Imprint: Exploring Interaction with Dynamic Interiors

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Abstract

Interactive architecture and interiors present exciting new opportunities for customizable and adaptable spaces, but few explorations into this topic attempt to understand how these spaces should be designed for interactions. This work presents Imprint, a prototype for an Interactive Wall that would exist inside of a dynamic living space, that was designed and built with the intention of testing out different models of interaction. Participants gave feedback on two iterations of Imprint. Based on the observations of an interaction trial and discussions, each interaction mode was found to fit better with certain contexts of an interactive surface. The connections between the interaction modes and contexts help build a greater understanding of interacting with various dynamic spaces, which can be used in designing new kinds of interactive interiors that users can easily adapt to.

Acknowledgements

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Contents

List of Figures

List of Tables

1. Introduction

The relationship between a person and their home is ever-changing, but always crucial. We constantly try to customize our living spaces, decorating our walls with posters, art, and mementos of the past. Yet barring permanently altering the space through great effort and cost, we have few ways to easily and instantly change the form of our homes when needed—whether that means adding a place to hold a few more books, or adding a new surface to work on for the day.

While many have conceptualized homes of the future with large wall-displays that can be interacted with like a screen [13, 14, 8], the idea of a home physically adapting to the inhabitants has not been treated in the same practical sense. Most works that focus on "Interactive Architecture"—architecture that reacts to user input with noticeable feedback—develop very theoretical or art-based examples that do not offer much to actual implementations of such systems. There is no doubt that being able to interact with large displays would provide a great amount of functionality and customizability, but being able being able to dynamically change the form of one's space opens up a number of opportunities that could never be achieved by 2D manipulation alone.

The goal of my work is to explore interaction with dynamic architecture and interiors through the creation and iteration of Imprint, an Interactive Wall prototype. I aim to get an understanding of how the specific ways in which a user can interact with a dynamic environment can affect their connection with it and their feelings of control and comfort with it.

Few other explorations on this subject actually delve into how the interaction design of interactive architecture is received by users in a way that attempts to improve upon it. Most also ignore how the context of the piece should affect its interaction design, or the ways in which people could adapt to using interactive spaces in their daily life. The Imprint prototypes were made specifically to test and explore interactions with a dynamic space in a practical way, based off of use cases participants described from their daily lives (or even some use cases that were exciting to them, if not an average occurrence). In doing so, connections were made and discussed between the users' use cases and the feedback gathered on different interaction modes.

My work shows a qualitative exploration of users' interaction with a small prototype made for an interactive interior space, and the observations made have implications for the broader question of how to approach designing a physically dynamic interior interface depending on its context.

2. Related Work

As new technologies have emerged that allow computers to sense input and changes in the environment, new ideas in how they can be used to affect buildings and interiors have emerged. The ideas of Interactive and Responsive Architecture seem to have formed entirely based on emerging technologies as opposed to any crucial need [12]. Yet even if humanity has lived with static homes for most of our existence, there are opportunities to fulfill specific "needs" or desires with interactive spaces, whether that means having shade from rain (but not from a blue sky) or being able to access videos easily in your shower [7, 8].

In the 1960s and '70s, the concept of Interactive Architecture was growing among the architecture community based on the idea that the future spatial needs of inhabitants could not be known by architects. Different ways of designing systems of Interactive Architecture were proposed.

One type of system was more anticipatory and automated, where sensors would interpret data and make changes to the space based on comparing the data to a specified instruction—similar to how thermostats work. In opposition to this model was a participatory solution, where users could modify an interface that represented the configuration of the space, a feedback system would let them know the impact of their modifications, and the building itself would then change based on the modifications. A hybridized model incorporating both approaches has been proposed as well [15].

In the design of the Imprint Interactive Wall, I have focused more on a participatory method based on the fact that this dynamic architecture would be at eye-level and body-level, meaning if the blocks move without the user being aware, it may be visually jarring or have actual physical consequences. While my main focus was on the participatory side, it may be beneficial to balance both methods with some subtle anticipatory features while mainly relying on direct manipulation.

2.1 Dynamic Environmental-Based Architecture

Certain dynamic architectures do not take input from a person, but instead use input from the environment. In some cases this is approached in a more artistic sense, as with the "Articulated Cloud" installation set up on a museum in Pittsburgh. Composed of thousands of small plastic squares that move and ripple with the wind, causing different reflections of the daylight, the installation appears as a "digital cloud". With this environmental input, the façade of the building appears dynamic to the observer [2].

Perhaps more practically, there have been other structures that respond to humidity levels, closing holes in the surface when the humidity gets too high to create a shelter from rain and opening back up when the humidity is low enough [7, 1]. These structures represent a more anticipatory approach to dynamic architecture that creates a system to allow conveniences for anyone under the structure without needing to involve them in the details. Of course they are also outdoor structures that do not exist in anyone's home, so the assumptions being made (high humidity means it is raining, which means the holes should close; low humidity means it is not raining, which means the holes should open) are delightful when they pan out correctly. But even if they happen to "malfunction" (the holes open too early, for instance), the trust lost from the people underneath is not as important considering they are in a space they were never in control of in the first place (i.e. a space not owned by them). And if they were given a more participatory design, it would be difficult to democratize such a system so that one person does not have full control—especially when the design is not based on any electronic control.

2.2 Interactive Architecture and Interiors

Interior interactive systems tend to work with more direct input, reacting to actions from the user as opposed to the environment, although sometimes adding some anticipatory features as well.

Certain interactive interiors are focused more on 2D interactions, though their reach can go beyond the location of the interface. The “Living wall”, for example, uses dynamic wallpaper that is embedded with circuitry and certain feedback features, like LEDs, as an interface. By interacting with the wallpaper, the entire ambiance of the room can be changed (by changing lighting or triggering sounds, for example). It also responds to movement in front of the wall, without direct manipulation. One can see such a system being a playful installation that allows exploration or as a platform for more necessary daily interactions (while still retaining some of that playfulness and exploration) [3].

Another example of an enhanced space that relies on 2D interaction is an interactive shower curtain that was proposed as a way to allow users to access media (music, news, karaoke, etc.) and feedback about their shower (temperature and length) as they wash [8].

Some interactive interior approaches attempt to cover both 2D and 3D features. A smart wall proposed by Farrow, et al., would be made of dynamic hexagonal blocks, described as “building blocks”, that could be reconfigured to create surfaces and dividers. The blocks could also change certain properties, such as their opacity (to allow for more or less privacy), and could be used as dynamic menus. The proposal focused more on the 2D menu interactions of the blocks than of any 3D interactions or movements, and it is unclear how the blocks could be rearranged [6].

