



*Citation for published version:*

De Angeli, D, Frangoudes, F, Avraam, S, Neokleous, K & O'Neill, E 2022, Towards Engaging Intangible Holographic Public Displays. in *2022 International Conference on Interactive Media, Smart Systems and Emerging Technologies, IMET 2022 - Proceedings.*, 9929788, 2022 International Conference on Interactive Media, Smart Systems and Emerging Technologies, IMET 2022 - Proceedings, IEEE, U. S. A., International Conference on Interactive Media, Smart Systems and Emerging Technologies, 4/10/22.  
<https://doi.org/10.1109/IMET54801.2022.9929788>

*DOI:*

[10.1109/IMET54801.2022.9929788](https://doi.org/10.1109/IMET54801.2022.9929788)

*Publication date:*

2022

*Document Version*

Peer reviewed version

[Link to publication](#)

© 2022 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other users, including reprinting/ republishing this material for advertising or promotional purposes, creating new collective works for resale or redistribution to servers or lists, or reuse of any copyrighted components of this work in other works.

**University of Bath**

## **Alternative formats**

If you require this document in an alternative format, please contact:  
[openaccess@bath.ac.uk](mailto:openaccess@bath.ac.uk)

### **General rights**

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

### **Take down policy**

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

# Towards Engaging Intangible Holographic Public Displays

Daniela De Angeli  
University of Bath  
Bath, United Kingdom  
dada21@bath.ac.uk

Fotos Frangoudes  
CYENS - Centre of Excellence  
Nicosia, Cyprus  
f.frangoudes@cyens.org.cy

Savvas Avraam  
CYENS - Centre of Excellence  
Nicosia, Cyprus  
s.avraam@cyens.org.cy

Kleanthis Neokleous  
CYENS - Centre of Excellence  
Nicosia, Cyprus  
k.neokleous@cyens.org.cy

Eamonn O'Neill  
University of Bath  
Bath, United Kingdom  
E.ONeill@bath.ac.uk

**Abstract**—Public displays are some of the most challenging interfaces to design because of two key characteristics. First, the experience should be engaging, to attract and maintain users' attention. Second, the interaction with the display should be natural, meaning that users should be able to receive the desired output with little or no training. Holographic displays are increasingly popular in public spaces such as museums and concert halls but there is little published research on users' experiences with such displays. Previous research has suggested both tangible and intangible inputs as engaging and natural options for holographic displays, but there is no conclusive evidence on their relative merits. Hence, we run a study to investigate the user experience with a holographic display comparing the level of engagement and feeling of natural experience in the interacting process. We used a mix of surveys, interviews, video recordings, and task-based metrics to measure users' performance on a specific task, the perceived usability, and levels of engagement and satisfaction. Our findings suggest that a tangible input was reported as more natural than the intangible one, however, both tangible and intangible inputs were found to be equally engaging. The latter findings contribute to the efforts of designing intangible public holographic displays and other interactive systems that take into consideration health safety issues, especially during the Covid-19 pandemic era in which contamination can be established with tangible and physical interaction between users and public displays, yet without affecting the level of engagement compared to the tangible experience.

**Keywords**—holographic displays, intangible input, human computer interaction, user engagement, augmented reality, public displays

## I. INTRODUCTION

Holographic displays (HoD) are increasingly popular in public spaces such as concert halls [1] and museums [2]. That is because the information shared by public displays are predominantly 2D [3], while what we wish to share is often 3D (e.g. buildings, products, artefacts.) Indeed, holography has been proposed as a useful technology to communicate information and foster public engagement in a variety of public spaces [4].

Access to inexpensive solutions means that entities such as museums can now afford to visualise 3D objects via HoD [5] or even holographic headsets [6]. However, designing displays for public spaces is particularly challenging, especially when considering health and safety issues, like during the Covid-19 pandemic, where additional technical

and physical limitations exist. As Valli states [7], “the way occasional users approach interactive artifacts in public spaces is very different from the relation between traditional users and personal computers”. First, public interfaces should provide an attractive, appealing experience that catches and maintains users' attention so that people are motivated to interact with it. In other words, public displays should be *engaging*. In addition, interaction with public displays usually lasts from a few seconds to a few minutes and users don't have time to spend learning how to interact with the system [7]. Thus, new or occasional users should be able to quickly and effectively use a public display without training. In this paper, we use the term *natural* to refer to the extent to which an interface has this characteristic. Although research in the field has intensified in the last decade [3], [8], [9], research to identify engaging and natural solutions for 3D interfaces in public spaces is still sparse.

There are different ways in which users can interact with 3D content in public displays and in which these displays can provide information to users. Typically, users interact using tangible means such as a mouse [10], an interactive replica of an object [11], a mobile device, or simply by touching the screen surface [12]. However, intangible inputs that do not rely on a physical controller but on sensors such as Microsoft Kinect or Ultraleap Leap Motion are also becoming increasingly popular [13], [14]. Both tangible [15] and intangible inputs [16] are proposed as an engaging way of interacting with digital content. However, they both have limitations [17], [18] and it is still unclear whether one is more engaging than the other. Similarly, research has suggested that both intangible [19] and tangible inputs [20] can offer natural interaction, but there is no conclusive evidence for one being more natural than the other.

While previous studies have compared intangible interaction with tangible controllers, those studies focused on interactions with a computer application [21] or a virtual environment [22], not with HoD. Other research has evaluated natural interaction with 3D content, comparing HoD with other displays [23]. Other studies have evaluated basic interactions with HoD using intangible inputs. For example, Caggianese et al. [24] developed a system based on Leap Motion to allow users to select, rotate and zoom holograms of Leonardo's models. Yamada et al. [25] allowed gestures such as swiping to rotate a hologram and pinching to zoom. Yet, the effectiveness of tangible interaction with holograms in the real world remains unclear [23].

