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Household Surface Interactions: Understanding User Input Preferences and Perceived Home Experiences

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ABSTRACT

Households contain a variety of surfaces that are used in a number of activity contexts. As ambient technology becomes commonplace in our homes, it is only a matter of time before these surfaces become linked to computer systems for Household Surface Interaction (HSI). However, little is known about the user experience attached to HSI, and the potential acceptance of HSI within modern homes. To address this problem, we ran a mixed methods user study with 39 participants to examine HSI using nine household surfaces and five common gestures (tap, press, swipe, drag, and pinch). We found that under the right conditions, surfaces with some amount of texture can enhance HSI. Furthermore, perceived good and poor user experience varied among participants for surface type indicating individual preferences. We present findings and design considerations based on surface characteristics and the challenges that users perceive they may have with HSI within their homes.

Author Keywords

User experience; surface texture; materiality.

CCS Concepts

•Human-centered computing → Interaction design;

INTRODUCTION

Touch screen devices have permeated all aspects of modern society with this including home life, work, and education [36]. Despite touch screen technology first being explored over 50 years ago [25], interactions still typically take place on a material internationally chosen for a touch based system (i.e. glass). Touching the screen of a smartphone will be familiar to many people, but what about touching the armrest of a sofa to interact with a projected TV remote interface? Research into the technology that can help to achieve touch interaction on a variety of surfaces is growing, however work examining user experience of touch gestures on surface materials is lacking. It is important to understand how surface characteristics map to a pleasant or uncomfortable interaction experience and how this changes based on the touch gesture used (e.g. tap, swipe). There are many different types of surface materials present within our homes (e.g., wood, plastic, metal, cloth) and these can be used as interactive surfaces to expand the potential of a space for carrying out tasks [39]. However, we know little about users' perceptions of using these alternative surfaces for interaction and methods that help to create experiences that take surface properties into account. We need to understand what challenges users perceive exist when using non-typical interactive surfaces within their home and the subsequent opportunities for smart home integration.

Projected touch screens turn everyday materials into interactive surfaces by overlaying an image onto the surface and detecting touches through the use of sensors (e.g., infrared) or built-in cameras. It is no longer essential to have a traditional display and instead we can utilise our environment to host the display. Devices such as the Sony Xperia Touch [44] provide the opportunity to place projected interactive content on top of household surfaces and allows for the examination of the challenges and opportunities in this space.

In this paper, we present a mixed methods study to understand user experience when carrying out typical touch gestures with different household surface materials; an area that we are calling Household Surface Interaction (HSI). We asked participants to complete five touch gestures on nine different surface materials using a commercially available touchscreen projector and to describe their experience of doing so. We interviewed participants to gather reflections on the use of interactive surfaces and to understand perspectives on how this technology would fit within home environments. We found that participants are willing to introduce HSI technology into their homes, but it is essential to consider how interaction techniques map to different household surfaces.

Paper Contributions: This paper makes three contributions. First, we present findings from a mixed method study exploring participants' experience of carrying out touch gestures on a variety of surface types. Second, we provide design considerations for developers and designers that are working in the space of HSI. Third, we present an application for exploring user performance in carrying out touch gestures. For transparency, we provide anonymised participant data and project code as supplementary material attached to this work.

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RELATED WORK

Interacting With Surfaces

Human-building interaction (HBI) is the interdisciplinary research area where human-computer interaction, architecture and urban design intersect. One important aspect of HBI is considering the physical space and how people may interact with their home environment [1]. In our homes, we interact with many services, objects, and surfaces everyday and there are many opportunities to expand these interactions with embedded systems [10]. There are many opportunities to examine where architectural features and computer interaction intersect, with augmented walls for daily tasks [34] proposed as an example of future computer interaction.

Room scale experiences are an area within HBI that shows promise in the future. The WILD room (Wall-sized Interaction with Large Datasets room) supports users interacting and exploring large and complex data sets through the arrangement of a grid of large (30 inch) displays [3]. The Microsoft IllumiRoom [26] was a proof-of concept system developed to explore the potential of augmenting the area around a TV using projected imagery for enhanced gaming experiences. Both of these examples take full advantage of the physical space and environmental features present within environments.

One method of achieving room scale experiences is through projecting content to augment a physical environment. This technique, referred to as Spatially Augmented Reality (SAR), can extend interfaces into the real world [38]. For example, supporting architects to explore new colours on the walls of a physical space [50]. Early work with SARs typically included a static physical environment, which can limit the usefulness of such systems but it is possible to combine SAR with shape-changing interfaces in order to combat this [33]. However, this can also lead to a reduction in overall user experience as users dislike interacting with a surface that has different physical properties to its visual identity (e.g. projected water patterns on a wooden table).

Materials and their associated textures play an important role when developing interaction techniques [13]. The type of material used for an artefact can offer different experiences and imposes constraints as well as offering affordance with regard to interactions [17, 29, 58]. When designing with a particular material in mind, the material itself can impact on what function a particular object can perform and also on what input/output methods are possible [43].

Challenges also exist when using non-typical materials for interaction. For example, Ventä-Olkkonen et al. [53] installed an interactive ice wall and found its properties made it unpredictable (such as becoming transparent), which caused issues for tracking systems to function properly. Surfaces can also inherit different properties due to interaction itself. For example, when interacting with liquids, aspects such as the degree of contact with the liquid, viscosity, temperature, and containment will all affect the possible interactions [20].

Individuals have varying associations with different material types (e.g., describing light materials as fun, solid materials offer control [21]), and this could impact on the interactions that may be accepted. Consumers make complex decisions about the materials that they are going to have within their homes, and these decisions may impact on their experiences in using tangible user interfaces [23]. Different technologies have emerged for classifying individual materials to understand situation contexts. Systems such as SpecTrans [41], RadarCat [60], and SpeCam [61] have all been shown to assist in classifying materials and extending potential interactions.