The Openarch prototype is a design for a smart home that uses walls as displays of context-dependent information. Walls can too be used for video calling, video watching, and displaying dynamic wallpaper. But the home also takes advantage of the idea of flexible architecture, using movable partitions to allow the owner to decide how they want to form their space [14].

The Festo Interactive Wall, on the other hand, has no element of 2D interactions. This "wall" is more of an art installation than a practical demo, demonstrating high-level concepts of how dynamic architecture may interact with and even affect the person using it by becoming emotive itself. It is comprised of multiple tall wall-like structures that lean away from an approaching person, which also causes changes in the LED skin. Although not a practical approach towards an Interactive Architecture system to be used on an average day, the Festo wall attempts to allude to the growth of "individualization, personalization and customization" in modern society, concepts my own work takes to heart and actually allows for in new ways [10].

Depending on the goal of the wall deformation, different wall structures could be implemented to create specific manipulation results. Hyposurface was a project that created a highly interactive wall composed of connected flat triangles that could move in and out at the vertices, allowing for a great degree of precision when it came to the shape of the wall itself. Curves could be formed, and were used when creating waves that radiated from a person standing close to it. The demo itself was an interactive installation and the wall was programmed to respond to users' interaction or even existence with rapid, fleeting responses, so it is unclear if such a surface could be used to help satisfy a particular need [11].

The CityHome project proposes a home, most likely an apartment, where the small space is made entirely multi-purpose thanks to all the functional components being built into the walls. With simple gestures made in the air in front of a wall, one could "pull out" their bed or a dining room table. Not only does the space physically adapt, but the prototype also suggests that one could download "apps" for it that allow the space to be more personalized. The space itself does not feel very customizable outside of the app feature; all the components are pre-built and theoretically come together, limiting the choices of the inhabitant in how they want their bed or their table to look and feel, not to mention how they would want to position them. These kinds of freedoms are given up for convenience, which may be practical in a small living space [4].

The CityOffice prototype uses partitions to adapt the space to different forms of work; a large meeting versus many small groups of people working collaboratively, for example. The prototype includes some more moving parts: tables and chairs that can move around by themselves, tables fitted with extra surface space that can fold or unfold when needed, and printers and laptop-charging spots that roll over to you when you need them. The space truly attempts to understand and adapts to the needs of those inside its walls. What's more, it does so by moving the different components of the room to where they need to go. CityOffice, unlike some of the other interactive spaces discussed, has a large focus on interactive furniture and anticipatory objects that are connected to each other and the space itself to create an entirely dynamic environment [5].

2.3 Interactive Furniture

Many explorations in different types of interaction and dynamic forms have occurred not in spaces but in the furniture inside those spaces. The TRANSFORM table, for instance, redefines the table as a piece that reacts to the presence and movements of a person. The topology can be altered, in one case, by "drawing" in the air above the table where the pins should rise, and in another case it can change in anticipatory way based on previous preferences (the creation of which theoretically would have occurred through some form of more direct manipulation). The table is both practical and has emotional and aesthetic elements. Although it is furniture, as a centerpiece it affects the entire space it is in [16].

Another example is a shape-changing bench that was designed specifically as a way to approach understanding how people experience shape-changing furniture. Users, unless they had observed someone else using the bench, would have no idea of how it worked or even that it was shape-changing until they sat on it. For some, this was not unwelcome, but multiple people became uncomfortable or even afraid when it began to move. One user is quoted as saying that, "'...when it moved, it was like an underlying feeling of unease suffused my body'" [9]. This reinforces the idea that designing dynamic changes that the user does not understand or expect may not be a good solution, although in this case it is likely that the experience of unease was magnified because such changes affected the body directly.

3. Design Considerations

When designing Imprint, an interactive wall prototype meant for an interior space, I partitioned my design considerations in three distinct areas: the surface, the device feedback, and the interaction.

3.1 Surface

Walls inside living spaces (besides their core role of holding up the shelter and delineating the indoor from the outdoor) tend to be used for décor and as a canvas for shelving or displays. Since Imprint could easily share wall space with displays or other types of smart walls, I felt that those 2D surfaces or devices were not necessary in my design. I focused instead on 3D designs and interactions. If the surface should be able to support shelving and surfaces, it needs to be able to form flat tops. Using "building blocks" as the main component, then, made the most sense—a grid of them is very customizable, and they create stable surfaces. Previous works reflect this design decision: the TRANSFORM table uses rectangular pins that are very customizable and have a flat top [16], and Farrow's smart wall with hexagonal blocks was designed with modularity in mind as well as the "building block" idea [6].

Because walls are canvases for decoration in a home, they have an aesthetic responsibility to both look sufficiently good and also be rather simple. The technology should not require a blatant setup; indeed, "the most profound technologies are those that disappear" [17]. If a more pronounced surface design were used, the owner's opinion of it would be more likely to change over time, making it more likely for the design to become distasteful to them. However, it is impossible to completely account for a person's change in taste, desire, or need over time—that is what interactive architecture hopes to provide for, after all—and so conceptually I would propose that any interactive interior have a changeable cover material. Although this is not included in my built prototype, it is important to recognize that a person may want to change the look of an interactive wall just as they may want to paint their static walls. For instance, as in Figure 3.1, a person may want the blocks to have clean-looking tiles or dark wood embedded in their wall.

Figure 3.1: 3D renders of Imprint in two different contexts. On the left, the blocks have white tiles as faces; on the right, the blocks have wood as faces, and are set into the wall above the desk so that they just seem to be a static wall. The concept of Imprint would allow for these style decisions to be made on the block face, and is easily integrated into the interior design.

Based on these considerations, the general design of Imprint is that of a grid of blocks with simple faces that do not disrupt the inhabitant's own style goals, but instead help to enhance them.

3.2 Device Feedback

Before an interaction occurs, the user should have an idea of how to approach using it. In many of the interactive pieces discussed, this was discovered through exploration, going up to the piece and seeing a response [10, 11, 16]. In a living space, although it is possible the inhabitant is the one who put the interactive piece into the house—and so likely has an idea of how to use it—it is just as plausible that the house already had the piece in it. Therefore, knowing that a section of the wall is interactive and knowing how that section should be interacted with is a difficult design to achieve while keeping the simplicity of a canvas.

