Master Thesis Project

CapFloor: An Interactive Luminous Floor using Capacitive Sensing

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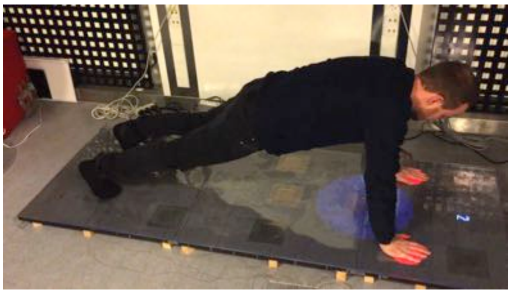
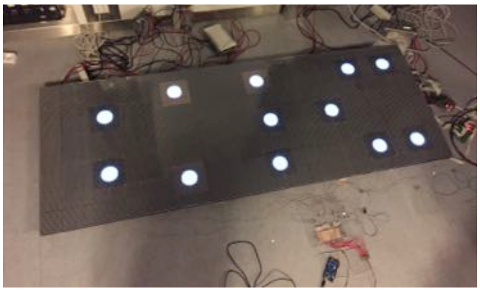
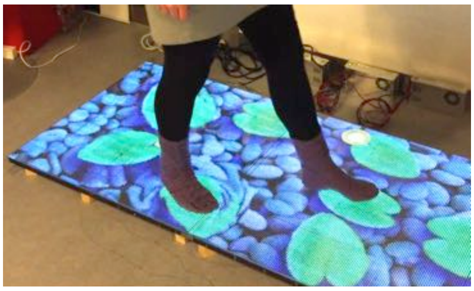

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Abstract

Interactive luminous floors have been designed with a great variety of constructions and technologies. Applied technologies includes camera-tracking, force-sensitive resistors and capacitive sensing. Although, despite the amount of research, neither one of the technologies used has proved to be a “one solution that fits all” applications. In this master thesis, we propose CapFloor, an interactive luminous floor consisting of LED-panels and a transparent capacitive sensing surface for tracking users in proximity or in contact.

Before reaching our final prototype, we have been through an iterative design process. This process included, contextual inquiries and exploration of different sensing technologies. Additionally, we investigate the core difficulties that exists when using capacitive sensing in a sensing surface that is placed directly on an LED-floor. Through the knowledge obtained during the design process, we provide an overview of the advantages and limitations concerning a selection of technologies applied in interactive floors. Finally, we show an example of how CapFloor can be used to guide and motivate users during their workout.

Acknowledgement

Firstly, we want to express our gratitude to Jörg Müller for the useful comments, remarks and guidance throughout this master thesis. Secondly, we want to thank Henrik Brink for feedback and comments during our writing.

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1. Introduction

With today's increased attention to a healthier and active lifestyle, the demand for fitness applications that can guide and monitor users' activities has increased. As a result, research and the advancement of new technologies has led to innovative products that motivate and assist people to achieve their exercise goals. In particular, the advancement of smartphones and more advanced sensors has assisted users, that otherwise would have problems getting started, staying motivated and keep track of their progress.

One area that has taken advantage of the technological progress is the field of exergames which has lead to products such as Wii Sport [1] and PlayStation Move [2]. So far, the majority of products developed has focused on either bodily movement in PC games or outdoor running, thus, muscle building and rehabilitation in fitness centers seems to have been neglected.

The exercises related to these users do in many instances occur on a yoga mat where sit-ups, pushups, and knee exercises can be conducted. Existing technologies that have proven to track and encourage user activity is interactive floors. Yet, combining these two areas has not been explored in a fitness environment, thus there is a potential for exploring how to successfully motivate and engage users in their workout through the use of interactive floors.

1.1 Motivation

Our reasons for combining sport and technology is based on our own personal interest in being active and exercising. Furthermore, we find our education in IT and Product Development helpful as a tool to discover interesting ways to motivate or guide people in their training or exercising - including interaction possibilities, the user experience, and environmental constraints in specific use-cases.

During this project, we have been affiliated with the CCI concern and their incubator: Stibo Accelerator [3]. They have also been interested in a solution that could be used in training surroundings to enhance the connection between their partners and the customers.

1.2 Design Process

Drawing inspiration from the research through design approach described by Zimmerman [4] we have been through an iterative process with several cycles.

We have investigated how to create an interactive floor for training purposes. In each cycle, research and experimentation has been conducted to gather information about sensor technology, floor requirements and user interaction.

The gathered knowledge has gradually caused a shift in our primary focus. Based on our prior motivation, the initial focus was to study people's workout, create an interactive floor and explore how visual feedback and guidance could enhance users' motivation and training results. We found that the technology best suited for this purpose was capacitive sensing. Through intensive experimentation and testing of the technology, the results gathered suggested that the general domain of interactive luminous floors could benefit from using this approach to eliminate some of the shortcomings of currently used technologies.

As a consequence, the focus shifted towards the capabilities of capacitive sensing as a tool for tracking and positioning of people on interactive luminous floors, and comparing it to other tracking technologies. Each cycle provided new insight and knowledge which accumulated into the contribution of this thesis.

An overview of the design process can be seen in figure 1. The figure shows in chronological order the design process from our initial brainstorm to our final prototype. As a result of our many iterations during the capacitive sensing exploration, this phase is illustrated with a double line.

