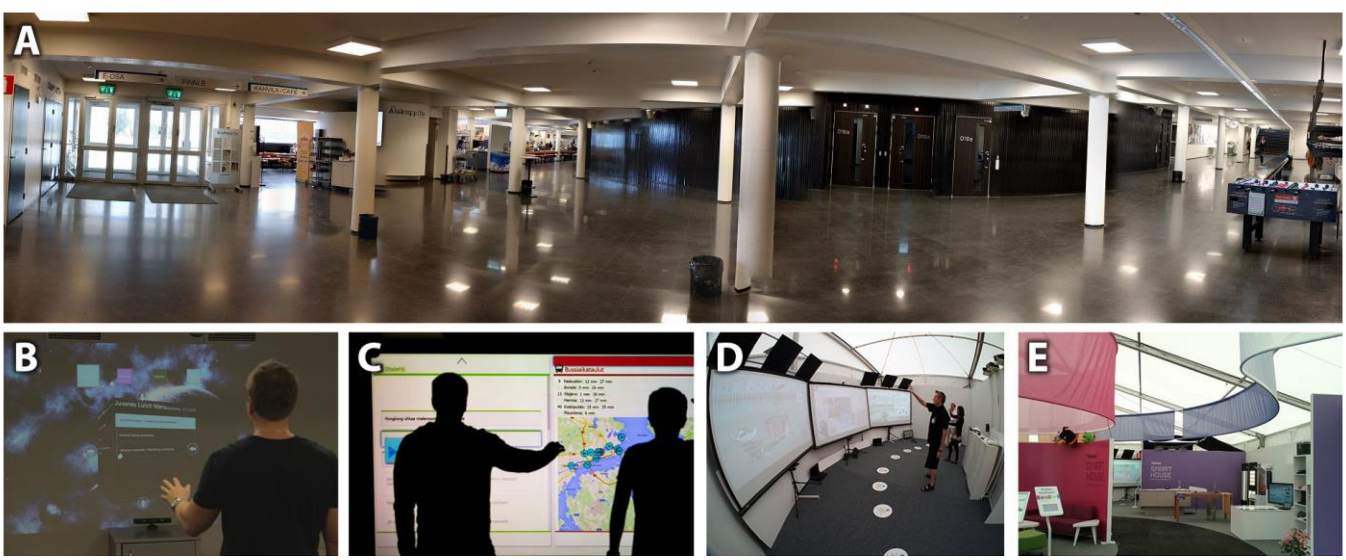


**Figure 1. Public displays and their locations. A) Panorama of the deployment location for Information Wall from the installation's perspective. Cafeteria on the far left, auditorium on the far right. B) Information Wall. C) Information Wall 2. D) EnergyLand. E) The deployment location for EnergyLand at a housing fair. The installation is at the far back of the room.**

2012 (Figure 1E). EnergyLand was installed in a 7 by 5 meter rectangular area inside a large 400 square meter Smart House tent. EnergyLand consisted of three large interactive screens arranged along the length of a wall and three poles on the opposite wall held a projector each, one for each screen. Microsoft Kinect sensors were used for gesture recognition, and a computer/laptop was placed under each screen. Two sets of speaker arrays were placed above the left and right screens, and a 5.1 channel speaker system under the center screen and under the projectors.

From these two deployments, we gathered a total of 10 issues that were caused by external factors. We will describe these issues later in the paper, when we present the taxonomy of external factors.

### Literature Review

For the literature review, we gathered a collection of papers using snowball sampling. First, we included papers that we were already familiar with due to our work on the field, such as those by Ojala et al. [54], Alt et al. [6], and Müller et al. [49,52]. Then, we reviewed the references in these papers, and added cited papers to the collection based on their title, or what was said about them in the citing paper. Following, we used Google Scholar to look for additional papers citing the papers already in the collection, and added papers based on the title and abstract. With this method, we gathered a collection of 132 papers. Of these, we further identified those that presented an in-the-wild public display deployment, or challenges or lessons learned regarding such, or discussed user behavior around public displays. This resulted in the final collection of 71 publications that were used in the literature review.

Two researchers carefully reviewed the 71 publications and noted down every issue, challenge, or observation that was attributable to an external factor. We found a total of 51 issues from 22 publications (several papers reported more than one issue). The 71 reviewed publications are listed in the references of this paper, with the 22 papers that were part of the taxonomy marked with an asterisk.

The fact that most reviewed papers did not report any issues suggests that a large segment of experienced issues within the HCI community may go unreported. Furthermore, as noted earlier, such issues are rarely the focus of research papers. Rather, we specifically had to look for them within the fine details of the papers – for example, issues were often only briefly mentioned to explain why certain study decisions were made.