In the design of Imprint, because the prototypes were designed to test interaction and not to actually be placed in a living space, signifiers of how the wall should be interacted with were not built in. They were, however, considered in the design. To preserve the style of the blocks as blank canvases, motion was decided as a better signifier than any physical marking. For instance, when a person is detected in front of the wall, it makes subtle motions in unused blocks (i.e. blocks that are not extended or that have anything in front of them), making a wave or a flurry of small movements to indicate that the wall is in a way "alive" and can take input. This is of course just one of many possible ways interactivity could be signaled.

3.3 Interaction

The focus of Imprint is to gain a greater understanding of how natural body movements can be used to interact with dynamic architecture in the most seamless way. After all, how could we even begin to test the usefulness of tangible interaction systems such as this if the user has a hard time controlling them? And what would be lost in a study if the emotional and physical connection between user and device is neglected? It was for these reasons that physical interaction became the focus of this work. Deciding on this type of motion-based interaction was dependent on certain design considerations.

As discussed multiple times previously, an important decision was to be made between making Imprint an anticipatory or automated device that moved without direct input, making Imprint a participatory device that only responded to direct input, or making a hybridized version [15]. In the case of the shape-changing bench, while technically it responded to direct input, the input was unknown to the users until after it occurred. The response that then played out (i.e. the change in shape of the bench while the user sat on it) was, therefore, unexpected and at times very unwelcome [9]. When based inside of a living space, if a key physical piece changes its shape without a reason clear to or controlled by the inhabitant, as in the case of the bench or of the environmentally-motivated structures [7, 1], the inhabitant may no longer feel in control of their space. In the space that a person should be able to feel the most comfortable and in control—their own home—it is important to make sure the design does not get in the way of that comfort or control. A balance may be struck, as demonstrated by the TRANSFORM table [16], where certain assumptions are made that allow for the convenience of anticipatory design without being too intrusive or too unplanned. It may be nice, then, if when holding an object like a book near the wall, the blocks directly underneath extend to form a shelf. It may be less welcome for the wall to detect that you are holding a drink and have blocks extend along the side as you pass that could act as a table just in case you wanted to set the drink down. This latter example could feel too intrusive, suggesting an action that you may never have intended or wanted to perform.

4. Imprint: The Interactive Wall

I have constructed and iterated on Imprint, a prototype of an Interactive Wall that can form new surfaces through simple interactions. Imprint is composed of blocks (designed to be embedded in a wall) that can move in and out linearly based on sensed movements, allowing the user to create shelves, simple work surfaces, or even words or pictures.

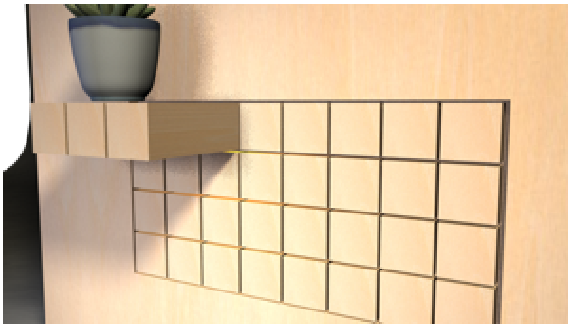
4.1 Imprint Prototypes

Two prototypes were created in the iteration process of Imprint. The first prototype was built to test the core functionality of the blocks and gather initial feedback, and the second was built to demonstrate and test the more refined interaction models. While gaining feedback about the first prototype, certain interaction methods were found not to be worthwhile, and the ones that were found to be worthwhile or that came up multiple times in feedback were explored in the second prototype.

4.2 Hardware

Both prototypes shared a general hardware design. The blocks for each prototype were set up in a grid style with a supporting frame.

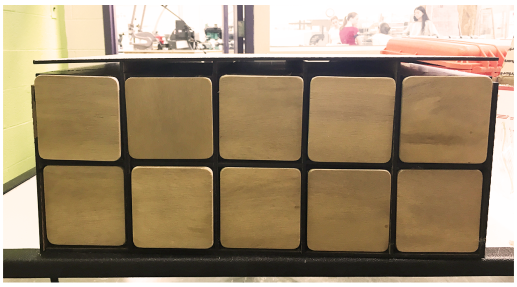
Each block had a dedicated servo set up with a gear rack and pinion (which allow for linear motion), and a capacitive sensor made of foil attached to the block face for interaction.



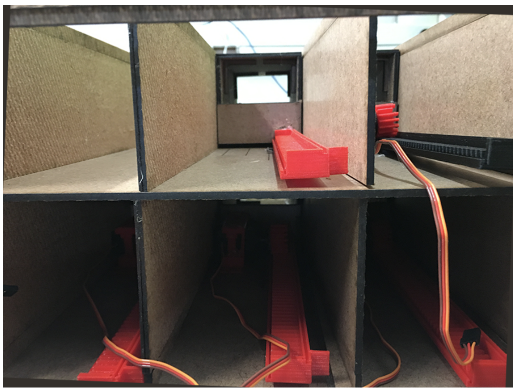
(a) The block grid inset into a wooden ”wall”, with three blocks extended to create a ledge and the rest at default position.

(b) Additional blocks partially extended on the second and bottom row.

Figure 4.1: A 3D render of the basic setup of Imprint.



(a) The front block faces of an Imprint prototype



(b) The grid as seen from the back of the prototype

Figure 4.2: An Imprint prototype from front and back

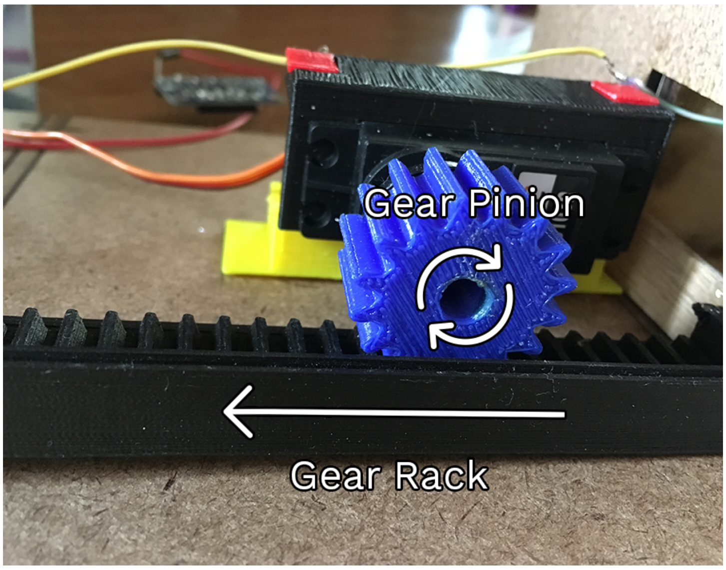


Figure 4.3: The gear pinion turns in a circular motion, pushing the rack linearly.