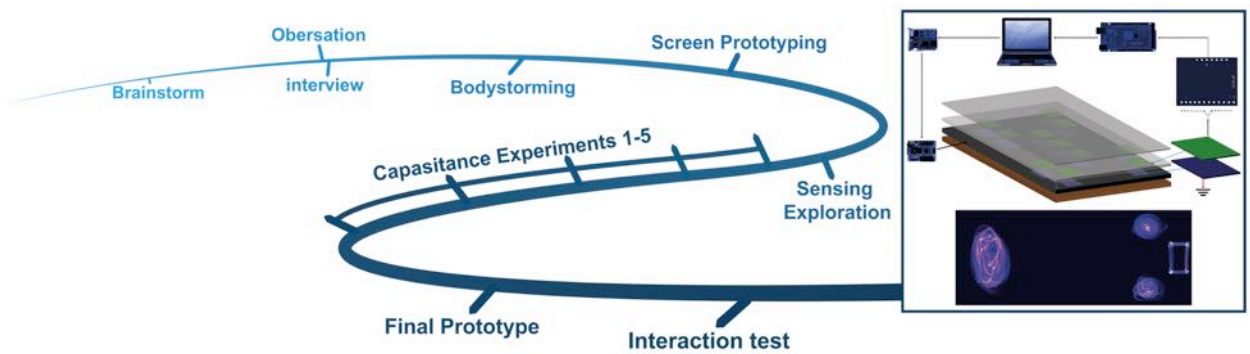


Figure 1: Design process overview.

1.3 Research Scope

The main goal of this thesis is to create an interactive floor which can act as a platform for training guidance and motivation in a gym environment. We explore the technological possibilities of using a LED-floor with a capacitive sensor as tracking method.

In addition, we explore the limitations and advantages of a selection of technologies that have been used to create digital floors in the past.

This thesis does not explore nor test whether or not the floor can motivate or guide people through their training. This thesis should also not be viewed as an exhaustive review or assessment on what technologies are best qualified to be used for building interactive floors in general.

1.4 Research Question

What are the potentials and limitations of using capacitive sensing on a LED-floor for an interactive sport guidance system? Subsequently, we want to explore:

- Is an interactive LED-floor appropriate for training guidance?
- Can capacitive sensing be used to track people during their workout session?
- Advantages and limitations of capacitive sensing in relation to other existing interactive floors

1.5 Learnings

Throughout this thesis, we have explored the capabilities capacitive sensing and how to use Optolite AgHT8 Conductive Film(OCF) as a transparent sensing electrode. In addition, we have investigated how to integrate the technology into an interactive luminous floor to provide guidance and feedback to users during their workout exercises.

The most important learnings from our design process are summarized in table 1.

Phase	Description	Results and learnings	Ch.
Contextual inquiry	We account for the process that resulted in identifying the requirements for the interactive floor.	The sensors needed to meet the following requirements: ● Be able to recognize users from a distance and their body postures ● Discern between distances ● Register multiple input simultaneously ● Not obstructive and transparent (should not cover LED's and users should be able to walk and make exercises on the floor) ● Robust to environmental changes ● Easy to install	4.1
Sensing Exploration	Explore which sensing technology that could fulfill the previously established requirements.	CapSense and MPR121 fulfills the following requirements: ● Sensors can be placed arbitrarily on the floor depending on where we want interaction. ● Enabling the construction of a transparent sensing system. ● Recognizes user's body posture ● Allows multiple inputs simultaneously ● Allows easy construction and implementation ● Individual placement of sensors	4.3-4.5
Experimenting with MPR121 and CapSense	Optimizing sensor stability and proximity sensing	The sensing technology applied to the final concept was MPR121. The choice was based on the following: ● System does not have to be recalibrated. ● Sense conductive objects reliably at a distance of 10 cm. ● Can use transparent OCF as an electrode. ● Sufficiently stable readings over time. ● Detect multiple inputs simultaneously. ● Its capability to filter out noise from the environment. ● Able to apply smaller electrodes without remarkable loss of proximity sensing, thereby increasing tracking resolution.	4.6 - 4.11
Test with multiple sensors	Investigation of possible interaction procedures and if implementing multiple sensors impacts the stability of sensor readings.	12 sensing electrodes were implemented for the investigation. The investigation led to the following learnings: • Placing sensors in the same circuit and close together, impacts sensor readings. • Wires running along the floor to the sensing electrodes can recognize small changes in capacitance when in direct touch with limbs. • We achieved a sufficiently reliable proximity sensing of 5 cm. • Enables swiping and tracking of high-level posture and human limbs. • Unable to differentiate between hands or feet.	
Evaluating final concept	In this section we test if and how CapFloor can provide guidance and feedback during various exercises. The test is conducted with 3 participants.	The main findings from the user-test includes: • Construction needs to be robust. • Sensors need to cover the entire floor. • Exercise programs needs to be made dynamic to fit body size. • Guidance and diversity in feedback increase motivation. In accordance to training exercises tested, we found: • Lunges, core and push-ups were most suitable. • Bridges and sit-ups need additional feedback. • Squat needs additional data else should be avoided. Even though these aspects impacted the user experience and use of CapFloor, the overall feedback from the participants was positive.	4.12

Table 1: Overview of learnings.

1.6 Thesis Structure

Chapter 2 will give an overview of relevant related research concerning interactive floors technologies. Chapter 3 will go through a small selection of related research in regards to the challenges in designing interactive training games. Chapter 4 describes the overall design process, from the initial exploration and observations to the development of the final prototype, which we call CapFloor. Furthermore, this chapter contains our experimentation with different capacitive sensing technologies and the final interaction test. Chapter 5 is a discussion of the advantages and limitations of capacitive sensing. Chapter 6 proposes future work for capacitive sensing floors. Finally, Chapter 7 concludes on the thesis project, research question and contribution.

1.7 Contribution

This thesis contributes to the HCI community with an alternative approach to create interactive luminous floors. We propose CapFloor, an interactive luminous floor consisting of LED-panels and a transparent capacitive sensing surface for tracking users in proximity or in contact.

Additionally, through knowledge obtained during the design process, we contribute with

1. An example of using interactive luminous floors for training guidance and motivation.
2. An exploration of capacitive sensing.
3. An overview of the advantages and limitations concerning a selection of technologies applied in interactive floors.