Touch screen devices support the execution of a large number of tasks but the touch gestures used to carry these out are very similar and can fit into a small number of categories. Villamor [54] breaks interactions down into subcategories with the following techniques being some of the most widly used in common touchscreen applications:

- **Tapping** – carried out by briefly touching the surface with one fingertip and is commonly used for selecting UI items.
- **Dragging** – consisting of moving a single finger across a surface without losing contact and is commonly used for deleting UI items within applications
- **Holding** – consisting of a surface being touched for an extended period of time and commonly used to display UI commands and menus.
- **Pinching** and **Spreading** – consisting of touching a surface with two fingers and either bringing them closer together (pinch) or further apart (spread). These gestures are commonly used for scaling and zooming.
- **Swiping** – consisting of quickly brushing the surface with one finger and is commonly used to dismiss notifications.

We know little about the intersection between touch gestures and surface material textures. There is a trend for technology to be embedded into the home, with a clear user preference for object metaphors and interaction styles to agree with any physical characteristics of a tangible UI [22]. Designers would benefit from guidance on preferred interaction techniques for different materials. Prior work has explored opinions on materiality and how different materials could be used in the design of digital artifacts [28], and we take inspiration from this when determining a more structured exploration task. With this in mind and in anticipation of the role surface materials can play in this landscape, we frame our first research question where we ask *RQ1: What surface characteristics do users find pleasant / uncomfortable to interact with and does a link exist between touch gesture and the surface used for interaction?*

Designing for Surface Interactions

When designing for surface interactions, a common method of providing contextual information to the user is through projection. The challenge with projected interfaces is in not knowing what materials a user will project onto and what surfaces they will want to interact with. The unfamiliarity of a surface as being interactive can cause misunderstanding for users in whether it can act as a digital interface [53]. Work has sought to understand the relationship between people and everyday things in the home, and highlights the challenge this present designers [56]. A key challenge in designing what we refer to as Household Surface Interaction (HSI) is in the uniqueness of every home. It is very difficult for a designer to know what materials a specific application will be using. It may be possible to narrow down surface characteristics by examining specific use cases (e.g. kitchen based graphical interfaces [6]), but determining exact limits is challenging due to the design preferences of home owners and what materials they wish to incorporate within given environments. When projecting images onto a surface, the properties of that surface will affect the quality of the image [24]. To overcome the surface colour restriction limitation it is possible to capture the colour and texture of surface and apply a correction to the projected image to preserve image quality [5,35,62].

It is important that form and materiality are considered with regards to the user experience of tangible user interfaces [55]. However, when we consider projection based interactive surfaces, designers are not in control of the surfaces people will interact with. Döring [12] presents the interaction material profile as a means of considering the materials used within HCI and the effect such materials can have. There is both a micro and macro perspective on the general aspects of the material and the application-specific aspects of the material.

A key aspect within modern touch interfaces is the use of tactile feedback. Tactile feedback assists in reducing task completion time [37]. However, the effect physical material properties have on the overall sensation of tactile feedback for a user is unclear. It is possible to augment home surfaces with vibration motors in order to give tactile properties, but more advanced techniques are also possible such as augmenting texture onto objects through reverse electrovibration [2].

A second aspect of designing surface interactions lies in the technology used to facilitate user input. SmartSkin [40] used a mesh of electrodes to augment a surface for touch detecting, providing users with a means of interacting with a system using their hands rather than input peripherals. Depth cameras are an alternative to body tracking gear when understanding user intent [4]. Finally, the human body itself can be used in an environment to interact with surfaces by detection of changes in noise radiated by power cables and appliances [9].

The complexity of creating usable surface interactions produces many challenges. Early work in this domain has examined surface interactions in offices [27,30], kitchens [7,32], and art installations [42]. However, the complexity of modern homes requires an analysis of the current challenges and opportunities that exist in order to promote the adoption of this technology. We use this to motivate our second enquiry in this work where we attempt to uncover *RQ2: What challenges do users perceive exist when using HSI within their home and where are the opportunities for future smart home integration?*

Understanding and addressing these research questions is important for three reasons: 1) To increase the likelihood of an optimal user experience during HSI, 2) To understand areas where users may accept the integration of HSI within their homes, and 3) To assist developers in creating application experiences that take into account digital and physical factors. This research is an opportunity to identify the direction that future design in this growing technology field should take and to provide design considerations for this space.

AN EVALUATION OF SURFACE INTERACTIONS

We carried out a mixed methods study to understand user performance and experience with touch gestures on different surface materials. The study involved interaction trials on different surfaces followed by an interview to reflect on the overall study and to understand perspectives on how household surface interactions would fit within home environments.

Materials and Apparatus

Demographic Information: We used a questionnaire to collect demographic information. This included age, gender, the highest level of completed education, technology literacy, ownership of a touchscreen device (and frequency of use), experience with augmented reality.

Surface Materials. We sourced materials typically found in the home by visiting carpet, kitchen, and tile stores within our local area. In total 114 surfaces were collected and consisted of 85 carpet samples, 18 counter tops, 5 tile or slate samples, and 6 artificial grass samples. We examined each surface and notes taken on surface material properties. We then initially selected 15 surface samples aiming to reach a broad range of surfaces based on type, lightness, reflectivity, and texture. We used two surfaces that were made of smaller parts because our homes are not perfect (e.g., gaps in old flooring, tiles with little grout) and we wanted to discover what participants thought about these imperfections. All artificial grass surfaces were removed from our initial sample due to the high level of difficulty in reading and interacting on this surface. Pilot testing showed that we had underestimated the amount of time taken to complete a series of touch gesture tasks, and reduced the total number of surfaces to 9. We removed surfaces that had similar material properties while still maintaining the broad selection of surfaces required by our selection criteria. The surfaces selected for our study included 3 carpets, 3 counter top surfaces, 2 slate surfaces and 1 tiled surface. Surface summaries are provided in Table 1 and surface images in Figure 1.

Experimental Equipment. To test the application of HSI we used the commercially available Sony Xperia Touch [44]. This short-throw projector produces a 1366 x 768 resolution screen at 23" projecting at 100 lumens and uses an IR sensor to allow 10-point multitouch input. We used a custom-designed 3D mount to best match up surface material height to device IR location. We used a OnePlus 5T running Google Science Journal to measure room lighting levels before each experiment session, and an audio recorder to capture participant comments and interview discussion for later transcription and analysis.