### Outcome

The final data set consisted of 61 issues, including 10 issues from our own deployments and 51 issues from the literature. Issues from both sources were treated equally during the process, i.e., no special emphasis was put on our own experiences. Therefore, our own experiences formed a ~16% contribution to RQ1 and RQ2.

To address RQ1, we utilized affinity diagramming to categorize the findings. The process was conducted by three researchers – the two researchers who conducted the literature review, and a third researcher for a fresh perspective. We considered that the process was complete when a *consensus* was reached, that is, when all three researchers agreed with every issue and the category they were assigned to. This resulted in six categories: *weather*, *events*, *surroundings*, *space*, *inhabitants*, and *vandalism*, which will be discussed in detail in the next chapter.

As a second layer of analysis (RQ2), we considered the strategies researchers used to deal with the observed issues, and identified four categories of responses. *Ignoring* means doing nothing to address or control the observed effect. *Adapting* means either changing some property of the deployment that introduces a trade-off (a suboptimal solution), or addressing the effect once while not ensuring that the same effect will not happen again. *Solving* refers to a permanent solution that either eliminates the original cause, or changes some property of the deployment to eliminate the effect, without introducing a trade-off. Finally, *embracing* means taking advantage of the observed effect, to turn the negative into positive.

## EXTERNAL FACTORS IN PUBLIC DEPLOYMENTS

Our taxonomy of external factors consists of *weather*, *events*, *surroundings*, *space*, *inhabitants*, and *vandalism*. In this chapter, we present each category in detail, and discuss how to recognize and deal with these factors All sources that contributed towards this taxonomy are presented in Table 1.

The distribution of issues per cause and reaction are presented in Figure 2. Of the 61 issues, 39% were *ignored*, while 39% were *adapted* to. Only 13% of the issues were *solved*, and 8% were *embraced*. In this section, we will also provide examples of how researchers dealt with the experienced issues with respect to these reaction types.

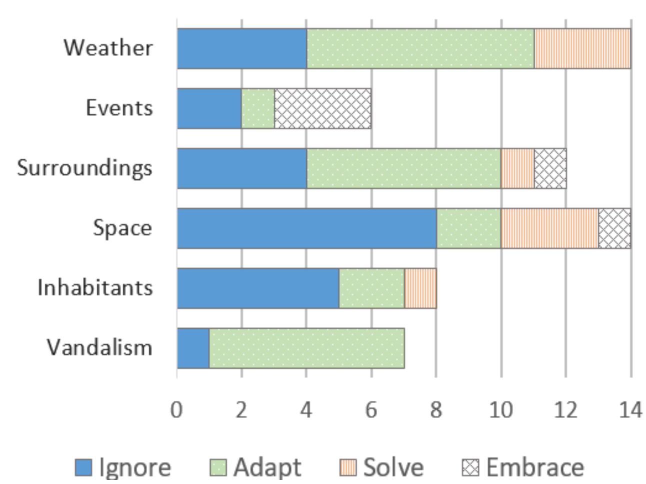


**Figure 2. Distribution of issues per cause and reaction.**

| | Ignored | Adapted | Solved | Embraced |
|---|---|---|---|---|
| **Weather** | **EnergyLand**<br>Ojala et al. [54] x 2<br>Valkanova et al. [68] | **EnergyLand**<br>Ackad et al. [2] x 2<br>Ackad et al. [3]<br>Harris et al. [31] x 2<br>Fischer & Hornecker [25] | **EnergyLand**<br>Dalsgaard & Halskov [19]<br>Harris et al. [31] | |
| **Events** | **Information Wall**<br>O'Hara et al. [53] | O'Hara et al. [53] | | Schroeter et al. [60]<br>Akpan et al. [4]<br>Finke et al. [23] |
| **Surroundings** | Ackad et al. [2], Storz et al. [62]<br>Dalsgaard & Halskov [19]<br>Fischer et al. [24] | Harris et al. [31] x 4<br>Storz et al. [62]<br>Memarovic et al. [46] | Harris et al. [31] | Tomitsch et al. [67] |
| **Space** | Schroeter et al. [60] x 2<br>Fischer et al. [24]<br>Churchill et al. [17], Kukka et al. [44]<br>Peltonen et al. [57], Müller et al. [51]<br>Fischer & Hornecker [25] | **EnergyLand**<br>Fischer & Hornecker [25] | Müller et al. [52]<br>Fischer et al. [24]<br>Fischer & Hornecker [25] | Cao et al. [13] |
| **Inhabitants** | **Information Wall** x 2<br>Storz et al. [62]<br>Dalsgaard & Halskov [19] x 2 | **Information Wall** x 2 | **Information Wall** | |
| **Vandalism** | Taylor et al. [65] | Dalsgaard & Halskov [19] x 4<br>Heikkinen et al. [33]<br>Müller et al. [51] | | |