2. Interactive floors

In this chapter, we examine various technologies that have been used to create interactive floors. Specifically, we investigate:

- Vision-based tracking, foot-centric systems and capacitive sensing
- Their capabilities
- How they are utilized
- Their advantages and limitations

The findings are then applied to the requirements identified through our contextual inquiries. This comparison ultimately leads to the choice of technology that is best suited for guidance and feedback to users during their exercises in a fitness environment.

During the last decades, various technologies have been used to create interactive floors.
Applied technologies includes camera-tracking, foot-centric systems and optical or capacitive sensing. Despite the amount of research, neither one of the technologies used has proved to be a “one solution that fits all” applications. In each design, issues exist where the designer in one way or the other is forced to enter a compromise between environment, cost, interaction or display.
One of the most used and front edge technologies in commercialized products is camera-tracking, but research has also been done into the area of laser projectors [5] and light emitting photodiodes [6] to track and position of people walking on an interactive floor.
While the most well-known application might be interactive dance floors, interactive floors has also shown to support elderly in their daily life and as a tool for kinesthetic learning for children. The vast span of applications means different levels of requirements and therefore, one technology might be suitable to use over another depending on the application.

2.1 Camera-tracking

Camera-tracking is widely used and has recently entered the commercial domain with great success due to the development of Microsoft Kinect [7] and Motion Leap [8] In this section, we will describe how a series of interactive floors make use of camera-tracking to identify and keep track of a user's feet and body.

The advancement and research within camera-tracking in relation to interactive floors has resulted in two primary methods used to construct such a system: rear projected and front projected floors. To describe the advantages and limitations of these methods this section is divided into two parts. The first part contains work in relation to front projected floors, the second to rear projected floors.

2.1.1 Front-projected floors

Front projected floors typically use a projector for display and a camera for tracking. These are then attached to the ceiling above the interaction surface. To achieve a satisfying display with equal amount of brightness and best possible tracking, the projector and camera is placed in the ceiling in the center of the projected surface (figure 2).

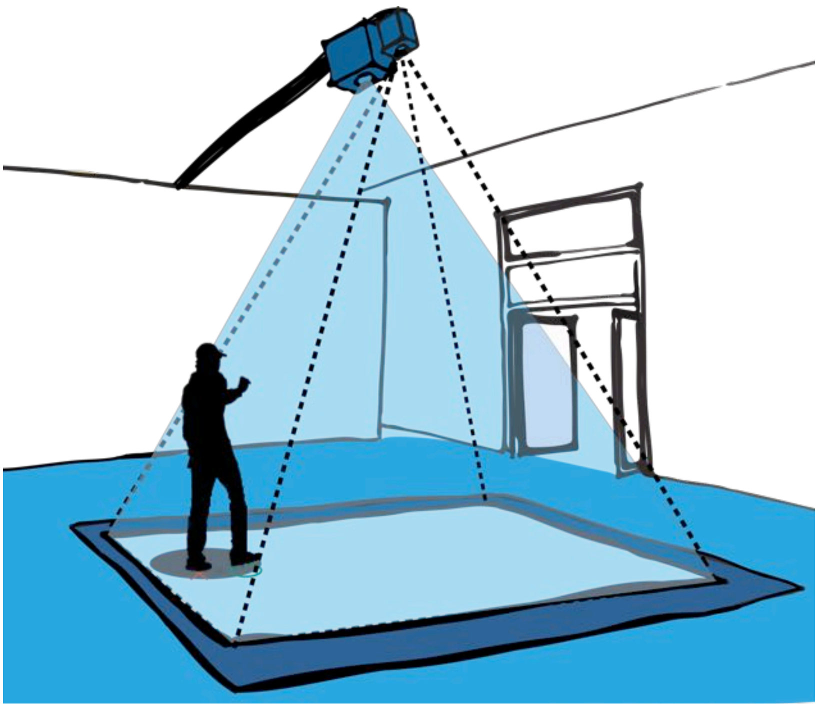


Figure 2: Example of front projection setup.

The IFloor [9] uses this procedure and mounts the projector and camera into the ceiling. This setup only requires a basic installation to work and by moving the technology to the ceiling away from the interaction, the system becomes more robust and less fragile from harsh user interaction. Although it requires minimal installation, the system demands a construction that can hold a projector and a camera, as well as a floor where there are no obstacles to obscure the projection and camera tracking. As a consequence, the environments where it can be properly installed is constrained to specific environments. IFloor for instance, is installed in a library, and public indoor spaces seems to fit this technology the most. Wizefloor [10], a commercial product that enhances children's activity, is typically used by schools or other daycare institutions where there is space and room for the product to be installed. Similar to the IFloor, Wizefloor deploys a projector and camera in the ceiling above the surface to enable tracking of users. Especially when dealing with interaction from kids, this construction makes the system much less vulnerable to repairs or broken circuits. The trade-off from tracking from above is that problems with people occluding both the display and tracking can occur. This issue is most noticeable when the user is standing just beneath the tracking camera, which causes a great area in the middle of the surface to be untrackable. It is also detectable when one or more users are walking around on the surface. While this is an issue belonging to this particular setup, by designing a graphical surface that affords interaction going from outside of the surface to the edge of display greatly decreases the risk for problems with occlusion and shadows.

Further problems include ambient light which can impact the tracking and quality of display which otherwise is in high resolution.

2.1.2 Rear-projected floors

Instead of designing interaction and afford user behaviors that avoids issues with tracking, rear projected floors are unaffected by these constraints. This is due to the fact that cameras and projectors has to be installed beneath the projected surface. Such a construction also requires a transparent and hazardous glass that can carry the weight and interactions of users (figure 3).