Lab Setup. All experiment sessions took place in our in house user testing lab, illustrated in Figure 2. Participants were allowed to use a chair during the experiment to aid in comfort levels, but we did not have one positioned in front of the projector. We positioned the projector desk facing away from the window with blackout and vertical louvre blinds drawn. Room lighting was kept in a low range in all sessions (38-71 Lux; Mean = 45.05, SD = 7.47).

Interaction System. We created a custom system in order to gather information on participant performance and experience in using a number of interaction techniques. The system con-

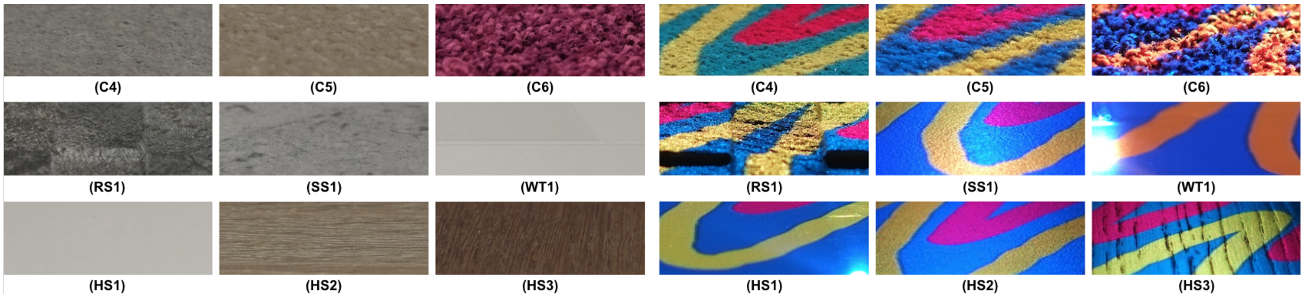

Figure 1. Images of our nine surfaces in a well lit room (left) and with the AR projector projecting a colour full image in a dark room (right).

Code	*Type*	*Lightness*	*Reflectivity*	*Texture*
C4	carpet	medium	matte with reflective strands	flat with slight roughness and shallow pile
C5	carpet	medium	matte with reflective strands	flat and rough with shallow pile
C6	carpet	dark	matte with reflective strands	flat with slight roughness and deep pile
RS1	slate	dark	matte	very rough wavy checked
SS1	slate	medium	matte	flat with slight roughness
WT1	tile	light	glossy	flat and mostly smooth
HS1	acrylic counter	light	glossy	flat & smooth
HS2	wooden counter	medium	matte	flat with slight roughness
HS3	wooden counter	dark	matte	flat with slight roughness

Table 1. Description of the lightness (colour tone), reflectivity, and texture of the nine material surfaces.

sisted of two main components: a frontend web application built using NodeJS, Angular, toccaJS (to support in touch gestures), interactjs.io (to support multi-touch), and hosted using Heroku; and a back end API built using PHP, mySQL, and hosted within an Azure Web Application.

Five touch gestures types were selected to cover the various ways in which people typically interact with touch screen displays. We implemented two different versions of the five gesture types within the frontend web application for a total of 10 tasks per trial. We use the gestures described previously in Related Work (tapping, dragging, holding, pinching, spreading, and swiping) and summarise these in Figure 3.

Our system cycled through the 10 gesture tasks in numerical order as a default. Within an experimental setting a call was made to our data gathering API which then provided a randomised order of interactions by using the PHP `shuffle()` function. The system collected start and finish time for all individual gesture tasks using the javascript `date.getTime()` function which was then sent to the API.

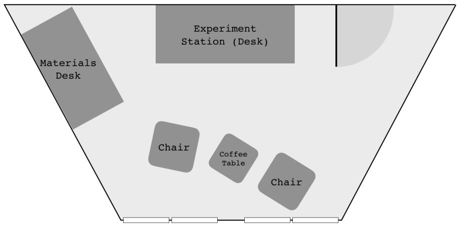

Figure 2. Room layout of lab used during experiments. Participant interviews were conducted whilst sitting in the chairs, with a separate desk area used for our touch screen projector and associated materials

Experience with Surface Material Questionnaire. We used an end of task questionnaire with five questions to gauge experience of interacting with each surface. Q1 asked participants to rate how easy it was to complete the gesture task due to the texture of the surface on a 1 (very easy) to 7 (very difficult) rating-scale. Q2 asked participants to explain their experience with the texture of the surface (open ended). Q3 and Q4 asked the participants to say which of the five gesture tasks resulted in a good and poor user experience, respectively (none, all, or specify which applied). Finally, Q5 was an opportunity for participants to provide any other comments they had about the surface material properties (open ended). We asked participants to discuss their answers aloud.

Interview Guide. We used an interview guide to ensure a level of consistency between interviews, while also designed to be semi-structured to allow for more natural dialogue and so that we could explore further any interesting points raised. The interview began by focusing on understanding participant preferences towards their favourite and least favourite surfaces and why, providing an opportunity for participants to reflect on all of the surfaces they had used. We then asked participants if using the system was natural and asked to discuss how they chose to interact with the system. We asked participants if anything surprised them or stood out as interesting during the touch gesture study. The interview guide concluded by asking participants if they could see themselves using this type of technology at home, what they would use it for, and what limitations they would face in their home environment.

Experimental Procedure The total study took one hour of participants' time, and we reimbursed all participants with a £10 Amazon voucher and a branded research lab notebook and pen.