**Table 1. Summary of reported challenges that contributed to the taxonomy, divided by cause and reaction.**

### Weather

Weather is a diverse, unstable and unpredictable phenomenon, and can affect both indoor and outdoor public deployments in various ways. We found that the primary causes for issues in the *weather* category are sunlight, rain, temperature, and humidity.

#### *Reported Causes*

*Sunlight* has caused issues especially with display visibility and sensor performance. In our Energyland installation, even though the installation was located inside a large, completely covered tent, the sunlight was bright enough to penetrate the tent's fabric and interfere with the Kinect sensors, which rendered the system unusable. We solved the problem by hanging thick, dark black curtains above our installation (Figure 3) to improve the gesture recognition.

Ackad et al. [2] also reported two issues with sunlight with their outdoor gesture-controlled display. Sunlight interfered with the sensors, as well as hindered the visibility of screen content. They adapted to the issues by only running the system from 6 pm until midnight, when sunlight no longer hit the deployment space. Similarly, Fischer and Hornecker [25] only ran their media façade system after dusk, since the projections were not visible enough in daylight. Harris et al. [31] reported varying visibility with their screen in an outdoor setting, and added hoods to the screens to minimize the effect from external lighting. Likewise, Ojala et al. [54] report low visibility with their UBI-hotspots in direct sunlight, however this issue was ignored.


**Figure 3. Curtains hung above the EnergyLand installation to prevent issues with sunlight.**

*Rain* resulted in serious issues with our EnergyLand installation near the end of the fair when a rain storm soaked parts of the floor and destroyed the computer running the system and one of the speakers. While the computer was quickly replaced with another unit, we were unable to replace the speakers within the available time frame. Hence, visitors had to experience the system without a soundscape for the remainder of the fair.

Harris et al. [31] had issues with rain and other harmful weather conditions with their deployment that was setup in the woods. They needed to keep an eye on the weather forecast at all times. To offer some protection for the equipment, polythene bags were used. A back-up procedure was to simply not run the setup on very rainy days. Dalsgaard and Halskov [19] reported an interesting effect from rain on their motion-tracking media façade installation. Reflections from puddles after rainfall were incorrectly identified as people by the sensor. This was eventually solved when colorful carpets were installed to more clearly mark the interaction areas.

More general-purpose weather effects were reported in several papers. A pilot study of a public voting installation by Valkanova et al. [68] suffered from unpleasant weather conditions (rain, wind, cold) that resulted in fewer users (and interviewees), as most passersby were not motivated to stay outdoors. Ackad et al. [3] studied user behavior on an outdoor installation, and had to schedule their studies based on weather conditions. Ojala et al. [54] noticed that winter months affected the UBI-hotspot usage as their capacitive touch screen foils did not respond to gloves. During the deployment of their setup in the woods, Harris et al. [25] noticed that high levels of humidity will attenuate radio waves, which they needed to tune on the spot.

#### *Recommendations*

The effects of *weather* can range from screen visibility issues to destruction of equipment. Since weather cannot be controlled, researchers must be aware of its potential effects and be ready to adapt. Representative examples of such adaptations are those by Ackad et al. [2] and Fischer and Hornecker [25], wherein the deployment was run only during evenings to avoid sunlight issues. However, while they could work around the issue by decreasing the deployment time, this workaround is far from optimal.

Weather can also have positive effects. Ojala et al. [55] found that sunny and warm days result in more users as well as increased interaction times, and interestingly, this phenomenon was also observed in indoor locations. This is likely because even for indoor activities, people still need to go out and move to the location – and they may be encouraged to do so by the nice weather.

We present the following considerations:

- Consider the effects of sunlight on the deployment: sunlight affects screen visibility as well as the performance of many motion tracking sensors.
- Cover sensitive hardware. Rain and humidity can cause surprising issues even in seemingly well covered environments.
- Consider how weather conditions affect people. Warm and sunny weather can result in more interactions and increased interaction times, even for indoor locations [55]. Inclement weather, such as cold and wind, decreases the number of people outside and their willingness to interact [68].