Capacitive sensing allows for human touch to be sensed without any force. Capacitive sensors can also stand in as cheap proximity sensors, but there is a tradeoff to be made in that the greater the distance it can detect, the slower the sensor is.

Figure 4.4: The capacitive sensor, made of a square of foil, is set under a thin wooden block face.

Both the servos and sensor were hooked up to an Arduino Mega. For each prototype a program was made to interpret the input of each sensor and, in response, send instructions to the servos to rotate according to the direction the block should move.

Each prototype share this core hardware design, but the implementations differed, partially due to the change in interaction focus.

4.3 Interaction Modes

To help direct the creation and testing of interactions, interaction modes were defined as specific options in the way Imprint could be interacted with. These interactions occur in two different states: the selection state, during which the user chooses which blocks to edit, and the edit state, during which the blocks that were chosen move to some extension position, possibly depending on where the user directs them to go.

The main dimension of the modes that is important when editing the blocks is whether the blocks are manually edited, meaning the user can manually edit the extrusion length of the block, or if they are automated, meaning they automatically extend the full length. These modes are based on the concern of how much control the user should have or need when deciding how far out the blocks extrude.

If being able to control this length is simple and quick, then it seems to have more opportunity for different types of uses as well as for playfulness and exploration. The goal was to make this action feel as simple as possible, but also to keep the charm of being able to control an object—in this case, the blocks—without needing to use physical force as they move. Instead the user seems to be performing a magical feat, like using "the force" from Star Wars. This effect is somewhat lost in the auto mode, where the blocks and user are not engaged in the ongoing feedback loop that creates the sensation of complete control. However, the user may not need the precision of edit mode unless the block length is great (which the built prototypes do not demonstrate). In these cases, the daily use of an interactive interior such as this probably does not need a manual mode.

Touch was another concern, and may be a factor in the physical connection formed between user and device. Using touch can be more precise when selecting the block, allowing the user to drag a finger or hand across multiple to select exactly those blocks. However, if the user kept physical contact while moving and editing them it would likely cause more difficulty, even if it could allow for a more direct

Table 4.1: **Selection State**

Touch	Touch block to add to selection; could be achieved by dragging hand or fingers across, or by tapping them.
Touchless	Hold hand(s) in front of blocks to select; can move hands across to select multiple.

Describes the state during which blocks are selected by the user to be edited. The dimension this was tested on was *touch* versus *touchless*.

Table 4.2: **Edit State**

Manual	Touch	Keep light contact with block to extend selected block group; increase pressure to move blocks back in.
Manual	Touchless	Move hand away to extend selected blocks out; move hand towards device to move blocks in.
Auto	(Touchless)	All selected blocks automatically extend fully (if not yet extended) or slide back in (if already extended).

Describes the state during which blocks are edited by the user to the right extension length. The dimensions this was tested on were *manual* versus *auto*, and in the context of *manual* editing, it was tested with *touch* versus *touchless*.

feedback loop between user and block during motion. The manual touch mode was deemed least likely to be beneficial. Note that there are many ways to implement the core idea of each mode, and the implementations for each was chosen as a representative to help get qualitative feedback for each category. In addition, the manual versus auto concern could also have been explored while selecting blocks (for instance, when holding an object in front of the wall, an *auto touchless* selection mode may mean the blocks directly underneath the object extrude to form a shelf). This was not in the scope of the prototypes, and so was not explored in this work.

4.4 First Prototype

The first Imprint prototype was built to test core functionality and interactions. The feedback received when introducing it helped develop the interaction approach, especially in guiding the interaction design to focus more on touchless interactions.

This prototype was a 2x2 block (four blocks in total) version of Imprint. Each block measures 1.5' x 1.5' x 8', with an extension length of about 7.5'. The capacitive sensors were set up using the MPR121 breakout board for Arduino. Although helpful for using multiple capacitive sensors at the same time, the board actually limited their range such that each sensor could only detect a hand a up to an inch or two away, resulting in an interaction system that was much harder to get a feel for (unless you were simply using touch) even after lengthy use.

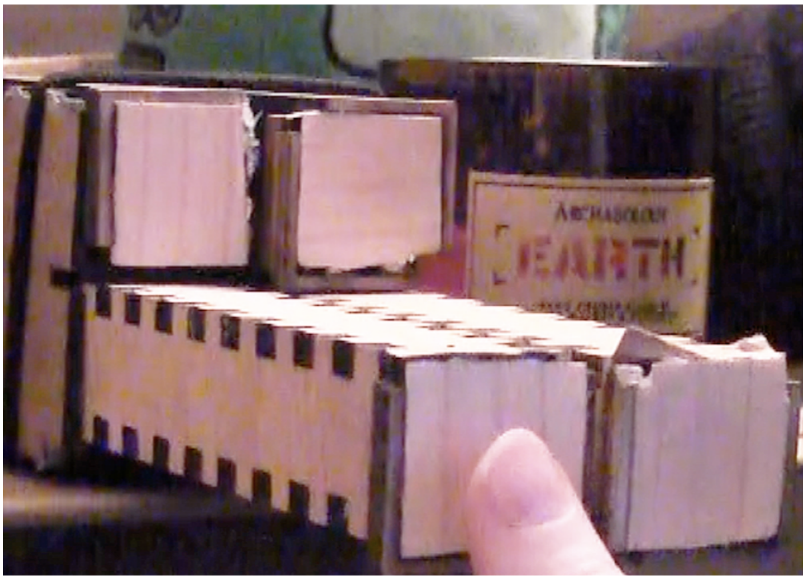


Figure 4.5: The first prototype was smaller, but included early versions of both the *auto* and *manual* modes.

This prototype included an *auto* mode and a *manual* mode. The *manual* mode was split into touch and touchless versions. All modes required the user to touch the blocks they wanted to select and move. In *auto* mode, the user would touch a block and it would extend fully in response. Any number of blocks could be selected at a time. If a block had been extended previously, another touch would cause it to slide back into the "wall". In *manual touchless* mode, the user would first drag their finger(s) across blocks to select them, then would move their fingers away from the device to pull blocks out, or towards the device to "push" them in. In *manual touch* mode, the user would select blocks in the same way, then continue to touch the final block lightly to move the selected blocks out (after a short period where the device waited for any additional selections), or touch more firmly to move the selected blocks in.