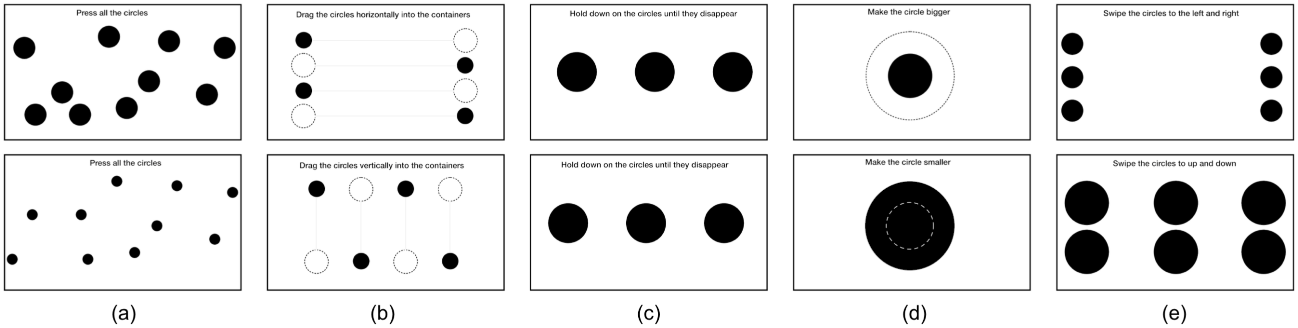

Figure 3. The 10 tasks that we included in our Touch Gesture System. Tasks involved (a) tapping 10 targets (large and small), (b) dragging 4 targets (horizontally and vertically), (c) holding 3 targets (0.5 and 2s), (d) pinching 1 target inwards and spreading 1 target outwards, and (e) swiping 6 targets (horizontally and vertically). We have inverted the colour of the images (black to white and white to black) for easier viewing.

At the beginning of an experiment session, participants were welcomed and asked to read and complete informed consent forms (in line with approval from our Institutional Review Board). Participants then filled out *Demographic Information* and were given a demonstration of the ten gesture tasks that they would be completing on a hard wood surface. Demonstrations were given by the researcher to limit participant exposure to materials not used within the study.

After demonstrating the gesture tasks, we gave participants instruction to remember for the study. 1) Focus on the experience of interacting with the current surface material, 2) If an interaction appears to fail initially, keep trying (e.g., tap a different circle) or ask for assistance if needed (e.g., to skip a trial), and most importantly 3) Interact in a way that is most natural and comfortable. The final point was important for two reasons. First, although the interaction techniques are standard, we acknowledge that everybody has their own way in carrying out those gestures (e.g., pinching with the thumb and middle finger vs thumb and index finger). Second, people have varying degrees of sensitivity to textures and the surfaces we chose covered a broad range of textures.

Participants completed the 10 gesture tasks on the 9 different surface materials (counterbalanced between participants) using our created *Interaction System*. After participants had completed interaction trials on a single surface they were provided with the *Experience with Surface Material Questionnaire* and asked to discuss their responses aloud. This allowed us to ask participants to elaborate on points they were making. Once all surface interactions had been completed participants took part in an interview driven by the *Interview Guide*.

Results

40 participants took part in the study (one participant, age = 84, was removed from analysis as they did not complete the study within the scheduled time). The remaining 39 participants (Male = 18, Female = 20, Undisclosed = 1) were aged between 19-78 years old (Mean = 28.03, SD = 11.28).

We asked participants to report their highest level of education: high school (1 participant), 1st year university undergraduate (1), 2nd year university undergraduate (5), 3rd year university undergraduate (1), 4th year (honours) university undergraduate (17), MSc university postgraduate (8), PhD university postgraduate (5), and one participant had a postgraduate diploma. Participants also reported technology literacy on a 1 (poor) to 7 (excellent) rating-scale (Mean = 5.62, SD = 1.18).

All participants owned a touchscreen device and reported how many hours a day they use their device. Participants reported: Less than 1 hour a day (2 participants), 1-2 hours a day (7), 2-3 hours a day (8), 3-4 hours a day (5), 4-5 hours a day (8), and more that 5 hours a day (9).

In total, 31 participants had some level of experience with AR. Twenty two participant responses indicated the level of exposure to AR – 5 participants had at least a reasonable amount of experience with AR (e.g., developing for the Microsoft HoloLens), while 17 participants reported limited or occasional use of AR (e.g., "Pokemon Go with AR mode enabled briefly but not much other experience"). Among the 31 participants, there were various mentions of AR features (e.g., AR stickers, Snapchat filters, Google Maps AR), apps (e.g, Pokemon Go), and devices (e.g., Nintendo 3DS). No participant indicated experience with an AR projector.

As expected, participants interacted with the system in different ways. For some this included using both dominant and non-dominant hands. With regards to digits used (i.e., fingers and thumbs), the participants utilised many strategies that involved various combinations of digits. Thirty five participants said that they found the overall system natural to use and four participants did not. One participant commented on using the system flat on a surface and highlighted that they are " *used to just have[ing] a tablet or my phone and just using it vertically, but having it horizontally, it just feels a bit weird.*" (P35).

Task Interaction Speed

We gathered task completion time for each individual gesture task within the study. Data was sanitised by applying closest match to missing data points (48, 1.4% of data-set) [14]. Missing data points were due to uncomplete tasks and unreliable internet connection between device and API. We condensed data with mean timings between gesture tasks computed for each participant. We then divided timings by the number of individual gestures (e.g. single taps) that took place within a given task to offer comparisons on a single gesture level.

Mauchly's test indicated that the assumption of sphericity had been violated for the main effects of surfaces, $\chi^2(35) = 54.89$,

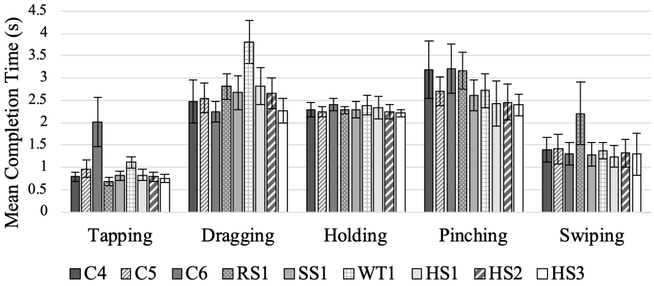

Figure 4. Individual touch gesture completion times between different surfaces. Error bars show standard error.

p = .018, interactions, $\chi^2(9) = 59.27$, p < .001, and in surface*interaction effect, $\chi^2(527) = 1093$, p = < .001. Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = .73 for the main effect of surfaces, ε = .59 for the main effect of interactions, and ε =.32 for the surface*interaction effect).