### Events

As one category, we consider *events*, such as festivals, that temporarily (but significantly) alter the characteristics of the deployment space or its surroundings, hence affecting the installation.

#### *Reported Causes*

With our Information Wall installation, we observed issues caused by an event for the elderly that was held in the nearby auditorium and the adjacent lecture rooms. Despite the large, open deployment space, it became unusually full when hundreds of people poured out of the rooms. Some noticed the display and came to investigate, and some tried interacting with it. However, other people constantly disrupted the interaction (and observation) by moving past the display between the users and the sensor, effectively blocking both the sensor and the screen. We also observed some discomfort from the users, as they ultimately felt they were in the way of others when interacting. These observations did not lead to any action on our part, as there were no easy solutions available.

O'Hara et al. [53] reported that a temporary outdoor urban beach was installed in front of the large BBC screen in Birmingham. Because the BBC screen required users to execute large physical movements, and because the beach installation expected crowds, this was a safety hazard. To overcome this, barriers were erected around the active gameplay area to keep the crowds safely separated, and a professional speaker was also introduced to help manage the crowd and gameplay, which increased financial costs.

Some positive effects due to events have also been reported. A deployment by Finke et al. [23] was surrounded by tables, chairs and a coffee bar. At the end of the student semester, more chairs and tables were brought into the deployment space to offer students sufficient room to prepare for their final exams. This resulted in a larger audience and more interactions with the system. In addition, Akpan et al. [4] reported that a party held at the premises in which their interactive Shadow Wall was installed resulted in a much higher amount of interactions as well as longer durations of interactions, as the party transformed the configuration of the space to a more relaxed one. O'Hara et al. [53] also mention that the above-mentioned temporary beach somewhat changed the nature of the space, as people who were interviewed mentioned that they came to the place to rest, take a break, wait, sit or socialize.

A general observation of the effects of events was made by Schroeter et al. [60] who noted that events change the demographic in the area. For instance, they state that on normal days, people around public displays can be "broad and diverse in terms of their interests". However, during events, usually a more specific crowd is present. Thus, the effect of events can be embraced, for example by focusing the content of the display towards this specific group.

*Recommendations*

Events typically have two effects. First, they alter the social setting of the space. For instance, O'Hara et al. [53] and Akpan et al. [4] experienced a positive effect, as an event resulted in a more favorable, relaxed setting. Second, events affect crowds and people flow. Events often equal to higher amounts of people, which can lead to security risks and interference with interaction, but can also lead to positive effects, such as an increased number of users. We derive three practical considerations from the reported issues:

- Stay aware of the magnitude and nature of upcoming events in the area. Events affect the social setting, demographics, and the amount of people.
- The deployment should be robust enough to handle interference caused by crowds, even if such crowds are not normally present. For instance, people in the background should not prevent others from interacting.
- It is possible to turn events to one's advantage, by tailoring the content of the deployment to serve the participants of the event. Events tend to bring in more users and foster interaction in general.

### Surroundings

As the third category, we consider *surroundings*, which refers to areas and their persistent characteristics surrounding the deployment space. This includes nearby buildings, their functions, and traffic. Research on public deployments has focused extensively on the effects of immediate surroundings near a display, such as people flow and its subsequent interaction effects. However, several issues reported in literature point towards the effects of buildings and artifacts surrounding the area of deployment, from which the display or installation is likely not visible.

*Reported Causes*

Tomitsch et al. [67] report a higher flow of people before and after a show in the theater, adjacent to their installation, and how the nature of each show would affect the demographic of people in the area. For Fischer et al. [24], the day-time pedestrian traffic near their installations was dominated by students from a nearby university and at night by visitors to a nearby theater. Ackad et al. [2] further note that due to an adjacent theater near their installation, passersby often had limited time to interact, as they were on their way to see a show. Yet contrary to *events*, the functions of the surroundings are perennial. Therefore, public displays should be designed to account for the effects of surroundings, for example by designing content that serves the theater visitors [1,2].

Surroundings can also impact the deployment's hardware. Storz et al. [62] had an installation that was in a tunnel under a heavily trafficked street. Diesel exhaust continuously interfered with their equipment, for example by clogging the projector filters used in the installation, despite custom-built cases, housings, and other prior preparations. Furthermore, maintaining the hardware required closing the road, which was especially difficult during high traffic periods such as university semesters. For Harris et al. [31], their setup in the woods needed to be disassembled on a daily basis to prevent moisture deposits from accumulating on electrical boards. Dalsgaard and Halskov [19] reported windows across the street from their installation causing reflections, which were incorrectly interpreted as people by their motion-controlled system.