4.4.1 Feedback

I received feedback from people in the tangible interaction community during a conference demonstration, as well as from three undergraduate students who interacted with the device itself. General feedback was positive about the concept, with multiple people commenting that they could use it in their daily life, and a few just wanting to play with it. Those that got to interface with the device commented on the different modes of interaction.

When the *manual touch* mode was brought up, participants commented even without trying the mode that it would be difficult to use, an expected response. One person noted that if they were touching the block at all while editing distance, it would be easier if they were touching the side of a block, as that seemed to be more natural for changing the length (that same participant noted that this would not integrate well with the initial selection of the block when it was flush with the wall). Using the *manual touch* mode proved to be unwieldy in practice.

Some participants and commenters preferred the idea of the *auto* mode initiated through touchless interactions; they seemed to just select the blocks and use them without any additional work. Some seemed more interested in the *manual touchless* interactions, especially those who seemed to want precision. One participant who preferred the manual approach even discussed some interaction models that could allow the blocks to be moved to very exacting measured lengths. The *auto touch* mode was not specifically criticized, but was not given much attention.

4.5 Second Prototype

Feedback on the first prototype encouraged a focus on the touchless interactions, and two devices were built in the second prototype stage to focus on these.

One much smaller device holding only one block was built to test the manual touchless mode, where users could move the single block with the proximity of their hand. The capacitive sensor for the block used increased resistance to allow for greater proximity to be detected–up to about eight inches was possible without the device slowing down too much.

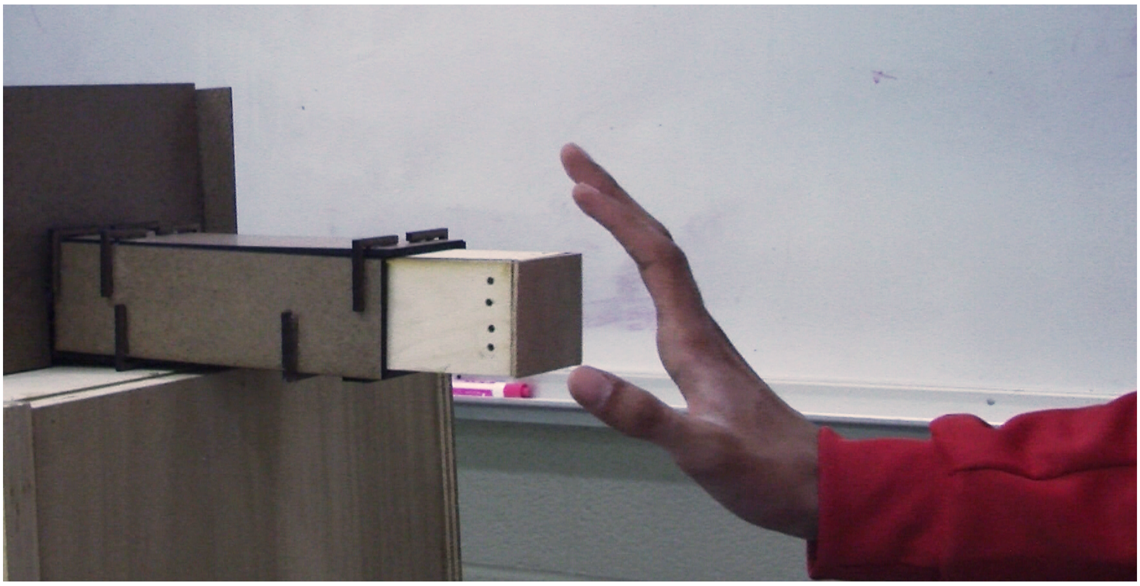


Figure 4.6: The one-block device made to test out *manual* mode.

A larger prototype with multiple blocks was built to explore the auto modes. This version of Imprint was a 5x2 block (ten blocks in total) matrix. The capacitive sensors also had increased resistance compared to the first prototype, but lower than the one-block device. Because this device had many more blocks than the one-block device, the additive effect of the increased resistance would have resulted in a much slower device. This device is a greater representative of the overall concept of Imprint, but this limitation made it difficult for it to include all interaction modes.

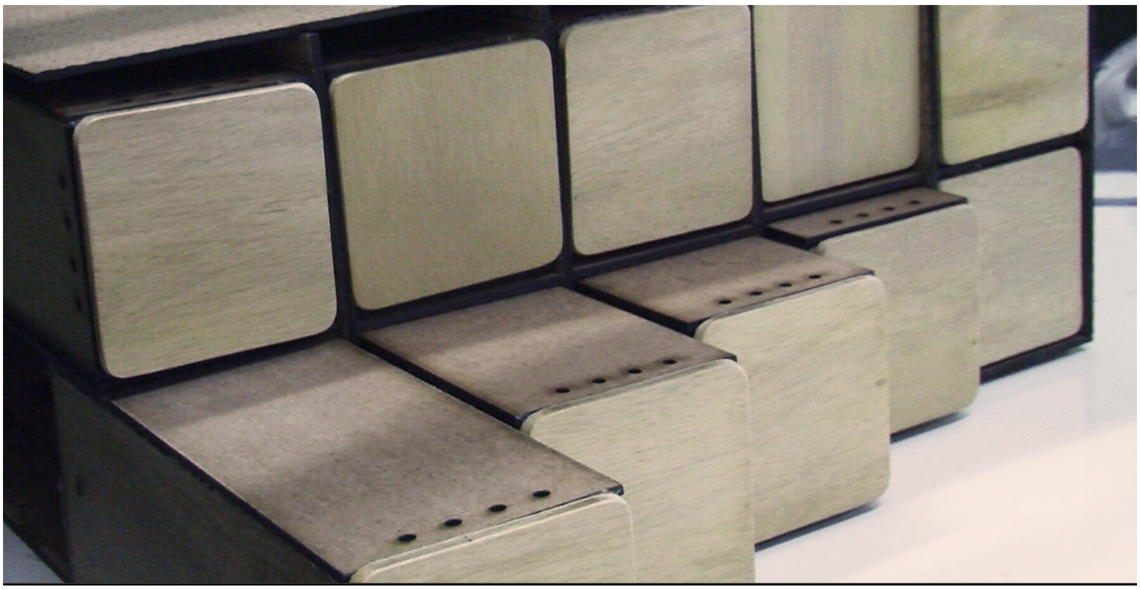


Figure 4.7: The ten-block device made to test out *auto* mode.