There was a significant main effect, F(5.83, 216) = 4.51, η_p^2 = .109, p < .001, of the surfaces on the overall time taken to complete an interaction. Pairwise comparisons revealed that WT1 produced significantly slower interaction completion speed than C5, HS2, and HS3. HS3 also produced significantly faster interaction completion speeds than C6 and RS1. A significant main effect, F(2.35, 87) = 98.13, η_p^2 = .726, p < .001, was also observed on time taken to complete different interaction techniques. Pairwise comparisons revealed that tapping produced significantly higher interaction completion speed than all other interactions (dragging, holding, pinching, and swiping). Swiping produced higher interaction completion speed than dragging, holding, and pinching. Holding produced significantly higher interaction completion speed than dragging and pinching. We observed no significant difference between time taken to drag and pinch. Finally, an interaction effect F(10.12, 374.3) = 6.54, η_p^2 = .150, p < .05, was observed between surfaces and interaction methods. We made no pairwise comparisons after consultation with [15]. Descriptive information can be seen within Figure 4.

Surface Interaction Experience

We asked participants to indicate how easy it was to complete the touch gestures due to the texture of the surface. Participants rated each surface on a scale of 1 (very easy) to 7 (very difficult) and we conducted a Friedman test to investigate whether there was a significant difference in perceived ease of use among the nine surfaces. We found a significant main effect for surface: $\chi^2(8, N = 38) = 166.20, p < .001$. Wilcoxon signed-rank tests with an adjusted alpha level revealed a statistically significant difference when comparing C4 to C6 and RS1; C5 to C6, RS1, HS1, HS2, and HS3; C6 to SS1, WT1, HS1, HS2, and HS3; RS1 to SS1, WT1, HS1, HS2, and HS3. SS1 to WT1, HS1, HS2, and HS3. See Table 2 for mean ratings and direction of significance.

Interestingly, the surface rated as easiest to complete touch gestures was HS3, which has some amount of texture, rather than a surface that was completely smooth and most similar to the screens we use on our devices (e.g., HS1). The surface rated as most difficult to complete touch gestures was C6 (purple carpet). C6 and RS1 were both significantly least favourable to surfaces SS1, WT1, HS1, HS2, and HS3, yet the two surfaces themselves both exhibit very different properties.

To better understand the ratings, participants explained their experience. We used an open coding approach to analyse the qualitative data [51]. Participant feedback broadly fit into two main categories: *texture* and *image clarity*.

Texture. Our participants found texture to be both a positive and negative experience. The softer textures of the carpets were appealing for reasons such as experiencing an "*[I] pressed a button feeling*" (P24), but interactivity was affected by carpet pile: "*you got the whole length of the thing to smooth out*" (P3). To address this dynamic interference often a lighter touch was needed: "*I felt like I had to be a little more softer when I was pressing*" (P21), but it was not intuitive to do so. Both SS1 and WT1 were relatively flat, although SS1 had a more texture, and participants acknowledged the surfaces being nice to touch and easy to use. Participants commented on SS1's roughness and WT1 was found have some resistance or a sticky sensation (8 participants), likely due to the gloss. Although some participants did not find the tile pattern to be an issue, 17 participants felt the grooves affected interaction or the projected image. RS1 was the most textured surface. Thirty seven participants commented on the texture being uncomfortable or annoying, and 34 participants exhibited negative comments towards its unevenness:

> P20 *"...the ridges here were kind of interrupting the flow, initially anyway, and then I found myself just having a lighter touch over time, and that seemed to work."*

However, 10 participants provided positive feedback towards RS1 surface texture describing it as looking "*cool [laughs] for artistic reasons but it wasn't very practical*" (P24). The shape of the material could lend itself to the experience of a particular task: "*Weirdly enough I chose tapping as a good one because there was certain angles which I guess was ergonomic*" (P10). While not a very practical surface, RS1 did highlight that shape could be beneficial in some instances and some participants liked the surface texture of the stone.

The three solid surfaces (HS1, HS2, HS3) were all relatively well received. Participants found the materials provided a nice and easy to use surface. Eight participants found HS1's smooth glossy texture to be familiar (e.g., a smartphone screen), "*It's just hard to know whether society has primed me because of the ubiquitous nature of something shiny being easier to interact with.*" (P30). However, 14 participants found it to also be unpleasant: "*It felt sticky, and it isn't, I can tell it's not a sticky surface at all.*" (P22). Both HS2 and HS3 had more texture than HS1 on account of the grain of the wooden surfaces. Eight participants commented that texture was a good thing for both HS2 and HS3 (e.g., P7 said "*It's like you actually feel like you are interacting with it instead of just touching the surface*". Additionally, it is important to consider that *"it's nicer to go with the grain"* (P38), which can enhance the experience of interaction:

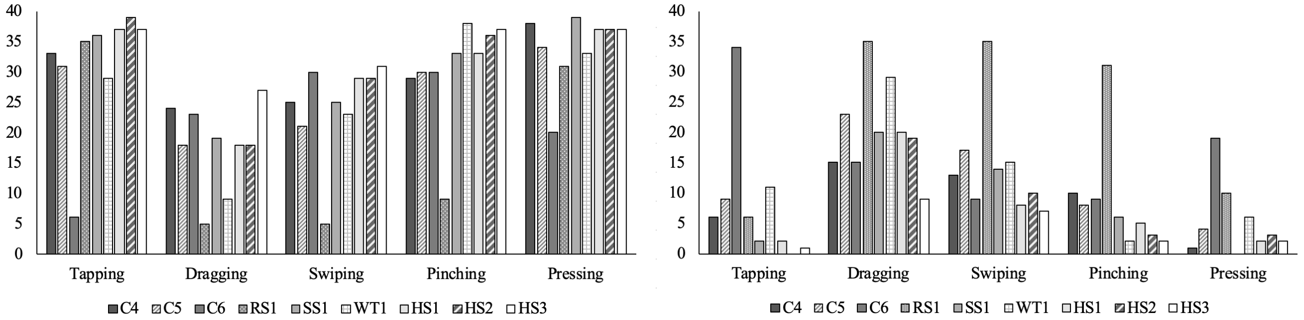

Figure 5. Left Chart: Frequency of participants indicating the interaction on a particular surface resulted in a good user experience. Right Chart: Frequency of participants indicating the interaction on a particular surface resulted in a poor user experience.