Moreover, surroundings can create adverse deployment conditions, including lack of electricity or unreliable network connectivity. Harris et al. [31] had no access to electricity for their deployment that was set up in the woods. Generators were not an option due to noise and running cables to each device would have been impractical. They adapted to the issue by using batteries and low-power devices where possible. Further, trees blocked GPS signals and radio frequencies. This was solved by adding three booster antennas for their own network. Due to the dynamic and unstable nature of woods and similar areas, the ground can change from hard to soft and shift unexpectedly. Solutions included placing network access points to trees and adding base plates to the ground where required. Issues with network connectivity within the deployment location were solved by Memarovic et al. [46] by connecting wireless receivers from the rooftops of local houses to the installation. It was also important to make at least a part of the content available offline in case of network issues.

*Recommendations*

Understanding the functions of surroundings, for example nearby buildings, traffic conditions and vegetation, provides a better understanding of the potential user demographics and technical limitations. We present three considerations:

- Identify key locations in the surrounding areas, such as theaters and malls, as they provide further insight for times of day with large crowds and specific demographics.
- Consider the possibility of designing for these locations. Ackad et al. [1,2] tailored the content of their public display to serve the visitors to a nearby theater. Ideally one should take this into account a priori in the fundamental design decisions of the deployment.
- Technical limitations need to be studied before the deployment to accommodate network failures, power issues, and other potential factors that may interfere with the equipment.

Factors in *surroundings* may have similar effects as those in the *events* category, such as increased people flow; however, the differentiation is based on the prevalence of cause. Properties of the *surroundings* are permanent, and cannot be made to go away without architectural interventions.

### Space

We consider *space* as the physical attributes of the deployment area, whereas with the previously discussed *surroundings* category we refer to areas outside of the deployment area. With *space*, we follow the definition of Harrison and Dourish [32]: space is the actual physical structure of a "three-dimensional environment in which objects and events occur". A space is made a place by its inhabitants [32]; therefore, place is the social and cultural construct within a physical space. Issues arising due to inhabitants of a space are discussed later in the *inhabitants* category. Here, we report issues that were caused by properties of the deployment space.

*Reported Causes*

In EnergyLand, we had access to the floorplan of the tent and used it to define the installation layout. However, a few days before the deployment, the location managers informed us that details provided of the space were incorrect – there was a double wall structure inside the tent and the thickness of the wall was not provided. We had to adapt by setting the first and third display at an angle (Figure 3), when originally all displays were supposed to be parallel to the wall. Although such a small change may seem trivial, studies have shown that display orientation can have a significant effect on the dynamics of the installation [41]. Moreover, the angles made the interaction spaces for each display somewhat overlap. Fischer and Hornecker [25] also report discrepancies between their initial plan for a media façade installation and the actual physical properties of the façade, and they had to adjust accordingly.

Schroeter et al. [60] note that due to their installation's size and positioning amongst other booths at their deployment location, the visibility of their display was limited. For Fischer et al. [24], a railway track ran across their installation space, with the media façade being on one side of the tracks and the interactive controller device on the other. This prevented them from connecting their system with a network cable, and regular Wi-Fi was not an option due to electrical interference from the trams. A solution was found in the form of a GSM USB adapter. In another case, Fischer and Hornecker [25] had to cover the illumination of an entrance to an underground parking space, as it interfered with their media façade. Müller et al. [52] reported that after moving the installation to a different space, patches on the floor would be recognized by system as users while actual far away users were not. Both issues were solved by moving the camera to floor level.

For Müller et al. [51], nearby elevators influenced the use of their public display installation as people would often interact with the system while they waited but abruptly stop when the elevator arrived. In CityWall [57], people waited out the rain under the sun shade on the installation window without even realizing that it is interactive. Furthermore, Fischer et al. [24] state that their installation was jammed when around 70 people suddenly came out of a bus from a stop nearby. Churchill et al. [17] noted that by installing a display in a foyer with a T-junction, people moving in the space were colliding with those interacting with the display. Kukka et al. [44] noted that one of their displays was sandwiched between two bulletin boards, located in a busy walkway opening to a cafeteria. Instead of making the display more noticeable, this instigated display avoidance.

However, not all space dynamics are perceived as being negative by researchers. An installation by Cao et al. [13] was located at a public university atrium, which had open seating, a café nearby, and access to classrooms. This resulted in increased traffic, especially when classes were ending or starting. This was desirable for the researchers as it promoted the usage of their installation. Moreover, Fischer and Hornecker [25] found that the built environment, such as pillars and trees, can create "comfort spaces" wherein people can comfortably observe the installation. While Fischer and Hornecker [25] also note that these comfort spaces might "interfere with designers' intentions of achieving a certain situation in a given setting", we note that they also encourage people to engage with the installation, as people can first observe how it works without being "out in the open".