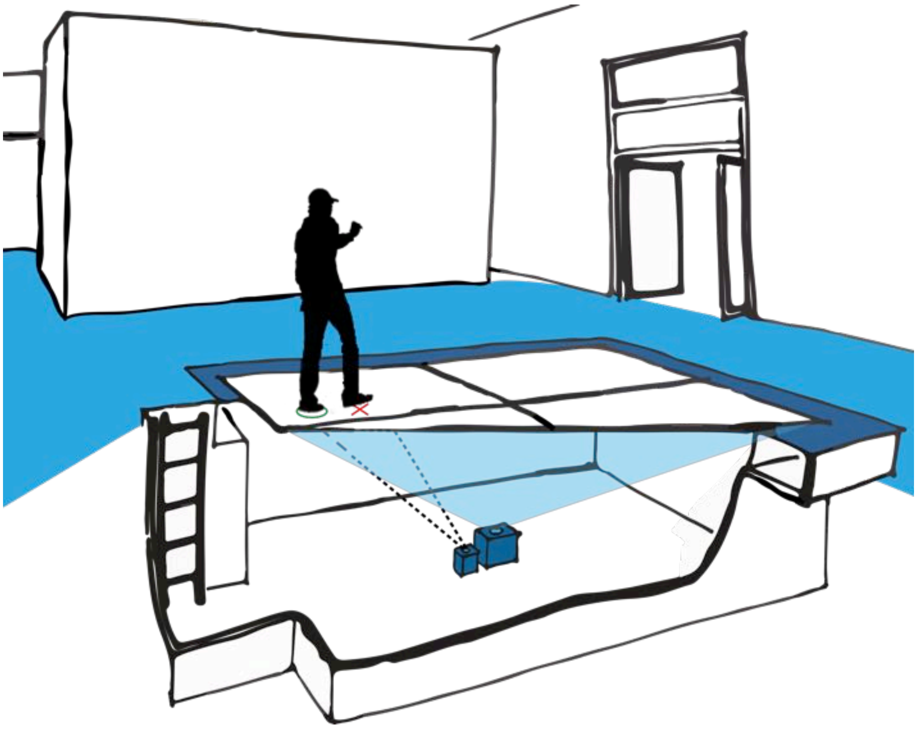


Figure 3: Example of back projection setup.

In IGamefloor [11], a precursor to the Wizefloor, the installation demanded a 3 meter deep hole, 4 projectors and 4 cameras. The cameras were placed next to the projectors from where they can track the silhouettes from users' limbs such as their hands and feet.

By placing the web-cameras and projectors beneath the projected surface they avoid the above mentioned problem of occluding the tracking or cast shadows on the display from the users themselves or other nearby people. As a consequence, they are able to track users with more precision and track multiple users at the same time without having areas where tracking is lost. Subsequently, they are able to only track where the user has direct contact with the floor, thereby removing the risk of false readings. The disadvantages with such an installation is that it requires a great amount of space and is expensive compared to front projected tracking. Additionally, as it was the case with front projection, ambient light can impact the stability of tracking people reliable.

Where the technology above enables only direct interaction with users' limbs, integrating Frustrated Total Internal Reflection (FTIR) increases the tracking resolution. Briefly explained, FTIR is based on infrared (IR) LED's that distributes their light into a transparent material, such as acrylic. The acrylic then retains the light inside, called FTIR. When a finger or foot touches the acrylic, it causes the light from that particular area to leave the material and then be registered by the camera [12].

In [13], they apply FTIR, along with camera-tracking to identify a user's feet. The high resolution of the camera registers the IR light and makes it possible to distinguish between different users based on shoe prints. Furthermore, the resolution makes it possible to calculate the pressure distribution of their body. This can be used to extract data about whether the person is standing, walking or sitting and give an approximation of their full body posture as well.

The project GravitySpace [14], applies the same concept of FTIR to recognize both people and objects. Their setup includes a projector that projects onto a surface from beneath. This makes it possible to interact with visualizations on the surface. In addition, they prove that it is possible that by solely using imprints from users, it is possible to recognize multiple activities such as users pose, collisions with furniture and a measurement of their full body posture. In [15] they use the same approach to track Kickables knobs. The users can then interact with the knobs to control a visual slider projected onto the surface to control for example sound volume. The high tracking resolution in the projects using FTIR enables tracking of pressure and direct touch. Under these circumstances this data can be used to infer a number of important aspects that can help users in their everyday life.

2.1.3 Summary - camera-tracking

To summarize, the advantages and disadvantages of using camera-tracking to create interactive floors depends highly on the technology used and the position of the camera. Combining rear projection camera-tracking with FTIR makes is possible to uniquely identify users based on the shoe imprint of their feet and is less susceptible to occlusion. As a consequence, users can interact more creatively without causing tracking issues.

In contrast, placing a camera above the projected surface, occlusion and shadows can potentially become a major problem, leading to limited interaction creativity. However, the construction and installation of such a system is much more feasible compared to rear projection systems.

What these two technologies have in common is that they both require a large area. Hence, they also have the possibility to impact or be impacted by the structural elements of the environment. In addition, for reliable tracking, they are only able to recognize objects in direct contact with the floor. An overview of front and rear projection is provided in table 2.

	Construction	Interaction	Constraints	Advantages
Front-projection	• Projector for display. • camera for tracking. • Attaching projector and camera to a ceiling.	• Touch or hovering over surface.	• Occlusion. • Shadows. • Multiple users. • Ambient light. • Intrusion on privacy. • needs a specific environment to work.	• Reliable technology. • Easy construction. • High display resolution.
Rear projection - in combination with FTIR	• Projector for display. • Camera (IR) for tracking. • Transparent surface. • Positioning of projector and camera beneath interactive surface.	• Direct touch. • Body posture. • Objects. • Uniquely identify users . • Body postures. • Recognize objects.	• Intrusion on privacy. • High cost. • Extensive construction. • Ambient light sources. • Only recognize direct contact with the floor.	• No occlusion. • No shadows. • High tracking resolution. • High display resolution.