> P36 "*I liked [HS3] as well. It was very similar to [HS2], but I think because of the vertical nature of the grain, I actually found the dragging easier.*"

Surface texture can both enhance and diminish HSI user experience. An interesting observation we made was that participants would describe surfaces as warm (e.g., C6, HS2) and cold (e.g., WT1, RS1). The aesthetics were also noted as interesting and surfaces can be used when there is a need to inspire a professional or premium feel (e.g., regarding WT1 P18 said "*I think that the material looks more professional, just because it looks nice even when it's not on, but then the feeling of it might not work for certain apps*"; P10 described C4 as feeling "*luxury*"). Participants also commented on the natural feelings presented by surface textures and the benefits that this create. P30 commented that "*it was very satisfying to do a vertical drag on a vertical grain on the wood. It kind of accelerated where I was going, but only if you're obviously going exactly in that direction.*", with P31 adding that "*it's more natural to the touch.*"

Occasionally participants would comment on the sound of interacting with a surface and how this could be either a positive or negative experience. P30, for example, commented that *"[HS3] made a satisfying noise to tap [laughs], yeah just a nice wooden property"* whilst other participants focused more on the negative aspects of sound, commenting that *"if you drag your nails across [SS1] or something, it [makes] horrible noises"* (P23) and that RS1 *"has a kind of tile-y scape-y sound"* (P38). This was not something we had considered when selecting materials, but it highlights the importance of how texture might create a sound and that this could alter an experience.

Image clarity. When projecting onto a surface, the colour and pattern of that surface alters the look of the projection. While a particular material may be enjoyed for its texture, it may not be suitable when required to read finer details (e.g., text). A balance needs to be met between a desired texture and image clarity. While we are most interested in the user experience of touching the surface, participants commented on the projection of our system onto the surfaces. When the image was particularly difficult to perceive participants mentioned they were working from memory because the onscreen instructions were no longer easy to see. We anticipated this and it was one reason that we counterbalanced surfaces and provided demonstrations before the main experiment began. Carpets C4 and C5 received comments that they provided both good and poor image clarity, whereas participants only mentioned C6 for poor image clarity. Both C4 and C5 have shorter piles and so the image is clearer, however, compared to a solid surfaces the fibres still break up an image (as shown in Figure 1). Participants found SS1 and WT1 to have relatively good image clarity, although the dividing lines of both would interfere with the completeness of the projection. Twenty three participants commented that RS1 mostly had poor image clarity and this was on account of the 3D surface structure. All three solid flat surfaces (HS1, HS2, HS3) only received comments describing that they offered good image clarity.

Although, the image projected on RS1's surface is distorted, it provided a good amount of contrast due to its colour (P22 and P29). However, contrast was not always appreciated such as with surfaces WT1 and HS1 because their shiny and reflective surfaces could become too much in a darker room.

Two of our surfaces (SS1 and WT1) consisted of smaller sections. The dividing line could create challenges during interaction or in breaking up projected images: "*it kind of interrupts the flow of the task when your hand goes over it*" (P11) and "*apart from being able to like read what it was saying, I didn't have any issues really*" (P37).

Material Preferences. Our participants provided comments on their initial reactions after using each surface. Most interesting was the variability in preference. While a majority of participants might agree on a particularly positive aspect there were also examples of contrasting opinions. For example, P32 on RS1 "*It was very weird [laughs]. It was weird because you don't expect it to have bumps, but I quite enjoyed it though. It was nice.*" and P36 on C4 "*You know, if you imagine this was a desktop, doing that all the time, I think there's just too much tactile feedback on a surface like this.*". P3 described HS1 like "*...when you run your hand down a bus window or something like that [and] there was no character to it, whereas at least the carpet was funny you know.*" P12 "*Again, for that particular task I would say [RS1] was my least favourite, however, if it was, I don't know, if I was a car over a bumpy terrain like in some racing game or whatever, you know, then that would make sense because it was in context with the task.*" If home surfaces are to become interactive, people may be able to choose the surfaces that they want to work with but it is important that the device and software can adapt in a way to maximise the success of those interactions.

We asked participants to indicate their favourite and least favourite materials at the beginning of the interview, and to reflect on their usage of all surfaces. In some cases, participants found it difficult to pick one and would therefore discuss two or three. HS1 was the most liked surface (16 participants) with this being followed by HS2 and HS3 (8 each). 7 participants indicated that their favourite surface was SS1, 2 indicated C6 and WT1, and 1 indicated C5. Participants least favourite surfaces were C6 and RS1 (18 participants each), 4 indicated HS1 as their least favourite surface, C4 and WT1 were each indicated by 1 participant to be their least favourite.

Interestingly, four participants indicated HS1 to be their least favourite and two participants found C6 to be their favourite. Surface material preferences vary and this warrants future work to maximise the usability of interacting on different surface materials to meet people's needs.

> P2 "*I guess you don't really think about what surfaces or what it feels like when you do these things until you try it with different surfaces, so it is quite interesting.*"

Interactive Surfaces in the Home

We asked participants to reflect on their experience and discuss how such interactions would fit within their home. Our participants suggested many cases that they saw this technology being appropriate for, including: entertainment (e.g., music instruments, art, games, reading; 28 participants), communication and productivity (20), kitchen use (11), to impress and support social gatherings (8), education (e.g., kinesthetic learning; 7), functional controls (e.g., lighting, fan, large keyboard; 6), increase being active (e.g., use outside; 3), public engagement (3), use in bathroom (e.g., to avoid wet hands on a traditional screen; 2), and information (e.g., weather; 2).