As the capacitive sensor could get a much greater distance in the second prototype, it was necessary to smooth the sensor input and form an approximation model for understanding the proximity of a body part from a sensor.

An Exponential Moving Average (EMA) was used to smooth the input of the sensor (see 4.9). An approximating linear equation was found from ten trials where a hand was moved in from a distance of 12 inches, and then tweaked based on real-time feedback. he trial was performed once and the numbers were then iterated on with repeated use of the device, resulting in the use of a 1 unit difference between two readings equates to about .003 inches. This is not an exact measurement, but was useful in finding the approximate distance of a hand.

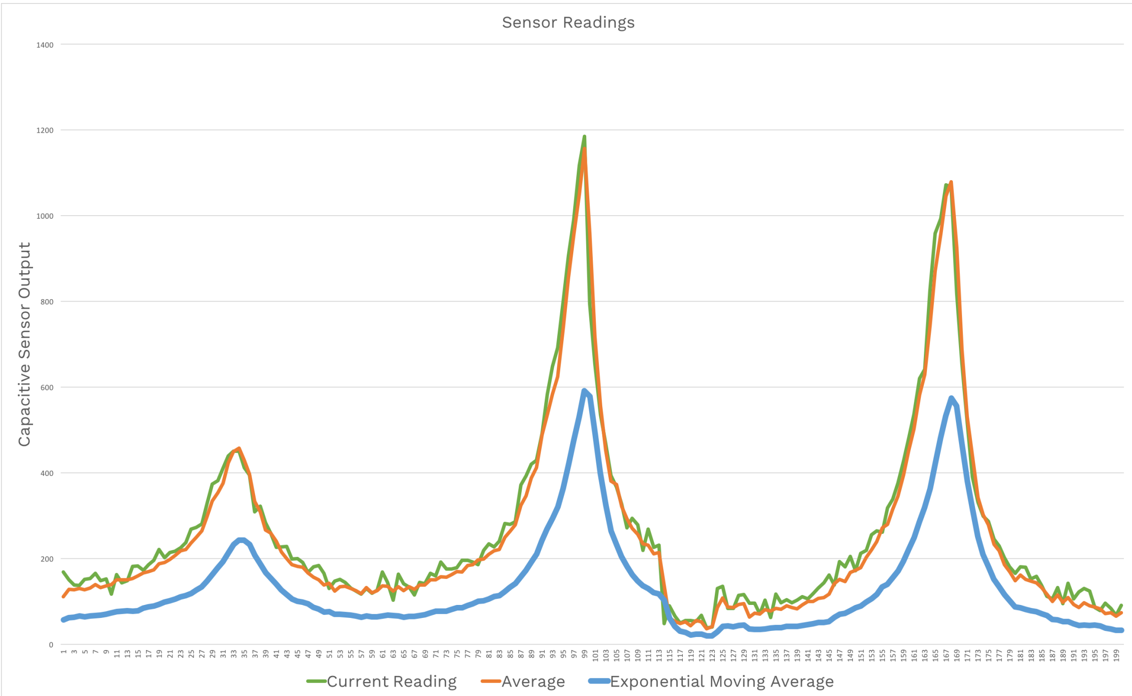


Figure 4.8: Capacitive sensor output over readings (about five readings occurred per second) as a hand moved closer and farther from the sensor, where the peaks are when the hand is closest. The raw reading and an average of four readings are noisy, while the Exponential Moving Average line below the other two is smoothed and has a relatively quick response time.

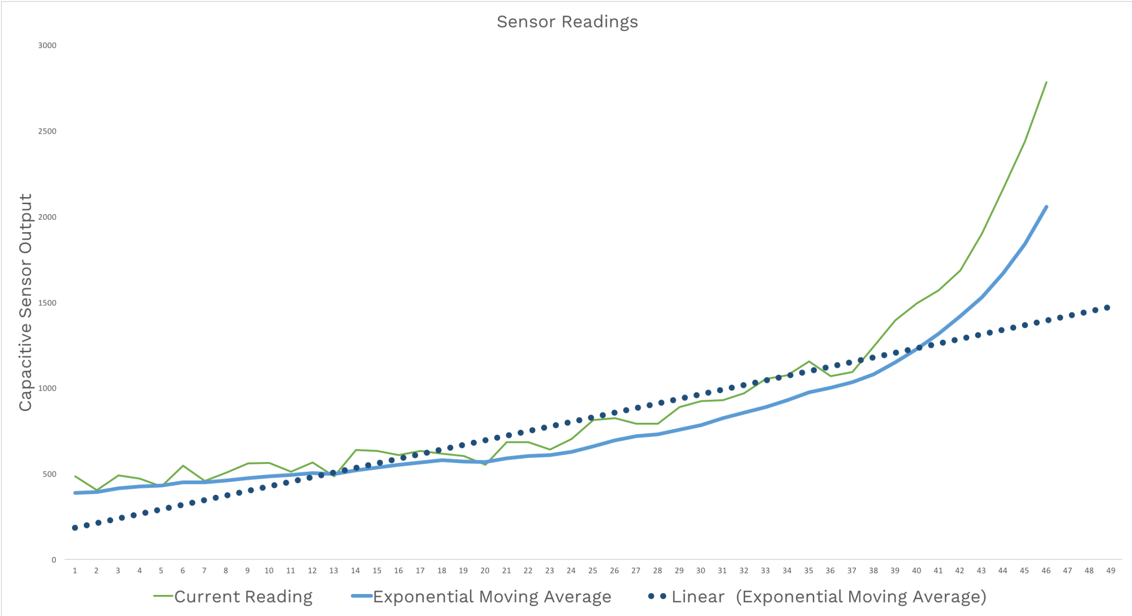


Figure 4.9: Capacitive sensor output over readings as a hand moved closer to the sensor from 12 inches away. The green line represents the raw reading from the capacitive sensor, and the blue line represents the smoothed value from the EMA. A linear function is shown based on the EMA with the dotted blue line.

4.5.1 Feedback

To gather feedback on this prototype, which was geared even more towards testing the specific interaction modes, I set up a small interaction trial. First, the participants were asked about how they would use an interactive wall (without explaining the details of Imprint's design), then they tried out or viewed the interaction modes, and finally we discussed interaction modes in terms of use cases and contexts.