*Recommendations*

Researchers must study and understand the functions of the space, comparable to the previously presented *surroundings* category. A somewhat similar approach was utilized by Müller et al. [50] when designing interactive displays for shop windows, as they observed the deployment space with regards to people flow and passersby attention, to identify the most suitable windows for the displays. However, we emphasize the focus on identifying *external factors*. We present the following considerations:

- Observe the physical characteristics of the space, including the layout, placement of doorways, pillars, elevators, machinery, and other displays and installations. Further, identify how said characteristics affect people flow and the use of the space.
- Identify permanent structures, such as pillars and other objects, within the layout that can potentially create "comfort spaces" for the users. Fischer and Hornecker [25] found that these spaces allow people to comfortably observe the installation.

By knowing the physical characteristics of the space, one can predict some of the effects on the deployment. Once there is a clear understanding of the space, researchers can begin to map out the use of the space by its *inhabitants*.

**Inhabitants**

Deployment spaces, as well as the surrounding areas, are usually filled with a multitude of people, each with varying roles. While current pervasive display research largely investigates people as passersby, i.e., potential users, with the term *inhabitants* we consider their usual, day-to-day roles within the space, such as students, janitorial staff, security guards, and store owners.

For clarification, stakeholders are not part of the *inhabitants* category, as stakeholders are an internal part of the deployment project, and are therefore not an external factor.

It is notable, however, that the same person can be both - the key is the *role* the person is acting on. For instance, location managers can be stakeholders, and the actions they undertake *as stakeholders* would not be considered an external factor, however they would still be inhabitants in their usual roles as location managers. For further reading on stakeholders, we refer to Elhart et al. [22] and Hosio et al. [34].

*Reported Causes*

With our Information Wall installation at a university campus, security guards kept turning off the projector at night. We were unaware of this for a long time, but eventually found out when we asked the local managers to investigate if the projector was faulty. One of the managers contacted the security guards to ask if they, by any chance, are turning the screen off during their nightly rounds. Indeed, the guards were turning off the projector because they assumed that it should not be on during the night. The real cause was surprising, as we were at no point in contact with the guards. In fact, we never even *saw* the guards.

We also experienced various other surprises regarding local inhabitants. The large, open deployment space is occasionally used to set up temporary stands. For instance, members of student organizations occasionally set up stands to sell tickets to parties, and members of various clubs set up stands to promote their club and recruit new members. We experienced several occurrences wherein the stands had been set up so that they obstructed the use of our installation, or at the very least made interacting uncomfortable, even though there was plenty of room in the space for the stands to be positioned elsewhere.

Sometimes we found furniture or other equipment temporarily positioned so that they obstructed or hindered the use of Information Wall. Some of these were presumably left behind from the above-mentioned stands when they were taken down. Each time, we simply moved the furniture slightly to ease the situation, but left the furniture to be cleaned up by the people responsible for them. Additionally, we observed two occasions where a janitor's cart was positioned partly in front of the installation – but the janitor was nowhere in sight. We took no action to address the issue, however we would have sought out the janitors if the issue had been more frequent.

Another interesting occurrence happened with local students. As part of the Information Wall, a cupboard (which contained the PC running the system) was placed underneath the screen, and the Kinect sensor was placed on top of the cupboard. Once, we found that the nearby coat hanger was (almost) full, so a group of people had left their jackets on top of the cupboard, completely covering the Kinect, which prevented the system from being used.

Dalsgaard and Halskov [19] installed a webcam-enabled public display behind the windows in the grocery section of a local department store. A local manager lowered sun-blinds in some of the windows, preventing the webcam from seeing passersby. Storz et al. [62] discuss that in one of their deployment locations, local managers tested the fire alarms weekly, during which time the power was cut off from the deployment space.

*Recommendations*

An important insight arises from the *inhabitants* category. Inhabitants are unrelated to the deployment - none of the reported issues involved intentional interference with the deployment (perhaps apart from the guards, however it was not their *intention* to disrupt the deployment). Rather, issues arising from this category are primarily due to inhabitants conducting their usual, everyday routines, and the deployment is simply in the way. From the inhabitants' perspective, it could be argued that it is the deployment that is invading *their* space.