During the touch gesture study, our participants were given the opportunity to explore the experience of interacting with a collection of household surfaces. In doing so, participants were able to develop an understanding of where potential limitations of HSIs are in relation to use in their own homes. Our findings in this area are split into two categories:

Finding Suitable Space within the Home. One of the main concerns raised by participants was having access to or finding an appropriate surface (e.g., carpet, counter top; 24 participants). P5 stated that they would "*have expectations of oh I'll use it everywhere and [then] realise that actually it's not really suitable in the kitchen, I'll need to put it somewhere else or put something down, which would bring its own problems.*" Although participants suggested ways to mitigate this problem. For example, P5 went further to describe "*...a sort of booklet of different surfaces*" to test with. This idea would be appropriate for informing people about limitations, but it does not improve the usability of the system. An alternative solution suggested was where the system becomes more contextually aware and adaptive with P20 suggesting that "*[Maybe] the system [can] be flexible enough to accommodate different surfaces in different ways.*", which may be possible when pairing the device with other sensing technologies such as RadarCat [60].

Code	Mean	Std. Error
C4	2.49	.246
C5	3.15	.261
C6	4.97	.283
RS1	4.87	.215
SS1	2.00	.160
WT1	2.82	.176
HS1	1.74	.183
HS2	1.69	.148
HS3	1.59	.159

Table 2. Mean and Standard Errors for participant ratings on ease of completing the gesture task due to texture. Lower values are better.

Another concern raised by participants was having available space or a clean, clutter free surface (19):

> P27 "*The kind of surfaces you have in your home, like, coffee table[s] and things like that, usually have stuff on them. [It's] more convenient just to have the iPad or something because you don't need to find the space.*"

P4 had concerns regarding the changing state of surfaces within a kitchen, stating that "*if the surface was dirty...food stains on it, it would make it a lot harder to use*".

Potential Applications and Environments. Whereas smartphones and tablets are a hand-held, self-contained unit, interactive household surfaces require real-world surface space to be made available. Eleven participants felt that HSI could be useful in the kitchen and therefore avoid the issue of dirtying a glass screen, however, a kitchen surface is likely to get dirty during use and could interfere with device sensitivity. Participants described alternative locations within the home that may also be suitable, for example:

> P7 "*I feel that a desk would probably be the best place to have this [...] The only downside would be that my desk is quite raised and I tend to sit very low, so it might be more difficult to see the system*"

> P15 "*I think the only rooms that are kind of solid flooring is the hallway, so it wouldn't really be an ideal place to have it set up, because people would be walking in and out all of the time, and getting in the way [...] I tend not to move things about realistically once it is setup that's where it lives.*"

Having a specific use case in mind when carrying out HSI tasks would mean that any technology supporting this is likely to be placed somewhere specific and remain there, much like a TV. In some cases, it would be necessary to make adjustments for optimal use, however some adjustments may not be feasible. Seven participants raised concerns that the environment could affect how usable current HSI devices could be:

> P12 "*You know we've got less lighting in here. Not all the lights are on. I would imagine if all the lights were on it might be a little bit difficult to see the projection.*"

In some cases it would be possible to control ambient lighting and this may be a suitable strategy depending on the task carried out. However, when considering that a home environment may have limited available space to use such technology, it may need to be placed somewhere that is likely to frequently experience environmental interference (e.g., P7 "*... because it is not actually being projected right into your eyes, it is onto a surface, so you'll need a more shaded area.*"). Other external factors that could interfere with successful use of interactive AR projection are pets (3 participants):

> P24 "*The cat would be interested in it and probably walk in front of it, and things like that, and press buttons.*"

DISCUSSION

There is large potential in using surfaces present within our homes as new interfaces for people to communicate with the digital world. The properties of these surfaces themselves can sometimes dictate the gestures that are achievable and the level of interaction that is possible. In this paper, we used a mixed-methods approach to measure the user experience of 39 participants during household surface interaction (HSI) involving 9 household surfaces and 5 touch interactions. We found that under the right conditions, surfaces with some amount of texture can enhance HSI, which is encouraging for the future of HSI becoming a part of daily life. However, as confirmed by our results, there are challenges in ensuring HSI provides a pleasant user experience. To support the goal of maximising positive user experiences, we discuss the implications of our results in relation to our research questions and present design considerations to use for future work in this area.

Interacting with Surfaces

RQ1: What surface characteristics do users find pleasant / uncomfortable to interact with and does a link exist between touch gesture and the surface being used for interaction?

1) Hard surfaces and prolonged interactions with movement can cause interaction difficulties. Hard surfaces can make HSI a relatively nice experience in terms of the solidity providing a supportive structure under which the finger can interact. However, the solid surfaces we used in our study varied in texture resulting in the discovery that texture on a hard surface plays both a positive and negative role in HSI user experience. Both WT1 and HS1 reminded participants of the smooth surface of modern mobile devices; however, there was an unexpected resistance from the materials that made participants think it was sticky. The high completion time for dragging gestures on these surfaces also reflected this. Interestingly, a low level of texture, such as the grain on wood, could avoid this for some participants but caused participants to question dragging type gestures that were *"against the grain"*. There was also an appreciation for the texture providing tactile feedback that adds to the experience of HSI, something that could be further enhanced by using methods similar to [2]. It is worth noting that for long durations of interaction the texture of the hard surface may become overwhelming. Interaction techniques such as dragging are unlikely to be beneficial for long time use, and so applications used for a long duration should consider short contact interaction (e.g., tapping).

2) Reactive surfaces can be a challenge but are also rewarding. The softer materials in our study created a changable surface topography. Our participants became aware that their own interactions with carpets could impede their ability to complete the task. Although the thicker pile carpet C6 was very soft, participants needed to 'reset' the surface by smoothing out the fibres because over time their continued interaction with the material disrupted successful HSI. The experience of tapping on carpets was also changeable dependant on pile depth. While the depth of C6 caused a sinking feeling through the projected image, a positive outcome of the shorter pile of C4 was that it provided the sensation of button tactility. A compromise is needed between soft materials and the ambient technology limitations to avoid poor user experience during HSI. We also suggest designers take advantage of the need to 'reset' surfaces in this way and that larger full-hand clearing gestures could serve a dual purpose (i.e., to reset the surface, and provide a method of UI input between application functions).