Table 2: Properties of camera-tracking used in interactive floors.

2.2 Foot-centric systems

A different procedure to create interactive floors can be accomplished by using force-sensitive resistors (FSR). In comparison to camera-tracking, the procedure of FSR demands another setup with a new set of pros and cons. The construction implements a surface that is typically divided into tiles, where each tile at minimum incorporates one sensor. Depending on the tracking resolution required, the floor can be either a comprehensive or a feasible task.

The Smart Floor project [16], involves a simple setup containing load cells and a steel plate. The data provided when users walk across it, is then applied to a model containing data that can identify each user.

Another way of using FSR is investigated in Z-tiles [17] where the interactive floor is created by placing tiles next to each other. Each tile consists of twenty FSR's that measures the position and weight distribution of the user. An advantage of using separate tiles is, that it is possible to customize the shape and size of the floor. As a result, designers can construct the floor to fit multiple applications and environments.

To avoid malfunction due to harsh user interaction the tiles are bundled together in a network so only one tile is responsible for outputting the data received by the FSR's. The preliminary work that led up to the development of Z-tiles is described in [18]. This project was installed in an opera and enabled people to modify and create music and sounds depending on their movement across the floor. To sense the distribution of pressure they implemented piezoelectric wires running across each other in a 16 x 32 grid. When the user is in direct contact with the floor, the wires produce a voltage corresponding to the amount of pressure applied, thereby making tracking of position and foot pressure available.

In [19] a high-resolution floor was created to investigate how such a floor could assist people and robots in the future. Each sensor was created by an inner electrode and an outer electrode separated by a spacing pad. When pressure was applied to the floor, the spacing was removed and the outer and inner electrode touch each other, thereby creating a switch. A different approach to maintaining a higher resolution of 6 mm is explored in [20]. Their floor consists of pressure sensitive mats that can be connected to each other to construct a floor that ranges in size from 4.160 square centimeters to 26,7 square meters while maintaining a resolution of 6 mm. The pressure sensitive system is created by using pressure sensitive polymer between conductive traces that can measure different pressure levels of the user's feet when they are in direct contact with the floor. The scanning rate of 30 Hz makes it possible to detect swift movements and the floor can therefore support various interfaces to control video games or interactive dancefloors.

Although these floors provide high resolution, are easy scalable and have a high update rate, they are missing a visual output component, which makes user-interaction intuitive and broadens the application area. Despite low resolution, Taptiles provides user-friendly interaction by doing so. They integrate a conductive grid beneath the floor that is connected to each LED. Relying on changes in light level above each LED, they are both capable of tracking people display graphical elements to guide users.

The luminous *Ada floor* [21] is created from the same set of requirements and retain high scalability by building upon the idea of using tiles that interlocks together. Each tile is constructed with three neon lamps, three FSR’s and a control board. The size of 66 x 66 centimeters pr. tile neglects high pixel and tracking resolution.

The advantages of building floors that rely on pressure sensing are multiple. First, they do not suffer from problems with occlusion and the display resolution remains the same by increasing the number of sensors. This is especially an advantage when building larger interactive floors. This is opposed to camera-tracking where the resolution and quality of colors decreases when the distance to the projector is extended. In relation to camera-tracking some advantages remains the same. Both technologies offer tracking of humans and objects and are able to uniquely identify steps and people based on measurement from users' direct contact with the floor.

The major difference is the possibility of seamless integration into carpets and ordinary floors, which makes pressure-sensing floors easy to hide and minimize intrusion on users' privacy.

The shortcomings found in relation to pressure-sensing is that none so far have been able to create a floor for visualizing graphical elements while maintaining a high tracking resolution.

2.2.1 Summary - foot-centric systems

The construction of these foot centric systems can be very cumbersome in many circumstances and are more vulnerable to malfunctions in hardware since interaction is taking place directly on or close to the hardware.

Yet they are tolerant to environmental changes, and size and shape can be customized to fit into places with more structural obstacles if ignoring the space beneath the interactive floor where the sensors and wires are placed. This can both be a limitation, but also an advantage if one's goal is to make an interactive floor that is less intrusive on user privacy and environment than camera-tracking. An overview of foot-centric system is provided in table 3.

	Construction	Interaction	Constraints	Advantages
Foot-centric systems	• Implementation of sensors or wires into or beneath the floor.	• Direct touch. • Amount of force applied. • Uniquely identify users. • Touch. • Recognize objects.	• Only direct touch. • Low display. resolution. • Extensive construction. • Flexible surface.	• No occlusion. • Can be hidden within the environment. • No intrusion on user privacy.

Table 3: Properties of foot-centric system used in interactive floors.

2.3 Capacitive sensing

So far, we have discussed how interactive floors can be created through the use of foot-centric technologies and camera-tracking. As previously mentioned, one of the advantages of pressure sensing is the possibility of seamless integration into floors and environment. In this sense, capacitive sensors contain many of the same properties. Yet they also offer even less privacy-critical tracking of humans due to their smaller size and sensing of electric fields. This method can penetrate non-conductive objects and recognize conductive objects without having direct contact with the floor. Thus, when the objective is to create a system that unobtrusively tracks humans, capacitive sensing offers a practical solution to do so. The concept of capacitive sensing has been known and investigated in various applications. For instance, it is the primary choice in the creation of multi-touch screens for smartphones. Despite being a front edge technology, only a few have explored the technology and how it can be applied to interactive floors.