To further enable communication with the inhabitants, a practical suggestion is to add background and contact information near the installation in case the inhabitants have issues or questions. With our Information Wall installation, we received a request by staff from another school to add temporary content about an upcoming event to our installation. In the absence of contact information near the display, these people had to go through multiple channels to finally ascertain who to contact about the display.

For *inhabitants*, we present the following considerations:

- Observe and identify different groups of inhabitants, and further aim to identify their routines and tasks in the space. Then, analyze how these routines and tasks could interfere with the deployment, and adjust the design accordingly.
- Consider engaging in a discussion with the inhabitants, and informing them of the deployment and its purpose, particularly if the deployment is likely to interfere with their normal routines.
- Consider adding contact details near the deployment.

**Vandalism**

With *vandalism*, we primarily refer to intentional interference with the deployment as well as the destruction of equipment. Public deployments are sometimes at the mercy of people who may not be regular inhabitants. Most notably, it is not realistic to consider vandalism to be a person's primary activity as an inhabitant, which is why vandalism should be considered a separate category.

*Reported Causes*

Heikkinen et al. [33] (also mentioned in Ojala et al., [54]) report that the safety glass of one of their outdoor installations was purposefully broken – the system was down for two weeks, and the expenses for repairs were significant. Similarly, Dalsgaard and Halskov [19] report that their information stand displaying videos on a bus shelter was destroyed. Dalsgaard and Halskov [19] further report that in one of their outdoor media façade installations, someone tried to remove a colorful carpet from the ground, possibly with the assumption that the carpet was enabling the interactions. In reality, the carpet was there to merely mark the interaction area more clearly.

In addition to physical harm, vandalism can stem from rude or unacceptable behavior. Dalsgaard and Halskov [19] reported a few instances wherein users would upload erotic content to one of their public systems which allowed uploading low-resolution animations. They also reported a user recording obscene gestures in an installation that allowed users to record short clips to be shown in displays around the city. The recorded clips had to be checked and edited before showing them to the public.

We also found an interesting link between misuse of an installation and playful behavior. Taylor et al. [65] installed a display aimed at gathering opinions on issues relevant to the local community. Users could give their opinion on polls by pressing corresponding buttons below the display. However, it was discovered that some people were interacting merely to play around with the system (to experience it) and pressing the buttons uncontrollably. Therefore, the results of the polls, which otherwise could have been useful to the community, were skewed.

Müller et al. [51] observed users engaging in (unintended) harmful activities through playful behavior, when studying transitioning between mid-air gestures and touch in their MirrorTouch installation. They reported two occasions where users first interacted with increasingly expressive mid-air gestures, and when transitioning to touch, they interacted with the screen so roughly that researchers needed to intervene to prevent damage to the installation.

Many more authors have observed playful behavior where they have not expected it, even though no actual issues have been encountered due to it. Examples of such are presented in [19,52,57,67].

### *Recommendations*

The effects of *vandalism* range from destruction of equipment to unintentional interference with the deployment. There may also be a link between playful behavior and misuse. While playful behavior has many benefits, such as enticing interaction [67,70], researchers should be aware of the possible negative consequences as well. We found a case where playful behavior turned too extreme and was about to lead to damaged hardware [51], and a case where playful interaction interfered with the serious purpose of an installation [65].

It is difficult to predict vandalism or misuse; however, to address some of them, we offer the following considerations:

- Go into the “mindset” of a vandal. What are the easy targets for vandalism? Consider attaching all parts of the deployment to something sturdy, and hiding components, such as wires, from plain sight.
- Consider moderating user-generated content. Dalsgaard and Halskov [19] experienced several occurrences wherein improper content was uploaded. Fortunately, such instances seem to be rare. For instance, Elhart et al. [22] had to go to great lengths to prepare for improper content due to requirements from stakeholders; however, they experienced no issues.

## DISCUSSION AND CONCLUSION

In this work, we investigated *external factors* that cause many surprising and unwanted effects on public display deployments. We conducted a literature review and, using affinity diagramming, identified a taxonomy of external factors: *weather*, *events*, *surroundings*, *space*, *inhabitants*, and *vandalism*. We found that our experience about the primarily negative effects of these factors hold true within the larger HCI community as well.

Our work differentiates itself from past research in two ways. First, we draw upon the *collective experiences* within the HCI community. Some past work has discussed challenges with public deployments, and while they offer valuable insights, the challenges have only been individual research groups' experiences [19,31,62]. However, many of the issues we collected have come from publications in which these issues were not the focus. This, in part, underlines the need to bring these experiences together. Second, we are the first to approach these challenges from the perspective of *cause*. This is important in offering a practical approach towards identifying and adapting to potential issues. From our viewpoint, researchers should be encouraged to look beyond the observed challenges, as identifying the cause may help in addressing the issue.