This paper contributes to filling the gaps in the literature by addressing the following research question:

*Does the use of tangible and intangible input methods trigger the same natural and engaging feeling when interacting with HoD-based applications?*

An experimental study was designed to compare users' experience of tangible (i.e. a smart replica) and intangible inputs (i.e. gestural interaction enabled by Microsoft Kinect) with 3D content on HoD. Our findings offer insights for the design of HoD and make methodological contributions to the investigation of this topic, especially in the time of the Covid-19 pandemic, in which it is essential to try and develop systems that minimize the physical and/or tangible interaction with public displays as much as possible.

## II. DEFINITIONS

### A. Natural interaction

While the concept of natural interaction is common in Human-Computer Interaction (HCI), a shared understanding of its meaning has not been established. The Handbook of Research on Human-Computer Interfaces, Developments, and Applications relates natural interaction to "a user interface that is effectively invisible and remains invisible as the user continuously learns increasingly complex interactions" [26]. Valli [7] argues that natural interaction should reduce the cognitive load on users. That is, natural interactions should require existing or simple skills [27]. A system that is too complex or abstract will require a higher cognitive effort. Therefore, we define natural interaction as "interaction that is intuitive, accurate, and requires a low cognitive load".

Some research seems to suggest that tangible interaction may be a precise and intuitive way to interact with digital information, especially with children [20]. With tangible inputs, users can understand the function of different objects based on their physical affordance [28]. However, not all tangible inputs are the same. For example, according to Benjamin Bach et al. [23], traditional desktop environments are more accurate than tablets. Furthermore, while previous research has compared intangible interaction with traditional tangible devices (i.e. keyboard and mouse), the results are not conclusive. For example, Erra et al. [22] found that traditional inputs such as keyboard and mouse are less effective with 3D environments than the Leap Motion, while Falcao et al. [21] argue that intangible inputs cannot replace keyboard and mouse due to usability issues.

On the other hand, forms of intangible interaction such as gestural inputs offer users the opportunity to engage with the display from a distance and to interact with a display without touching it [29]. However, gestural interaction may present some limitations. For instance, in certain cases parts of the body (e.g. a hand or arm) may obscure the gesture, or the system may track involuntary movements [30]. Norman [30] also points out that "most gestures are neither natural nor easy to learn or remember". Thus, a system based on gestures may not be inherently natural, especially if it requires users to go beyond simply pointing.

### B. Engagement

Engagement is a key concept in HCI. It informs the design of systems and facilitates users' interaction [31]. Despite its importance, in a recent review, Doherty & Doherty [32] found that "65% of publications that address engagement do

not provide a clear definition" (p. 6). Engagement is used to identify a variety of related yet distinct concepts [31], [32]. In HCI engagement is described as an enjoyable state of mind thanks to which users' attention can be maintained [33], or as flow, an effortless experience in which users lose the sense of self and time [34]. Engagement can be seen as an interaction between a user and external stimuli [35]. These stimuli should first attract the users' attention, then retain that attention and encourage a continuing relationship [35]. Sidner et al. [36] also describe engagement as the process of establishing, maintaining, and ending a collaboration. Furthermore, engagement usually indicates active attention, something that requires a level of effort and reflection while still holding our interest. Douglas and Hargadon [37] associate engagement with immersion, the experience of being absorbed by an activity. Zyngier [38] considers engagement as a mix of interest, participation, motivation, and effort. According to Pohl et al. [39], users can engage with a system or device at different levels of intensity, from casual, undirected, or light interaction to controlled, very focused, and fully committed interaction. Drawing on the range of previous work, in this paper we define engagement as: "an appealing and satisfying experience which grabs the users' attention, stimulating curiosity, and maintaining a high level of interest".

Researchers such as Zhao [15] and Ren et al. [13] suggest that gesture-based interaction is fun and may increase engagement in the form of imagination and self-expression. Corenthy et al. [29] also noted how gestural interaction offers opportunities for highly expressive interactions, like "public performance". However, Perry et al. [17] suggest that it may be an inhibitor for adults in public spaces due to the performative nature of the activity. Hence, intangible gestural interaction could either encourage or discourage interaction. Freehand gestural interaction is also less accurate than a tangible input such as a mouse, which could lower users' interest in the display. Another key issue with intangible interaction is that users cannot feel the object they are interacting with. They can receive visual, auditory, or olfactory feedback but not tactile. Kirsh [40] argues that virtual exploration alone cannot support engagement and imagination with archaeological objects. While devices have been developed to provide feedback with intangible interaction, they still do not provide a realistic "touch" experience [41]. A tangible form of interaction could instead recreate the feeling of material engagement [40]. Furthermore, the physical manipulation of the tangible object can effectively elicit the users' proprioceptive sense "without having to switch his attention from the data visualization to the interaction tool" [42]. Tangible interaction technology appears to be particularly engaging in a museum setting as it supports an experience that is not only digital but also physical [16]. For example, Petrelli and O'Brien [11] show the potential of tangible inputs to provide digital information in a physical context. However, not all tangible inputs are equally engaging. Indeed, Petrelli and O'Brien [11] also found that smart cards and replicas are more engaging than mobile phones. Furthermore, conflicting reports are suggesting that tangible interaction does not always improve engagement or learning [18].

## III. THE EXPERIMENTAL STUDY METHODOLOGY

The main objective is to compare participants' experience of tangible and intangible inputs with 3D content on HoD.

### A. Participants

Twenty-three participants (13 male, 10 female) were recruited through an open call to take part in the study. Their age was distributed as 52.2%, 39.1%, and 8.7% for the age ranges 25-34, 35-44, and 45-54 respectively. All participants received information about the experimental procedure and signed a consent form before starting the study.