There were 6 participants who performed the actual interaction trial: all were undergraduate students, ages 19-23, 2 female and 4 male. All participants were recruited from the workspace where the prototype was created or were separate volunteers. The trial took about 15-20 minutes, depending on how much the participant wanted to discuss. 9 participants, including the 6 who performed the trials, gave feedback on the use cases of the device, which informed feedback on the interaction itself. These 9 included both undergraduate and graduate students, ages

19-24, with 3 female and 5 males.

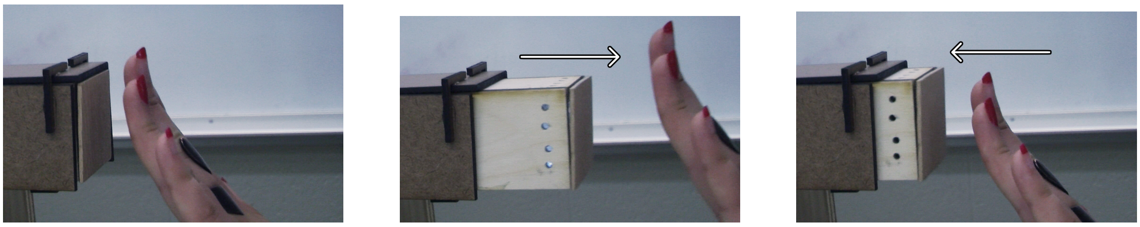
The small trial began by discussing use cases of the core concept of Imprint. They were asked what they could see using an interactive wall for (explained as a wall that they could edit to make any part extrude, allowing for surfaces or 3D forms to emerge from the wall).

Most responses were situations that one could see happening as an average occurrence, such as using the dynamic surfaces to organize a desk or workspace, using blocks to prop up a phone, making tables and chairs or benches, and shelves for decor, books, keys, etc.

About half of the participants also came up with purposes that fit more with a performance or entertainment than for average daily tasks. Multiple brought up that it would be interesting for the blocks to be choreographed or used in real-time with a performer.

Some participants expanded on the concept of the wall to include blocks without tops that acted as drawers, where tools could be kept (one participant brought up that this would be good for sanitized objects, perhaps in a hospital). Some also adapted the concept to work vertically, more in the style of the TRANSFORM table [16] (for modeling buildings or cities, for example) or an interactive floor (for making an obstacle course). And a few added additional functions, such as having the dynamic space react to the number of people in it, or using the motion of the blocks to move objects. These changes to the concept could be interesting to future prototypes or designs, but are not especially relevant to the interaction testing itself. Still, the fact that so many different use cases came out of describing the core concept of the wall shows how a general design like that of Imprint could be applied in many different areas. The interaction design is an important aspect of contextualizing the piece and catering to the audience of that context.

Participants were then able to interact with the device that used the *manual* edit mode. To do so, they simply had to move a hand to a few inches from the block face's surface and then start moving their hand. From there they could move their hand backwards and forwards in any way they wanted, allowing them to get a feel



(a) User moves hand to select block

(b) User moves hand away to extend block

(c) User moves hand in to slide block in

Figure 4.10: Interaction with single-block device using *manual* edit mode

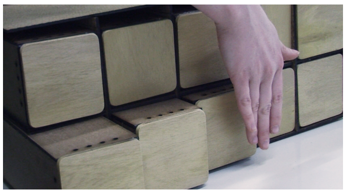
for the device.

In observing the actions of the participants, a few moved too fast–one even repeatedly attempted to use a more gestural control, pulling their hand away quickly while forming almost a fist to try and make the block come out. Some thought the device might not work well at first and moved so slowly that the block would not actually reflect a change. Because of some jitter in the capacitive sensing, moving too slowly would cause the block to move back and forwards slightly, which was an interrupt in the flow to the user. However, most got used to the interaction quickly, and enjoyed how the natural movement caused the block to move as well.

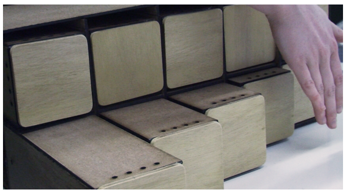
The participants gave feedback on the interaction as they performed the trial. Many felt that the interaction felt ”great”, ”natural”, and ”fun” while they were moving their hand. One even mentioned that it felt like using the Force in Star Wars. Clearly the interaction made an exciting emotional connection for multiple participants. Most also said they found it easy to get a feel for, though it was at times disrupted by the jitter and a slight lag due to capacitive sensor smoothing (as well as the capacitive sensor losing the hand when it moved too far away, although the lag would make it move out for a second after this movement anyway, helping to compensate). The interaction itself performed fairly well, with technical problems being the main reason for lack of comfort or control.

A few suggested that for a more intuitive flow, the precision could be lessened and the acceleration of the hand could be reflected more. The continuous servos

(a) User starts moving hand across blocks to select



(b) Blocks extend as they are selected



(c) Surface forms without editing

Figure 4.11: Users were presented with an interaction with the multi-block device using *auto* edit mode. They could not interact with it as the prototype was deemed too fragile.

would not allow for changes in speed, but future iterations could likely be improved by using acceleration much in the way computer cursors do, where the acceleration of the users finger or hand on the mouse is what affects the distance travelled by the cursor, not the actual distance travelled by the finger/hand. One participant called this a "broad strokes" approach, which balances the precision of the *manual* mode with the efficiency of the *auto* mode.

The participants were then asked how the *manual* mode would apply to the use cases they brought up, or any more they may have thought of, compared to a wall that used the *auto* mode, which they were shown an example of.

Participants felt that the *manual* mode, while fun to play with, would really only be needed for specific cases. Some suggested that using an *auto* mode where presets could automatically come out would work well–and this would require editing first (either using *manual* mode or some software) that could then be saved and reused. For the average task in a living or work space, this seemed to be the best hybrid option for the edit state of Imprint. The broad strokes interaction also was brought up a few times, but even those who brought that idea up thought that something more automatic would be better on a daily basis.

However, *manual* mode was preferred for use cases that required more active attention with the blocks–maybe while designing a model–or when the blocks are long, and you need them for different purposes (making a chair versus a table, for instance). Even some small tasks, like propping up a phone or open book on a shelf, could easily require different block extension lengths.

While talking about these interactions, participants also discussed how the edited blocks would be selected. They generally responded to the *touchless* selection with more interest than the *touch* selection, though most said *touch* selection would not be a particularly bad option. Not having to make contact just might be easier or more efficient, especially with your hands full, in which case it would be best if the wall could recognize which blocks should emerge based on the position of your hands.