In addition to the taxonomy of external factors, we investigated how researchers deal with issues arising from these factors, and identified four types of reactions: *ignoring*, *adapting*, *solving*, and *embracing*. Ignoring and adapting to issues were much more common responses, which suggests that the issues are often surprising, and are difficult to solve completely.

We note that in this work, we quantified how researchers *eventually* reacted to the issues. Based on our experiences and some examples found in the literature, for many issues that were ignored or adapted to, researchers initially reviewed their options and, in the absence of good and easy solutions, had to resort to sub-optimal solutions (adapting), or had to ignore the issue. In deciding the action to take, researchers must evaluate how severe the issue is, and consider available options and how much effort they require as opposed to the resources available.

When evaluating the severity of an issue, the purpose of the deployment is worth considering, as many public deployments are conducted to study a specific phenomenon. For instance, for a public deployment investigating display blindness in some form, an interaction-related issue might not be as severe as it would in many other scenarios. In

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|---|---|
| **Weather** | • Consider the effects of sunlight on the deployment as it affects screen visibility and the performance of sensors.<br>• Cover sensitive hardware, as rain and humidity can cause surprising issues.<br>• Consider how weather affects people. Good weather may increase the number of interactions, and bad weather may have the opposite effect – even for indoor deployments. |
| **Events** | • Stay aware of the magnitude and nature of upcoming events in the area - events may alter the social setting, demographics, and the amount of people.<br>• Design the deployment to handle large crowds, even if such crowds are not normally present.<br>• Consider turning events to the deployment's advantage, for instance, by tailoring the content to serve the participants of the event. Events tend to bring in more users and foster interaction. |
| **Surroundings** | • Identify key locations in the surrounding areas, such as theaters and malls, and consider how they affect the demographics in the area at different times of day.<br>• Consider designing content for the deployment that is specific to these locations.<br>• Identify technical limitations to accommodate network failures, power issues, and other potential factors that may interfere with the equipment. |
| **Space** | • Observe the physical characteristics of the space, e.g., the layout, doorways, pillars, elevators, and machinery. Identify how these characteristics affect people flow and the use of the space.<br>• Identify pillars and other objects within the layout that can potentially create "comfort spaces" for the users, which may encourage people to observe and subsequently interact. |
| **Inhabitants** | • Observe and identify different groups of inhabitants, and their routines and tasks in the space. Analyze how their routines and tasks could interfere with the deployment.<br>• Consider informing and engaging the inhabitants, particularly if the deployment is likely to interfere with inhabitants' normal routines.<br>• Add contact details near the deployment. |
| **Vandalism** | • Go into the "mindset" of a vandal, and identify easy and obvious targets for vandalism. Attach all parts of the deployment to something sturdy, and hide easy targets, such as wires.<br>• Consider moderating user-generated content, as people may upload improper material. |

**Table 2. Considerations for external factors in public deployments.**

addition, many research-oriented deployments are short-term in nature, due to which some issues might receive less attention than they would in long-term deployments.

In defining the available options in each situation, an important factor is the level of control one has over the deployment and the surrounding area. Researchers rarely own the deployment space, which significantly limits the amount and extent of available options. This brings us back to the importance of *adapting* to issues. Solving issues completely is difficult and, as we observed in this work, not always possible.

In conclusion, with this work, we hope to bring attention to external factors and help researchers reflect on and report issues experienced in public deployments. The prevailing approach in reporting deployments is to focus on *successes*; experienced issues are often considered threats to the integrity of the studies. In fact, experienced challenges can often be more informative than the successes, and can aid researchers and practitioners in carrying out more successful deployments. Moreover, there are now good venues to publish such experiences (e.g., CHI Stories).

We provide a go-to summary of the taxonomy of external factors with practical considerations in Table 2. The main contribution of our work is to help researchers and practitioners design *for* external factors, and be more prepared to address the effects. This is achieved in three ways. First, by using the taxonomy of the external factors, one can more easily identify such factors within the deployment. Second, we provide practical insights for each category, and report several examples on how past work has addressed the encountered issues. Third, we show that one must be prepared to adapt – many observed negative effects usually require changes in the deployment. Overall, we wish to provide a useful framework for understanding external factors and hope that it is built upon by the community, by sharing how the issues were reacted to in future deployments.

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* Part of the taxonomy of external factors.

*All referenced papers were part of the literature review.*