### B. Design

Participants interacted with an HoD created using Pepper’s Ghost technique [43]. More specifically, the HoD was a 3-sided hologram pyramid display comprising a 45-inch OLED display that projected to three Plexiglas plates that were positioned below it at 45 degrees each and around the vertical axis (Figure 1). The three sides of the pyramid each displayed the projected 3D hologram from a different angle based on their position. An RGB camera was positioned at the base of the front side of the pyramid and tracked a single user standing in front of the HoD. As the user moved, and based on the tracking of their position, the projected image at the front side of the pyramid would rotate accordingly to offer the illusion of looking at a 3D holographic object. The 3D model that was displayed using the HoD was a replica of an artefact owned by Bath Royal Literary and Scientific Institution collection in Bath, UK: a wood sculpture of a leopard with a drum on its back (Figure 1). Participants interacted with the holographic drum using two different input methods in a randomized order:

- **Tangible input:** Under the projection area, a small shelf held a smart replica of the original artefact, i.e. a 3D printed copy of the drum with conductive paint at the top of the drum that sent a trigger when touched. Participants played the holographic drum by touching this tangible input.
- **Intangible input:** A Microsoft Kinect V2 was installed above the HoD to enable touchless interaction with the display (Figure 1). Participants played the drum by ‘air-drumming’ in front of the display (i.e., they performed a similar motion as with the tangible input, by beating an imaginary drum in the same way they would beat a physical drum, with their hand extended palm down, and doing a vertical motion).

### C. Procedure

Each participant was invited into a large open space at CYENS – Centre of Excellence. A pre-session survey captured basic demographic data. Participants were then asked to interact with the HoD using one of the inputs, following a counter-balanced order. Participants could briefly play freely with the drum. They were then presented with 24 tasks. Each task involved playing the drum following a rhythmic pattern of pauses (white lines in Figure 1) and beats (red lines in Figure 1) presented visually above the holographic drum. Participants memorized when to hit the drum or pause and then repeated the pattern. They started with 4 familiarisation tasks, where the patterns ranged between 3 to 4 pauses and beats. Following the training, they performed 20 predefined tasks (a number that was decided based on our pilot testing and which proved to be sufficient for the purpose of analysing the results), displayed in a random order, with patterns ranging from 5 to 8 pauses and beats. The memorizing part of the task was only designed to increase at a certain level the difficulty and therefore for participants to become more focus on the task. However, the

impact of memorizing was not considered in the analysis of the results. After completing the tasks, participants filled out a post-session survey, and then took a 5-minute break, before following the same process with the other type of input (i.e., the study followed a within-subjects design.) Finally, the session was concluded with a short semi-structured interview.

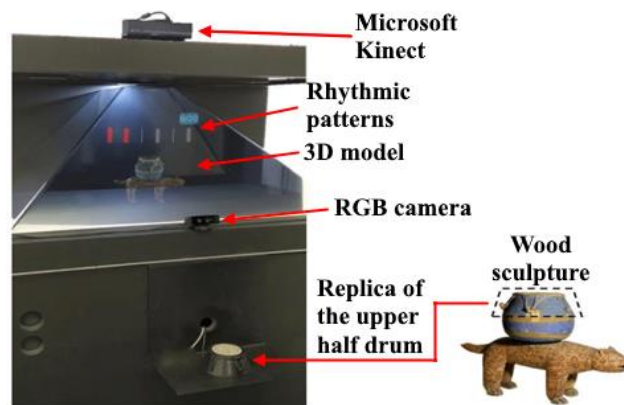


Figure 1. Interactive holographic display

### D. Measures

In this paper, we defined natural interaction as intuitive, accurate, and requiring a low cognitive load. We evaluated each of those three features using different methods.

**Intuitive:** We used the usability subscale from the meCUE (i.e. Module I), which is rated on a 7-point Likert scale and has been validated and can be used individually [44]. Interviews were also carried out to gain a deeper understanding of why a specific input was more or less intuitive. For example, we asked if they encountered any issues and if they would change anything. We gained additional understanding of participants’ behavior by analysing their body language in the video recording of each session.

**Accuracy:** Task accuracy as an objective measurement was assessed using the Dynamic Time Warping (DTW) algorithm [45]. DTW measures the similarity of two temporal sequences, by first computing the cost matrix, between each pair of the two series items. Then the DTW score is computed based on the optimal path that has the minimum cost between the two sequences. We selected DTW, as it allows the comparison of sequences of different lengths, and therefore we could detect instances where a user would beat the drum more or fewer times than required. For each trial, we compared the pattern provided as input from the user (i.e. the time-points of when the user hit the drum), to the expected pattern (each within a threshold), based on what the user was asked to mimic for each task. Based on the above we computed for each task a score between 0-1, with 1 being a perfect match.

**Perceived workload:** Finally, the perceived workload was assessed using the NASA Task Load Index [46], which consists of 6 items measuring mental, physical and temporal demand, performance (goal accomplishment of the task), effort, and frustration. All items are rated on a 21-step scale ranging from “very low” to “very high”.

On the other hand, engagement was defined as an appealing and satisfying experience that captures and retains

the users' attention. Following, are the metrics that were used to evaluate these features.

**Appeal:** The Audience Engagement questionnaire [47] was used to measure how engaging the holographic display was to users. We chose this specific survey because while it is short (7 questions), it measures users' engagement as well as interest, curiosity, and attention. Those three attributes are good indicators of users' appeal toward technology and digital experiences [48], [49]. All questions are rated using a 7-point Likert scale. Additional data related to users' interests were collected via interviews. For example, we asked whether they preferred a specific input and why.

**Satisfaction:** Participants' satisfaction was captured using the IBM After-Scenario Questionnaire (ASQ) [50]. ASQ is a validated three-item questionnaire focusing on users' satisfaction, concerning easiness of task completion, time to complete a task, and adequacy of support information. Similar to the previous questionnaires, ASQ also uses a 7-point Likert scale.