2.3.1 Introduction to capacitive sensing

According to [22] three modes exist to create capacitive sensing systems (figure 4). Loading mode, which requires the simplest configuration, uses a single electrode that both functions as a transmitter and a receiver. In shunt and transmit mode, one electrode acts as a receiver and another as a transmitter. An electrical field is then created between the two electrodes. When a conductive object interferes with the electric field, for instance a human, the displacement current decreases and a change in capacitance is measured. The difference between shunt and transmit mode is that in shunt mode, the distance between the transmitter and receiver is known, in transmit mode, the person works as the transmitter.

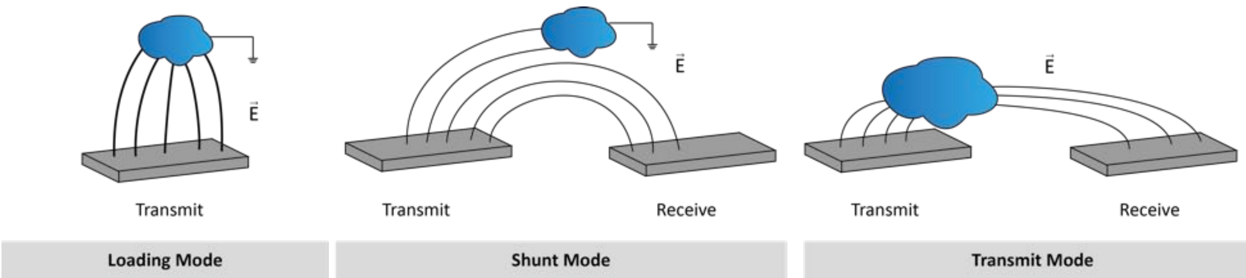


Figure 4. Capacitive sensing measurement modes [23].

2.3.2 Interactive floors using capacitive sensing

By integrating capacitive touch sensors into a woven carpet, The Smart Carpet [24] utilizes loading mode. Here, an electrode functions as both the transmitter and receiver. When a user walks across the floor, the capacitance changes on the electrode touched. As a result, they are able to detect the position according to the electrodes touched. Similarly, Tiletrack [25] provides tracking of user walking or standing on a floor, but in contrast to the Smart Carpet, TileTrack applies transmit mode to do so. Here, a carpet contains the transmitting electrodes and a wall standing next to carpet functions as the receiving electrode. When walking across the carpet, the user impacts the amount of displacement current between the transmitter and receiver. This results in a change in capacitance that can be used to make an approximate estimation of the user's position.

While these two provide important insight into use of the technology in interactive floors, others have explored the possibilities of more advanced tracking and interaction procedures of users.

2.3.3 Capabilities of capacitive sensing

Among these are capacitive sensing toolkits that provide multiple sensing opportunities and easy integration into products. The CapToolKit [26] is an open source toolkit which relies on loading mode where an electrode both functions as the transmitter and receiver. The toolkit have been used to develop multiple prototypes such as *capShelf* and *capTable* [27] which uses capacitive sensing for low level activity recognition. The capTable is able to sense a human hand from a distance of 70 cm by using electrodes that measures 20 x 20 cm, but can not differentiate between different users' hands, hence they are unable to differentiate between different users.

OpenCapSense [23] is another toolkit that has been developed to enable easy implementation of capacitive sensing into user interfaces. In relation to CapToolkit, which only supports loading mode, OpenCapSense additionally supports shunt mode.

In contrast to loading mode, shunt mode includes two separate electrodes where one function as a receiver and the other as a transmitter. This setup enables the possibility to execute parallel measurements by multiplexing through the transmitting and receiving electrodes which facilitates a simpler procedure to track at a higher resolution. In combination with machine learning, OpenCapSense explores how their toolkit can be employed to recognize if a person is lying down or sitting in a couch. Furthermore, they explore how shunt mode can be used to recognize gestures such as knocking and tabbing.

While the above shows the capabilities of loading and shunt mode, other projects have investigated the properties and applications of transmit mode. In DiamondTouch [28] transmit mode is created by integrating a grid of transmitters each with independent electrical signals into a table. The people sitting next to the table is connected to a receiver through their chair (figure 5). When a user is close to one of the transmitters, the corresponding electric signal is registered by the receiver associated with the user, thereby determining where and which user touch a part of the table.

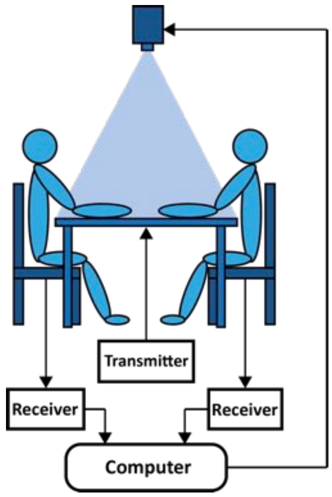


Figure 5: Setup of DiamondTouch using transmit mode [28].

Shortcomings with the use of transmit mode is that the user has to be coupled to the receiver. This requires a specific setup that either would involve attaching the receiver directly onto the user or demand very specific interaction. In several applications, this would be both undesirable and impractical to design for.

Other basic challenges with capacitive sensing arise when trying to infer additional information such as the distance from the hand to the sensor. This is due to the fact that the sensor only provides one-dimensional data. For instance, a certain change in capacitance between a hand 5 centimeters away, can be equal to two smaller objects three centimeters away. Such an issue arises in *TileTrack* and *Smart Carpet*. This is due to their relative low tracking resolution which disables them to differentiate between sensed objects. In contrast, other projects have explored higher tracking resolution and touch recognition that is much more comprehensive.