One participant was concerned about possible errors in the *touchless* selection mode (e.g. an adjacent block senses your hand when it was not supposed to). This participant suggested a lock mechanism where you could lock any blocks that should not move and then use auto mode to make other blocks emerge

In most situations, auto mode was preferred, and touchless selection was the most popular. The combination of these two felt the most efficient and convenient.

5. Discussion

5.1 Anticipatory, Participatory, and Hybrid Design models

The ideas of anticipatory and participatory design models have come up in different forms in the design of Imprint. While this study assumed a more participatory approach in that the user had to interact with Imprint to cause a change, I tested how a manual approach to changing the surface would be accepted versus a more automated approach. Generally, participants enjoyed the manual approach but did not want to have to perform it daily, perhaps meaning the best design for most general applications–especially daily tasks–would allow for modifications that could then be reused. The modifications could be edited manually first, then saved so that the editing effort would not have to happen again for that creation. Based on feedback from participants in the interaction trial, a hybrid interaction style seems to be the ideal.

5.2 Designing Interactive Interiors

Context should, of course, always be crucial to the design process.

Although I designed Imprint to be a part of a living space, participants did not think of such limits when discussing possible use cases. Since the interactions presented occur on blocks that could be generalized to be a part of any 3D interactive surface, the feedback received could span across many contexts.

The design of interactive interiors or surfaces should be reflective of how precise the user needs to be, how efficiently the user needs to accomplish their task, and how reusable their modifications would be.

For instance, one participant thought the core idea of Imprint might be good for a rock climbing wall. One could imagine that to create foot- and hand-holds, precision in the length extended by a block (which in this case may be much smaller than any I made) could be very important, so a *manual* editing mode could be useful (and feel more natural and direct than creating the holds in software, especially since the creator could try them out in real-time). And although one certainly would not want to make this task slower slower, this would probably not be an average mindless task, so speed is not expected or necessarily even good. Still, to save time, they may also want to reuse types of holds, especially since they would be adding many of them–often with similar or identical shapes–over time.

Yet if an interactive wall was being placed in a kitchen, where someone may want to use it to hold tools or to organize their food preparation, speed is often crucial, while precision in the depth of your shelves is probably less important. One might want a few preset lengths, but not to the extent of needing manual edits every time.

5.3 Touchless Interaction with Dynamic Objects

Participants in the study found the actual practice of interacting with the block in manual touchless mode to be a great experience. This may in part be due to novelty, especially in how it relates to powers we associate with science fiction and fantasy, which is why the feedback gathered was positive but did not reflect it being useful for most situations. However, it certainly has its uses, especially when some degree of precision is important—and in these cases having a natural interaction with dynamic physical feedback would create an improved connection between the user and what they are creating.

If only some precision is needed, it is likely that an interaction that focuses on the acceleration of the user's hand as opposed to simply the direction (which the second Imprint prototype focused on) would yield an even more natural result, especially considering modern user's mental model of how other control interactions (e.g. using a mouse or trackpad) work. If this method truly feels more natural, it may even help with precision while reducing effort.

5.4 Limitations

Hardware limitations interrupted prototype functionality at times, and made it impossible to make a larger prototype using higher quality proximity sensing within my constraints (which was mainly the budget allocated). Capacitive sensors experience drift, so that calibrating the input to a baseline value was difficult and a running average had to be used. Even then, the values would sometimes change quickly without getting any input from a person, meaning the device would have to be restarted. Besides the technical problems, using capacitive sensing for such a device would be unwise considering all the ways the sensor can be triggered (any capacitive object will set it off), and unintended editing might occur if the designer is not careful. Capacitive sensing was used for the Imprint prototypes because it allowed the interaction modes to be tested cheaply and effectively.

Imprint was designed with a focus on exploring how a person may most naturally use their body to interact with a dynamic space in a practical way. The prototype was not specifically designed to be fitted inside of a wall, although the concept imagines that as the context of it. While it could be very useful built into a living space, there are certain limitations that I have not attempted to cover in my work. These limitations include extra costs, especially through the increased energy consumption needed, and the extra maintenance it would need. These are only a few barriers that stand as reasons why a system such as this is not worthwhile to most people. I also did not cover designing ways to stop unintended interactions, or other features that may be wanted or necessary in such a device (like the lock feature suggested by a participant, which was in the early designs but was not covered by the prototypes).

5.5 Future Work

In the future, to avoid some limitations described above, it would be useful to work with different hardware. Using actual proximity sensors would likely provide better input, and even a camera that could identify the x, y coordinates of a user's hand may be an interesting approach. Gestures could also be explored, especially in the case of choosing between presets.

There are many features that could be explored in the context of an interactive wall like Imprint. More automation could be included, such as being able to move an object using block motion across the wall, which could be useful in assistive health care or just for transporting objects in a small setting.

The blocks of Imprint could also become modular, such that a block on its own may have different functions (an LED block, a heating block to warm candles, drawers that were discussed by participants, etc.). Blocks could even become programmable, perhaps being hooked up to a platform like If This Then That (IFTT) which would allow for customized reactions to whatever input you provide. Perhaps one day, if your wall detects that it is rainy outside, the block that your umbrella hangs from will glow and extend out farther.

The possibilities feel limitless when it comes to exploring this area. Imprint is limited to one dimension of movement and one material, each of which could be the focus of studies on their own. Further work could help not just to expand the ideas of interactive architecture and interiors, but to help bring them into our daily lives.

6. Conclusion

Interactive architecture and interiors have been an exciting prospect that get more possible every year. However, most explorations into the area create interesting prototypes but do not discuss how users respond to their interaction designs, nor do they discuss practical approaches to designing interactions with dynamic spaces. This work set out to gain an understanding of how users would interact with and respond to dynamic spaces in a more generalized way by introducing Imprint, an "Interactive Wall".

Interaction modes were classified and a trial was run to observe how users understand and contextualize these modes. Improvements on the interactions were also discussed that could be useful for any future designs using touchless motion interaction. The trial showed a preference for convenience in most cases, but also how a more hybrid or manual model might be useful depending on the context. Because of the adaptability of Imprint's design, the feedback gathered could apply to different types of surfaces and uses, and thus has implications on the question of how dynamic and interactive spaces could be designed in the future.

With a moving and dynamic space, the users being able to easily adapt and feel comfortable and in control are paramount, and my observations have aimed to build an understanding of how this can be done. The prototypes of Imprint have connected emotionally with people who related the interaction to something magical, or from a SciFi story. More importantly, though, they are a step towards making informed design decisions for interactive interiors, where people feel that they can imprint exactly what they want onto their space.

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