### E. Analysis

**Statistical analysis.** The assumptions of normality and homogeneity of variance were tested with Shapiro-Wilks and Levene's tests respectively. Paired-sample t-tests and Wilcoxon tests were used accordingly for comparisons between conditions (tangible vs intangible). Bonferroni corrections were applied to control for the inflation of Type I error resulting from multiple comparisons. The level of significance was set at  $p < .05$ . Effect sizes were estimated with Pearson's correlation coefficient,  $r$ . Finally, Pearson's product-moment correlation coefficient was used to test associations between variables. Statistical analysis was performed using IBM SPSS Statistics for Macintosh, Version 27.0.

**Content analysis.** The interviews were transcribed into a Word file. A coder ran a content analysis of the interviews. First, sentences were condensed. Then, each sentence was coded and divided into categories. Lastly, the instances of each category were counted. While this analysis was carried out by the same researcher who ran the interviews, transcripts and code were shared with a second coder who provided at least 96% agreement. A content analysis of the videos was also carried out. A researcher watched the videos, coded users' behaviour, and organised the data into an Excel spreadsheet. For the code, particular attention was paid to: which kind of gesture was used (e.g., tapping, touching, hitting, etc.); when users started interacting with the system correctly (i.e. immediately, during the 4 training tasks, before or after 10 tasks, or never); hand gestures (e.g., were participants using a light tap or a strong hit?); users' body language. Body language was coded based on Lewis' research on body language [32]. For example, when a person is confused they may seek support by clinging to something, such as a table or an object. The open palm-up hand shrug is also a sign of confusion. Swinging arms indicate that a person is focused, while opening and closing fists can be a sign of anxiety.

## IV. RESULTS

### A. Natural interaction

The objective assessment indicated higher task accuracy for the tangible condition as compared to the intangible. With respect to the subjective assessments, the usability subscale

revealed significantly higher scores for the tangible condition whereas performance and frustration from the NASA Load survey revealed significantly higher scores for the intangible condition (Table I).

The interviews also suggested that the tangible input was easier to use than the intangible. The tangible input needed less training, instruction, and feedback to use (Table I). A key issue with the intangible input was that it was not intuitive to understand where participants needed to place their hands to interact with the HoD. Participants suggested a few solutions: "maybe you should tell the users that they need to touch or gesture" (Participant 8); "maybe you could have a line saying ok, keep your hand below this line. A physical limit" (Participant 15). Participant 13 suggested that the display should show users "the range of the movement" and where "you should put your hand, and where to stop, if you have to touch or not". The display could tell users to "Place your hand here" (Participant 17) at the beginning and then provide "visual cues (...) You need something to see if my hand is in this right area" (Participant 25). Participants had "some issues with synchronization" (Participant 4) or forgot what they were supposed to do: "even with the practice, after a while, you forget, and then you do something else" (Participant 15). Thus, while the initial training session was considered very useful, participants still "made mistakes afterward" (Participant 9). Participants also missed some form of tactile or haptic feedback: "maybe put air pressure, or - I don't know - technology like gloves. Something to give you a bit more feedback" (Participant 6).

The intangible input also presented more technical issues (Table II). One reported issue was that "there is a bit of delay from the moment you actually do something" to the system reacting (Participant 19). In other cases, the sensor "did not capture the motion and then, some other times, it captures the motion that I did not do" (Participant 17). These technical issues caused frustration and distracted users' attention from their task. For example, Participant 17 explained how the sensor's poor tracking performance "was annoying because I was trying to understand if I was doing something wrong or if there is something wrong with the system", and Participant 25 suggested that technical problems were "making me lose concentration".

Content analysis of the video recordings also confirmed that the tangible input was more usable than the intangible. In the tangible condition about two-thirds of participants understood immediately how to interact with the input while the rest of them understood it during the training tasks. In the intangible condition, the majority of participants learned how to use the input mainly during the training task, but about 22% of participants never learned how to use the input (Table III). Participants using the intangible input asked a researcher for help far more times than with the tangible input (Table III). Analysis of participants' body language also suggested that participants were particularly confused using the intangible input (Figure 2).

### B. Engaging interaction

Interestingly, the engagement subscale, the satisfaction subscale, and the rest of the NASA Load Survey indicated no differences between the two conditions (Table I).

It is worth noting, however, that the interviews suggested a preference for the tangible input: 15 participants out of 23 preferred to interact with the tangible input rather than the

intangible (4/23), with 7 participants having no preference. There were a number of reasons for this. For example, 8/23 preferred a tactile experience like that provided by the tangible inputs because the experience felt more intuitive and more authentic, i.e., closer to interacting with a real drum: “It was easier and the user is more engaged. I don’t know, if it is touching, it makes you feel like you are doing the same as you have the real object. I don’t know, you are more engaged” (Participant 8). The intangible input was also considered more physically demanding by 4/23 participants. The main reason for this is that “when you find the perfect spot that you need to hit, you don’t want to take away your hand from there, and you don’t get rest” (Participant 25). By keeping their hand up, participants get tired: “if I stand there for 20 minutes and I have put my hand, like, in a position, just to press it down ... and down again ... for me after let’s say 2 minutes my hand is getting heavy so I cannot respond immediately” (Participant 21). With both inputs, participants suggested the experience would be more engaging if there were more ways of interacting with the HoD (11/23). For example, participants suggested being able to: “use both hands” (Participant 5); “rotate it a bit and scale it” (Participant 26); “add or remove texture” (Participant 8); offer additional gestures such as “a double hit” (Participant 6) or “to pet” the leopard (Participant 7).

Content analysis of the video recordings suggested that the intangible input caused more physical effort. For instance, the interaction in the tangible condition was performed either by merely touching or tapping the drum (i.e. the tangible input) whereas in the intangible input participants used stronger and/or wider movements.

### C. Association between variables

Correlations among variables for tangible and intangible conditions are presented in Table IV. In addition, correlations between objective and subjective variables which indicated significant results only for one of the two conditions are also plotted in Figure 4.