Among these is Touche [29] which explores how machine learning and *Swept Frequency Capacitive Sensing (*SFCS*),* can be used to successfully recognize multiple hand postures. Opposed to TileTrack and Diamond touch, which uses a single AC frequency, *Touche* uses a range of AC frequencies that all flow through the body in different ways resulting in richer information about how a user is touching an object. Recent research also shows that algorithms from machine learning can be used without RFCS to create a 3D positioning of hand and finger posture [30] enabling 3D input and hand gestures to be used for interaction with mobile devices through the use of a transparent electrode made by OCF. So, by combining different technologies it is possible to successfully differentiate between objects, a human body and their interactions procedures.

2.3.4 Summary - capacitive sensing

Despite auspicious signs and use in many popular commercial products such as laptops, sensing carpets and smartphones, many uncertainties still exist when employing this technology - especially in regards to larger installations where the interactive surface needs to be luminous. Introducing the technology into such an installation can also lead to unambiguous readings caused by the environment or other conductive objects nearby. Thus decreasing the stability and robustness. Still it remains, they are inexpensive, requires no line-of-sight to sense, offers seamlessly integration into the environment and the opportunity to create a transparent sensing module. An overview of capacitive sensing is provided in table 4.

	Construction	Interaction	Constraints	Advantages
Capacitive sensing	• Implementation of sensors into the environment.	• Direct touch. • Proximity sensing. • Direct touch. • Proximity. • Recognize objects.	• Impact to "conductive" environments. • Prone to technical issues. • Extensive construction for large interactive surfaces.	• No occlusion. • Transparent. • Sense through. structural elements • Low privacy intrusion. • Robust against changing light conditions.

Table 4: Properties of capacitive sensing in interactive floors.

2.4 Summary - interactive floors

When choosing which technology to use when designing interactive floors, one has to think of the trade-off between advantages and disadvantages. Every technology has domains where it will be preferred over others. Aspects to take into account when choosing the right technology can depend on cost, interaction, future users and the environment in which the floor is installed. Through exploration of interactive floors, we have addressed many of these elements and how they each relate to the applied technologies. A summarization of these elements are gathered in table 5.

	Front projected floors	Rear projected floor	Foot-centric systems	Light-emitting diodes	Electric field sensing
Tech-nology	● Camera Tracking of users' limbs.	● Camera tracking. ● FTIR. ● IR camera.	● Piezoelectric wires. ● Force-resistive sensor. ● Load cells. ● LED's or light bulbs as display.	● LED that functions as a photodiode and display.	● Capacitive sensors. ● Conductive elements (copper, OCF).
Con-struction	● Projector for display. ● camera for tracking. ● Projector and camera in the ceiling.	● Projector for display. ● Camera (IR) for tracking. ● Transparent surface ● Projector and camera beneath interactive surface.	● Implementation of sensors or wires into or beneath the floor.	● Conductive grid placed beneath the floor. ● Connected to each LED.	● Implementation of sensors into the environment.
Appli-cations	● Education. ● Games. ● Collaborative work.	● Education. ● Games. ● Assistive living.	● Interactive dancefloors. ● Games. ● Visual elements.	● Detect falls. ● Assistive living.	● Smartphones. ● Assistive living. ● Games.
Inter-action	● Touch surface with limbs. ● Objects.	● Direct touch. ● Body posture. ● Objects.	● Direct touch, ● Amount of force applied	● Direct touch ● Amount of force applied	● Direct touch. ● Proximity sensing, ● Gestures.
Sensing data	● Touch.	● Uniquely identify users. ● Body postures. ● Recognize objects	● Uniquely identify. users ● Touch. ● Recognize objects.	● Touch. ● Recognize objects.	● Recognize body postures. ● Direct touch. ● Proximity. ● Recognize objects.
Issues	● Occlusion ● Shadows ● Multiple users. ● Ambient light ● Intrusion on privacy ● Needs a specific environment to work	● Intrusion on privacy ● High cost ● Extensive construction ● Ambient light sources ● Only recognize direct contact with the floor	● Only direct touch ● Low display resolution ● Extensive construction ● Flexible surface	● Shadows ● Ambient light ● Direct touch only reliable reading. ● Low resolution	● Prone to "conductive" environments ● High cost ● Prone to technical issues ● Extensive construction for large interactive surfaces
Advan-tages	● Reliable technology. ● Easy construction. ● High resolution display.	● No occlusion. ● No shadows. ● High tracking resolution.	● No occlusion. ● Can be hidden within the environment. ● No intrusion on user privacy.	● Low cost. ● Less-privacy critical.	● No occlusion. ● Transparent. ● Sense through structural elements ● Low privacy intrusion. ● Robust to changing light conditions.

Table 5: An overview of a selection of applied technologies used to create interactive floors.

3. Interactive sport games

In this chapter, we examine two use-cases that have been used to create interactive sports games. Specifically, we investigate:

- Football lab [31] and Bouncer [32]
- Design considerations when designing interactive sport games

There have been a lot of examples on how to motivate people to be active through the use of interactive systems that use game elements as the main way to get people motivated. The most common examples are sports games to game consoles that use motion and bodily interaction to make exergames to enhance players' physical activity. In recent years, the concept of exergames has been aimed as a training method for developing the athlete's overall performance through specific training exercises in a targeted area of the sport.

Exergames in general are strong tools for getting people motivated and immersed in training exercises. But using interaction possibilities such as gamification without any awareness of how the motivation will influence the outcome can reduce the actual intention and goal with the exercises.

Because our use-case is situated in a gym environment, it is important to make the interactive floor able to motivate people to do the exercises correctly with focus on the exercises and not on competition. Therefore, it is important to look at our interactive floor as a combination of a training system and motivation tool like in Bouncer and Football Lab.

In both professional sport and general sport there is a lot of emphasis on training. Both for keeping up the current level of skill but also enhancing weak areas to perform better. In recent years, interactive training sports games has been used as a way to develop the athlete's performance by specializing the training to the individual and by making mundane exercises more fun and motivating.