3) 3D surfaces and physical joins are a consideration in interface design. Not all of the surfaces available in our homes are large uninterrupted piece of material. There are many examples of surface that are uneven or joined together, such as surface that are constructed by smaller components (e.g., slate, brick) or contain imperfects due to age (e.g., floorboards with gaps as mentioned by P24) or intentional cosmetic design. Our participants found that sometimes this was not an issue, such as in the case of WT1 when the tile pattern was made by a shallow grouting. Instead a larger issue was for joins that had increased depth, which not only affected interaction during dragging but the completeness of the projected image. When faced with the space restrictions of a home environment, HSI may be necessary on these imperfect surfaces, and so consideration should be made to avoid interactions that involve substantial contact with those 3D textures and joins.

4) Variations in people and surface associations affect application experience. It is important to consider that individual differences between people will account for variations in user preferences. While there was some consensus on attitudes to HSI for particular textures it was also evident that what one person dislikes another person likes. Reasons for this could be related to occupations and hobbies that toughen the skin of the hands and fingers (e.g., construction workers, rock climbers, guitarists), furthermore tactile sensitivity varies across the fingers [31], further decreasing with age [46] and temperature [19]. These individuals are likely to be less sensitive and more willing to use rougher surfaces. Another consideration is simply we have different sensory preferences. If done well, HSI extends the range of surface textures people can use, allowing them to work with a "warmer" and softer material like carpet rather than a "colder" and hard material like glass, if that is their preference. It is important to consider feelings towards materials in HSI applications, e.g., applications intended to evoke a warm, nurturing feeling can use carpet to enhance the overall activity experience.

Designing for Surface Interactions

RQ2: What challenges do users perceive exist when using HSI within their home and where are the opportunities for future smart home integration?

1) HSI should understand, and adapt, to mitigate poor user experiences. Our homes include many potential surfaces for

HSI. However, the opportunities to utilise HSI are restricted if ambient systems and applications are unable to adapt to the context of use. System adaption and user customisation are well established approaches to maintaining usability within different contexts [16, 18, 52, 59]. Applications for HSI could be designed to disable and remap specific interaction gestures if they are deemed unsuitable on a specific surface materials. For example, interacting with rougher surfaces by moving over the surface (e.g., dragging) was generally disliked by participants, but tapping on such a surface was a relatively pleasant experience. Other sensing technologies that supports material classification such as RadarCat [60] could pair with HSI devices for automatic interface adaption.

Another consideration is the surfaces present within our homes are multi-use, and space for the sole use of HSI is unlikely to occur. Interface design should be adaptable to both surface colour, environmental lighting, and other relevant factors. For example, in a kitchen, surfaces will come into contact with utensils, ingredients, and cooking appliances. Computer vision [45] and tag systems [57] have previously been used to bridge the gap between digital and physical worlds; this should be understood by HSI systems to reduce unintended input.

2) Surface interactions should supplement current use case and not aim to replace. Home surfaces can be multi-use, with users having different expectations of an environments purpose. Many of our participants viewed the use of ambient technology for HSI as supplementary to a particular goal. Our participants recognise there was something that HSI offered that was both beneficial and unique compared to other technologies such as smartphones. For example, work surfaces in the kitchen are made for getting dirty during cooking, whereas our smartphones are not. In this case, HSI can support users carrying out their task, but care is needed to not alter the surface in such a way that technology is the primary focus.

Our participants also discussed interesting cases where HSI could extend our experiences during entertainment by bridging the physical and digital worlds. They also discussed potential benefits in education by providing a sensory active learning session. Finally, participants discussed surfaces like wood, which have an "*ironic coupling of nature and tech*" (P30). This suggests that there is potential for further exploration of new systems that take advantage of more natural materials and pair them with digital systems for different domains.

3) Home environments can change throughout the day. Homes are living spaces and it is important to consider that our home environments constantly change throughout the day [11]. Situational impairments [49] are a relevant issue that users will face with HSI. In particular, our participants raised concerns about ambient lighting making a projected surface difficult to use during HSI. This is also known as a situational visual impairment (SVI). Prior work has investigated SVIs when using mobile devices under different lighting conditions [47]. Although designers are not well supported there are proposals for supporting them in addressing SVIs [48], which would be relevant for improving HSI. There is an opportunity here for designers of HSI to consider, and address, these concerns from the outset before they become issues for future applications.

Limitations and Future Work

Our study was conducted within a controlled lab environment and not within participant homes where interaction may have been more natural. This was particularly important for RQ1 and we decided early on within our study design that real home environments have too many uncontrollable factors. For example, the projector uses only 100 lumens, which limits its use in bright conditions when compared to even the typical output of a light bulb [8]. We recognised this limitation early and designed the set up of the room to account for this. We anticipate the technology to improve with future iterations. Furthermore, by using material samples we could ensure all participants had the chance to try some textures that they might not have access to. The ideation from RQ2 is, in part, a logical follow on from RQ1 and allowed participants to think broadly about the surfaces they have in their homes and how they relate to experiences they encountered with surfaces in our lab. Our work is a necessary first step in exploring HSI and subsequently, we presented guidance to better design future research and applications that may work in a home setting.

The user trials completed by our participants only looked at individual gestures and not interaction tasks. It is important to therefore expand this work beyond gestures and to look at how combinations of interactions may impact upon overall experience of carrying out HSI. We investigated single instances of users tapping, dragging, holding, pinching, spreading, and swiping. We do not know how the experience of using gestures would change when put into context within an application (e.g. tapping form choices and swiping between application pages).

Our participants were highly educated and had a mean age of ~28 years old. We must take care in generalising our results, the omission of one older participant due to lack of study time illustrates this point well. We are confident that regardless of age, there will be differences in preference for interacting with material textures. While we did not see many significant differences in task completion time and surface material, it might differ for much older and younger participants.

CONCLUSION

Technology that enables Household Surface Interaction (HSI) in our homes has mainly focused on the development of hardware capable of facilitating user tasks. However, challenges and opportunities exist when examining touch gestures carried out on several different surface materials. It is therefore important to consider the material properties of a surface when creating applications for use in a given context. To address this problem, we carried out a mixed methods user study examining HSI with nine household surfaces using five common touch gestures (tap, press, swipe, drag, and pinch). We found that HSI enhances the user experience of interaction, but that care is needed when pairing touch gestures with surface materials. We present design considerations based on surface characteristics and the challenges that users perceive they may have when implementing interactive surfaces within their homes.

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