TABLE I. TANGIBLE VS INTANGIBLE INPUT

Variables	Tangible	Intangible	t(22)	p	r
	M±SD	M±SD			
Task accuracy	0.88±0.06	0.74±0.13	-4.877	< .001	.72
Engagement	5.2±1.2	5.1±1.3	-0.576	> .05	.12
Mental demand	8.2±4.6	9±5	1.239	> .05	.26
Performance	7.4±3.8	12±4.3	5.187	< .001	.74
Effort	7.9±4.5	9.7±4.4	2.033	> .05	.40
	Mdn (min, max)	Mdn (min, max)	z	p	r
Usability	6.7 (1.7, 7)	5.3 (2, 6.7)	-3.064	< .002	.81
Satisfaction	6.3 (2.3, 7)	5.7 (4, 6.7)	-2.361	< .02	.60
Physical demand	6 (1, 15)	7 (1, 17)	-1.38	> .05	.22
Temporal demand	11 (1, 14)	9 (1, 16)	-0.172	> .05	.07
Frustration	4 (1, 21)	7 (1, 17)	-3.034	< .002	.71

\* p value was accepted as < .05/10 = .005 (Bonferroni). Abbreviation: M±SD = mean ±sand. deviation; Mdn = median; min = minimum; max: maximum.

TABLE II. KEY FINDINGS FROM THE CONTENT ANALYSIS OF THE INTERVIEWS.

	Tangible Input	Intangible Input
Intuitive	15	0
Not intuitive	0	14
Needs more training	3	10
Needs more instructions	3	22
Needs more feedback	2	10
Technical issues	2	15

TABLE III. KEY FINDINGS FROM THE CONTENT ANALYSIS OF THE VIDEOS

	Tangible input	Intangible Input
Learned immediately how to use the input	16	7
Learned during the training tasks	7	10
Learned after 10 tasks	0	1
Never learned	0	5
Number of participants who asked for help at least once (total requests)	3 (4)	10 (21)

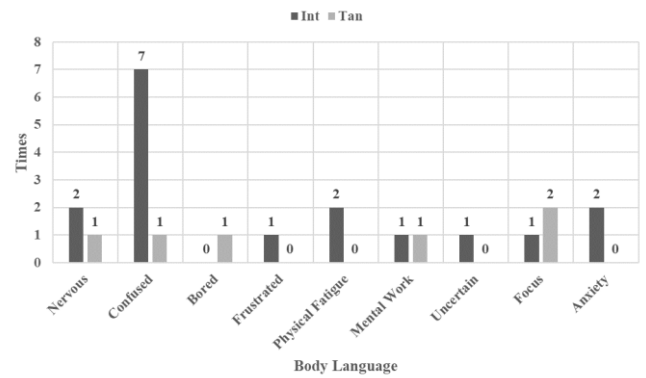


Figure 2. Body language with tangible (Tan) and intangible (Int) input

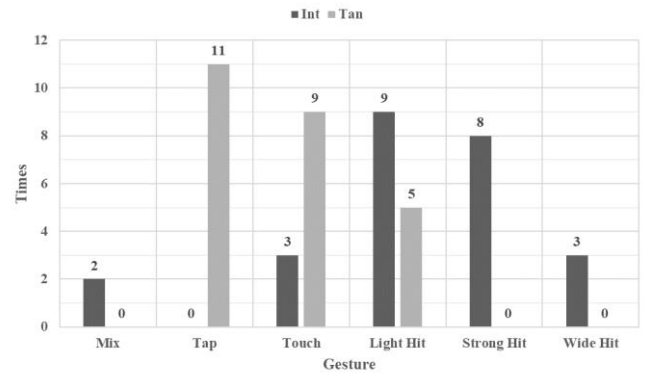


Figure 3. Gesture interaction with tangible (Tan) and intangible (Int) input

TABLE IV. ASSOCIATIONS BETWEEN VARIABLES

		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1.	Task accuracy										
2.	Engagement	.353									
3.	Mental demand	-.032	.061								
4.	Performance	-.495*	-.260	.116							
5.	Effort	-.202	.001	.774**	.396						
6.	Usability	.643**	.342	-.180	-.782**	-.374					
7.	Satisfaction	.549**	.505*	-.015	-.635**	-.244	.610**				
8.	Physical demand	-.340	-.143	.563**	.308	.683**	-.278	-.417*			

9.	Temporal demand	-0.137	-0.065	0.329	0.274	0.636**	-0.125	-0.168	0.486*		0.557**
10.	Frustration	-0.460*	-0.305	0.206	0.690**	0.454*	0.560**	-0.396	0.536**	0.400	

For variables which did not meet the assumption of normality (i.e., Usability, Satisfaction and Frustration in the Intangible condition and the same variables together with Physical and Temporal demands in the Intangible condition) a Spearman's rho test was conducted.

\* Correlation is significant at the 0.05 level (2-tailed). \*\* Correlation is significant at the 0.01 level (2-tailed).

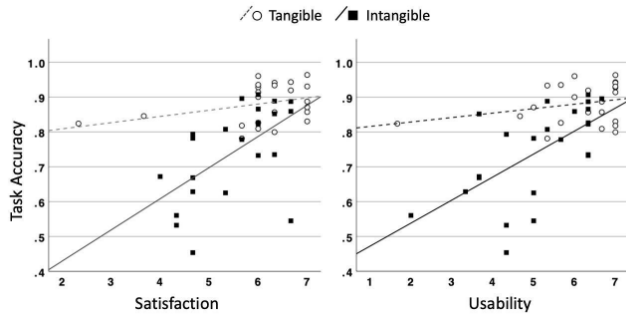


Figure 4. Correlations between Task accuracy and Satisfaction indicated  $r = .549, p < .01$  for the Intangible condition and  $r = .371, p > 0.05$  for the Tangible condition. Likewise, correlations between Task accuracy and Usability indicated  $r = .643, p < .01$  for the Intangible condition and  $r = .225, p > .05$  for the Tangible condition respectively. X-axes show a Likert scale from 1 = “strongly disagree” to 7 = “strongly agree”.

## V. DISCUSSION

Despite the many limitations that our study has (mostly with respect to analysis of the statistical correlations that do not reveal concrete causality), still, our findings offer insights on which input may provide a more natural and engaging experience with the HoD-based 3D content.

While both tangible and intangible inputs were equally capable of keeping users engaged, the tangible input resulted in more natural interaction than the intangible. That is, the tangible input was more intuitive, easier for users to understand and use, and did not require any extra training or instructions. Participants were also more accurate with the tangible input, confirming Bach et al.'s [23] findings that interaction with 3D holographic visualization is usually more accurate with tangible inputs. In general, participants performed higher with the tangible input, but the high level of success didn't seem to directly influence participants' satisfaction. This may suggest that the tasks were too easy with the tangible input, causing a ceiling effect that was not observed with the intangible input (see Figure 4). This effect may well be beneficial in public displays where users should be able to interact with an unfamiliar system and perform well without training [7].

For the intangible input, however, participants needed more time to learn how to interact. While the intangible input was less natural than the tangible one, users were more aware of when they performed well. As a result, performance and accuracy were more related to satisfaction with the intangible input than with the tangible input. In other words, participants were satisfied when they were performing well with the intangible input while there was no significant correlation when using the tangible input. Our findings also confirmed Corenthy et al.'s [29] and Zhao's [15] argument that intangible gestural interaction allows for more “expressive” experiences. Indeed, participants appeared more physically involved with the intangible input than with the tangible one, using wider and stronger gestures to interact with the HoD.

While Petrelli and O'Brien [11] suggest that tangible smart replicas are more engaging than mobile devices, the same cannot be said when compared to intangible inputs, i.e., tangible and intangible inputs can be as engaging.

A reason why the tangible input was more natural but not more engaging than the intangible input could be that easier tasks usually cause less engaged interaction [39]. While challenging tasks are proven to increase engagement, they should still match the skill level of the user [39], [51], [52]. In our case, it seems that participants' skills with the different input techniques were not equally matched to the challenge provided by the tasks. Participants were presented with the same tasks with both inputs. However, with the tangible input high skills – or ease of use – meant that the tasks were perceived as not challenging enough. On the other hand, participants found the tasks when using the intangible input more challenging. Participants were less skilled with the intangible input for three main reasons. First, gestural interaction is still unfamiliar to most people and there are not yet established standards or conventions [53]. While the HoD provided instructions and training tasks, participants required further guidance with the intangible input. A second issue was that the intangible input did not provide enough feedback. While the HoD provided visual and auditory feedback, these did not provide enough information to participants. A third issue related to technical limitations of the sensor used to enable intangible interaction. These limitations are not unknown and were already highlighted by previous research such as Pyun et al. [41]. Although the tasks were perceived as more challenging with the intangible input than with the tangible one, reducing the challenge with intangible inputs may not be an appropriate solution as it may result in increased apathy and less engagement, even when users are not skilled [54]. Massimini & Carli [55] argue that, for an engaging experience, challenge and skills should be at moderate or high levels. However, this is not necessarily a good solution for public spaces where users should easily be able to interact with the system without training or experience [7].

A solution could be to combine tangible and intangible experiences. As Participant 17 from the study suggested, the input should be both seamless (like intangible) and intuitive (like tangible). Participant 12 also agreed that a “combination of the two inputs would be better”. Participants 14 and 21 propose to use a magic stick, like a drumstick, to interact mid-air with the holographic drum. Wii Remote and the Sony PlayStation Move Motion Controller are well-known example inputs that are tangible (and intuitive) while allowing gestural interaction. This solution would also add tactile feedback, which Kirsh's work [40] suggests is something users need when using an intangible input.

## VI. CONCLUSION

Based on the findings from our study, we can conclude that in situations in which intangible interaction is recommended (e.g. in health safety issues or in VR experiences) it is feasible to design a friendly and effective interactive experience without the need for physical interaction. However, based on the analysis of our results, the optimum design would have been when developing interactive holographic displays in public spaces that combine both tangible and intangible experiences. Tangible input resulted in a more natural experience compared to the intangible but the challenges imposed by the intangible



interaction caused users to become more engaged and thus more concentrated on their task.

## REFERENCES

- [1] E. Shein, "Holographic projection systems provide eternal life," *Communications of the ACM*, vol. 57, no. 7, pp. 19–21, Jul. 2014, doi: 10.1145/2617664.
- [2] M. Wójcik, "Holograms in libraries – the potential for education, promotion and services," *Library Hi Tech*, vol. 36, no. 1, pp. 18–28, 2018, doi: 10.1108/LHT-11-2016-0142.
- [3] C. Parker, M. Tomitsch, and J. Kay, "Does the public still look at public displays?," *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, vol. 2, no. 2, pp. 1–24, Jul. 2018, doi: 10.1145/3214276.
- [4] P. M. Pombo and E. Santos, "Public engagement in science and technology using holography (Conference Presentation)," Mar. 2020, vol. 11306, p. 12. doi: 10.1117/12.2547240.
- [5] A. Kasomoulis, M. Vayanou, A. Katifori, and Y. Ioannidis, "MagicHOLO-A collaborative 3D experience in the museum," Nov. 2016, pp. 1–6. doi: 10.1145/3003733.3003813.
- [6] D. De Angeli and E. O'Neill, "Human or machine perspective? Throwing 'light' on optical see-Through headsets in museums," 2016. doi: 10.1145/2968219.2974047.
- [7] A. Valli, "The design of natural interaction," *Multimedia Tools and Applications*, vol. 38, no. 3, pp. 295–305, Jul. 2008, doi: 10.1007/s11042-007-0190-z.
- [8] T. Cox, M. Carter, and E. Velloso, "Public DISPLAY," 2016, pp. 371–380. doi: 10.1145/3010915.3010917.
- [9] V. Mäkelä, S. Sharma, J. Hakulinen, T. Heimonen, and M. Turunen, "Challenges in public display deployments," May 2017, pp. 3426–3475. doi: 10.1145/3025453.3025798.
- [10] E. van den Hoven, J. Frens, D. Aliakseyeu, J.-B. Martens, K. Overbeeke, and P. Peters, "Design research & tangible interaction," 2007, p. 109. doi: 10.1145/1226969.1226993.
- [11] D. Petrelli and S. O'Brien, "Phone vs. Tangible in museums: A comparative study," in *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, New York, NY, USA, Apr. 2018, pp. 1–12. doi: 10.1145/3173574.3173686.
- [12] J. Müller, F. Alt, D. Michelis, and A. Schmidt, "Requirements and design space for interactive public displays," 2010, p. 1285. doi: 10.1145/1873951.1874203.
- [13] G. Ren, C. Li, E. O'Neill, and P. Willis, "3D freehand gestural navigation for interactive public displays," *IEEE Computer Graphics and Applications*, vol. 33, no. 2, pp. 47–55, Mar. 2013, doi: 10.1109/MCG.2013.15.
- [14] V. Gentile, S. Sorce, A. Malizia, D. Pirrello, and A. Gentile, "Touchless interfaces for public displays," 2016, pp. 40–43. doi: 10.1145/2909132.2909282.
- [15] S. Zhao, "Exploring how interactive technology enhances gesture-based expression and engagement: A design study," *Multimodal Technologies and Interaction*, vol. 3, no. 1, p. 13, Feb. 2019, doi: 10.3390/mti3010013.
- [16] C. Claisse, "Crafting tangible interaction to prompt visitors' engagement in house museums," Feb. 2016, pp. 681–684. doi: 10.1145/2839462.2854107.
- [17] M. Perry, S. Beckett, K. O'Hara, and S. Subramanian, "WaveWindow: public, performative gestural interaction," 2010, p. 109. doi: 10.1145/1936652.1936672.
- [18] S. Marichal *et al.*, "CETA: designing mixed-reality tangible interaction to enhance mathematical learning," in *MobileHCI '17: Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services*, Vienna, Austria, Sep. 2017, pp. 1–13. doi: 10.1145/3098279.3098536.
- [19] K. O'Hara, R. Harper, H. Mentis, A. Sellen, and A. Taylor, "On the naturalness of touchless," *ACM Transactions on Computer-Human Interaction*, vol. 20, no. 1, pp. 1–25, Mar. 2013, doi: 10.1145/2442106.2442111.
- [20] H. Rante, M. Lund, and D. Caliz, "The role of tangible interfaces in enhancing children's engagement in learning," *MATEC Web of Conferences*, vol. 164, p. 01013, Apr. 2018, doi: 10.1051/mateconf/201816401013.
- [21] C. Falcao, A. C. Lemos, and M. Soares, "Evaluation of natural user interface: A usability study based on the leap motion device," *Procedia Manufacturing*, vol. 3, pp. 5490–5495, 2015, doi: 10.1016/j.promfg.2015.07.697.
- [22] U. Erra, D. Malandrino, and L. Pepe, "A methodological evaluation of natural user interfaces for immersive 3D Graph explorations," *Journal of Visual Languages and Computing*, vol. 44, pp. 13–27, Feb. 2018, doi: 10.1016/j.jvlc.2017.11.002.
- [23] B. Bach, R. Sicat, J. Beyer, M. Cordeil, and H. Pfister, "The hologram in my hand: How effective is interactive exploration of 3D visualizations in immersive tangible augmented reality?," *IEEE Transactions on Visualization and Computer Graphics*, vol. 24, no. 1, pp. 457–467, Jan. 2018, doi: 10.1109/TVCG.2017.2745941.
- [24] G. Caggianese, G. D. Pietro, M. Esposito, L. Gallo, A. Minutolo, and P. Neroni, "Discovering Leonardo with artificial intelligence and holograms: A user study," *Pattern Recognition Letters*, vol. 131, pp. 361–367, Mar. 2020, doi: 10.1016/j.patrec.2020.01.006.
- [25] S. Yamada, T. Kakue, T. Shimobaba, and T. Ito, "Interactive holographic display based on finger gestures," *Scientific Reports*, vol. 8, no. 1, p. 2010, Dec. 2018, doi: 10.1038/s41598-018-20454-6.
- [26] J. Rodrigues, P. Cardoso, J. Monteiro, and M. Figueiredo, *Handbook of research on human-computer interfaces, developments, and applications*. IGI Global, 2016, p. 663. doi: 10.4018/978-1-5225-0435-1.
- [27] J. Blake, *Natural user interfaces in .NET*, 1st ed. Manning Publications, 2013, p. 375. [Online]. Available: <https://www.quora.com/Natural-User-Interface-NUI/What-are-the-basic-principles-of-NUI-Natural-User-Interface-design>
- [28] S. Baraldi, A. D. Bimbo, L. Landucci, and N. Torpei, "Natural Interaction," in *Encyclopedia of Database Systems*, L. LIU and M. T. ÖzSU, Eds. Boston, MA: Springer US, 2009, pp. 1880–1885. doi: 10.1007/978-0-387-39940-9\_243.
- [29] L. Corenthy *et al.*, "Touchless Tactile Displays for Digital Signage: Mid-air Haptics meets Large Screens," Apr. 2018, pp. 1–4. doi: 10.1145/3170427.3186533.
- [30] D. A. Norman, "Natural user interfaces are not natural," *Interactions*, vol. 17, no. 3, pp. 6–10, May 2010, doi: 10.1145/1744161.1744163.
- [31] C. Peters, G. Castellano, and S. D. Freitas, "An exploration of user engagement in HCI," 2009, pp. 1–3. doi: 10.1145/1655260.1655269.
- [32] K. Doherty and G. Doherty, "Engagement in HCI: Conception, theory and measurement," *ACM Computing Surveys*, vol. 51, no. 5, pp. 1–39, Jan. 2019, doi: 10.1145/3234149.
- [33] T. W. Malone, "Heuristics for designing enjoyable user interfaces," 1982, pp. 63–68. doi: 10.1145/800049.801756.
- [34] M. Csikszentmihalyi, *Flow: The Psychology of Optimal Experience*. Harper & Row, 1990.
- [35] B. Taheri, A. Jafari, and K. O'Gorman, "Keeping your audience: Presenting a visitor engagement scale," *Tourism Management*, vol. 42, pp. 321–329, 2014, doi: <https://doi.org/10.1016/j.tourman.2013.12.011>.
- [36] C. L. Sidner, C. D. Kidd, C. Lee, and N. Lesh, "Where to look," 2004, p. 78. doi: 10.1145/964442.964458.
- [37] Y. Douglas and A. Hargadon, "The pleasure principle," 2000, pp. 153–160. doi: 10.1145/336296.336354.
- [38] D. Zyngier, "(Re)conceptualising student engagement: Doing education not doing time," *Teaching and Teacher Education*, vol. 24, no. 7, pp. 1765–1776, Oct. 2008, doi: 10.1016/j.tate.2007.09.004.
- [39] H. Pohl and R. Murray-Smith, "Focused and casual interactions," Apr. 2013, pp. 2223–2232. doi: 10.1145/2470654.2481307.
- [40] D. Kirsh, "Comparing tangible and virtual exploration of archaeological objects," in *Cyber-Archaeology*, M. Forte, Ed. Archaeopress, 2010, pp. 119–124. [Online]. Available: <https://philpapers.org/rec/KIRCTA-2>
- [41] H.-G. Pyun, H.-A. An, S. Yuk, and J. Park, "A gesture interface based on hologram and haptics environments for interactive and immersive experiences," *Journal of Korea Game Society*, vol. 15, no. 1, pp. 27–34, Feb. 2015, doi: 10.7583/JKGS.2015.15.1.27.
- [42] H. Saidi, M. Serrano, P. Irani, C. Hurter, and E. Dubois, "On-body tangible interaction," 2018, pp. 1–11. doi: 10.1145/3286689.3286692.
- [43] J. C. Sprott, *Physics demonstrations: A sourcebook for teachers of physics*. University of Wisconsin Press, 2006. [Online]. Available: [https://books.google.co.uk/books?hl=it&lr=&id=9wmgYI49YQ0C&oi=fnd&pg=PR9&ots=14kFx4YkTO&sig=HOr1AUF4Mj3uwMVcRFMMk3zCXyQ&redir\\_esc=y#v=onepage&q&f=false](https://books.google.co.uk/books?hl=it&lr=&id=9wmgYI49YQ0C&oi=fnd&pg=PR9&ots=14kFx4YkTO&sig=HOr1AUF4Mj3uwMVcRFMMk3zCXyQ&redir_esc=y#v=onepage&q&f=false)
- [44] M. Minge, M. Thüring, and I. Wagner, "Developing and validating an english version of the meCUE questionnaire for measuring user experience," *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 60, no. 1, pp. 2063–2067, Sep. 2016, doi: 10.1177/1541931213601468.



- [45] T. Giorgino, "Computing and visualizing dynamic time warping alignments in r: The dtw package," *Journal of Statistical Software*, vol. 31, no. 7, 2009, doi: 10.18637/jss.v031.i07.
- [46] S. G. Hart, "NASA-Task load index (NASA-TLX); 20 years later," in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Oct. 2006, vol. 50, pp. 904–908. doi: 10.1177/154193120605000909.
- [47] J. Webster and H. Ho, "Audience engagement in multimedia presentations," *ACM SIGMIS Database: the DATABASE for Advances in Information Systems*, vol. 28, no. 2, pp. 63–77, Apr. 1997, doi: 10.1145/264701.264706.
- [48] H. L. O'Brien and E. G. Toms, "What is user engagement? A conceptual framework for defining user engagement with technology," *Journal of the American Society for Information Science and Technology*, vol. 59, no. 6, pp. 938–955, Apr. 2008, doi: 10.1002/asi.20801.
- [49] P. C. Susanto, "Curiosity as an Effective In-stream Advertising Appeal: Visual and Textual Study of Levi's Circles Ad," *KnE Social Sciences*, pp. 426–434, Mar. 2019, doi: 10.18502/kss.v3i10.3927.
- [50] J. R. Lewis, "An after-scenario questionnaire for usability studies: psychometric evaluation over three trials," *ACM SIGCHI Bulletin*, vol. 23, no. 4, p. 79, Oct. 1991, doi: 10.1145/126729.1056077.
- [51] Csikszentmihalyi and Mihaly, *Beyond boredom and anxiety: Experiencing flow in work and play*. Jossey-Bass, 1975.
- [52] J. Hamari, D. J. Shernoff, E. Rowe, B. Coller, J. Asbell-Clarke, and T. Edwards, "Challenging games help students learn: An empirical study on engagement, flow and immersion in game-based learning," *Computers in Human Behavior*, vol. 54, pp. 170–179, Jan. 2016, doi: 10.1016/j.chb.2015.07.045.
- [53] A. Macaranas, A. N. Antle, and B. E. Riecke, "What is intuitive interaction? Balancing users' performance and satisfaction with natural user interfaces," *Interacting with Computers*, vol. 27, no. 3, pp. 357–370, May 2015, doi: 10.1093/iwc/iwv003.
- [54] C. J. Fullagar, P. A. Knight, and H. S. Sovern, "Challenge/Skill balance, flow, and performance anxiety," *Applied Psychology*, vol. 62, no. 2, pp. 236–259, Apr. 2013, doi: 10.1111/j.1464-0597.2012.00494.x.
- [55] F. Massimini and M. Carli, "The systematic assessment of flow in daily experience," in *Optimal Experience*, Cambridge University Press, 1988, pp. 266–287. doi: 10.1017/CBO9780511621956.016.