Football lab combines technology and games to develop an interactive soccer-training system that can gather data about the player. Furthermore, they are trying to motivate players through different game elements and improve the training experience for team sports. By using technology in the training session it is possible to train reaction and response to situations with high unpredictability, which also facilitates engagement of the users.

The research in football lab shows that when designing interactive technologies for exercises, designers should be aware of some of the difficulties. For instance, winning is not a part of normal training practice and users will often redirect their focus when using game elements to a more competitive aim. The user focus will most likely be more on beating the game with the best outcome and neglect the real goal of the exercise.

Bouncer investigates how game elements can affect the training experience and how designers can balance the engagement and purpose in these training games. The bouncer is a novel training installation for individual handball training that contains different types of games, each focusing on facilitation of training specific skills for different sports. They propose three different challenges designers face:

1. ***Users have different expectation according to what they see.***

One way designers can avoid this challenge is to use abstract representations instead of literal ones. As an example, if you use a goalkeeper as an obstacle in a shooting practice game, users will have expectations of how the keeper should react in certain situations, which is hard to simulate in practice. By using abstract representations like a geometrical shape, designers have more freedom in regards to game mechanics because users do not have the same expectation of these representations. This also makes it easier to focus the different exercises on facilitating specific skills.

2. ***Choosing the right level of sensing.***

In these types of interactive training games, it is possible to go in both directions in regards to the amount of sensing. This is not necessarily the appropriate way to do it. Sensing a user's every move and using this to dictate what is right or wrong, can affect the users’ motivation in a negative way and reduce the opportunities to experiment with using different strategies for getting the highest score. On the other hand, by sensing every user's movement the risk of unexpected behavior is reduced.

3. ***Introducing points into the training game.***

This is due to a risk of shifting the player’s focus from the exercise to a focus on getting the highest score. It is therefore necessary to clearly frame the game as a training exercise and not just a competition so the players get their mind on the exercise. Points can thereby be used to reward the players for doing the exercise correctly and with the correct focus on the execution.

3.1 Summary - interactive sports games

In regards to making an interactive training floor, we need to be aware of the challenges described above.

- The first is maintaining relevance when translating physical elements into digital representations.
- The second is choosing an appropriate level of sensing as game input.
- The third is introducing points in training exercises without reducing the sport relevance.

Many of these aspects need to be considered in the development of the training system and training program. Some of the findings from the aforementioned cases are still relevant in regards of how our prototype is built. As an example, our resolution is too low to show exact representations when making floor exercises. Hence, we are only able to use abstract representations or figures when the user is close to the floor. Furthermore, too much sensing and feedback can make the motivation disappear.

4. Design Process

In this chapter we will describe the decisions and explorations in each design phase. Each phase contained several iterations that ultimately have lead to the final prototype. We will elaborate on the following design phases:

- The contextual inquiry
- How we chose capacitive sensing
- Building the floor
- Experiments conducted
- Final test

The findings ultimately resulted in CapFloor (picture 1). The setup is illustrated in figure 6 which contains an overview of the technological implementation and physical prototype:

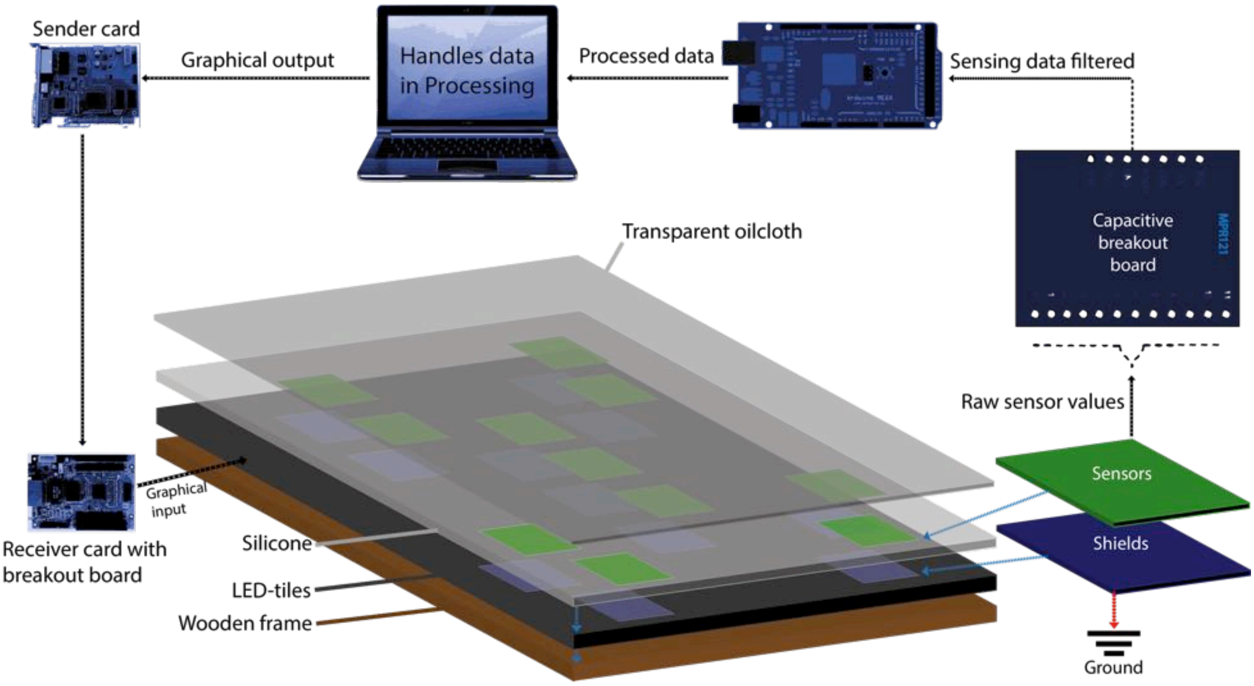
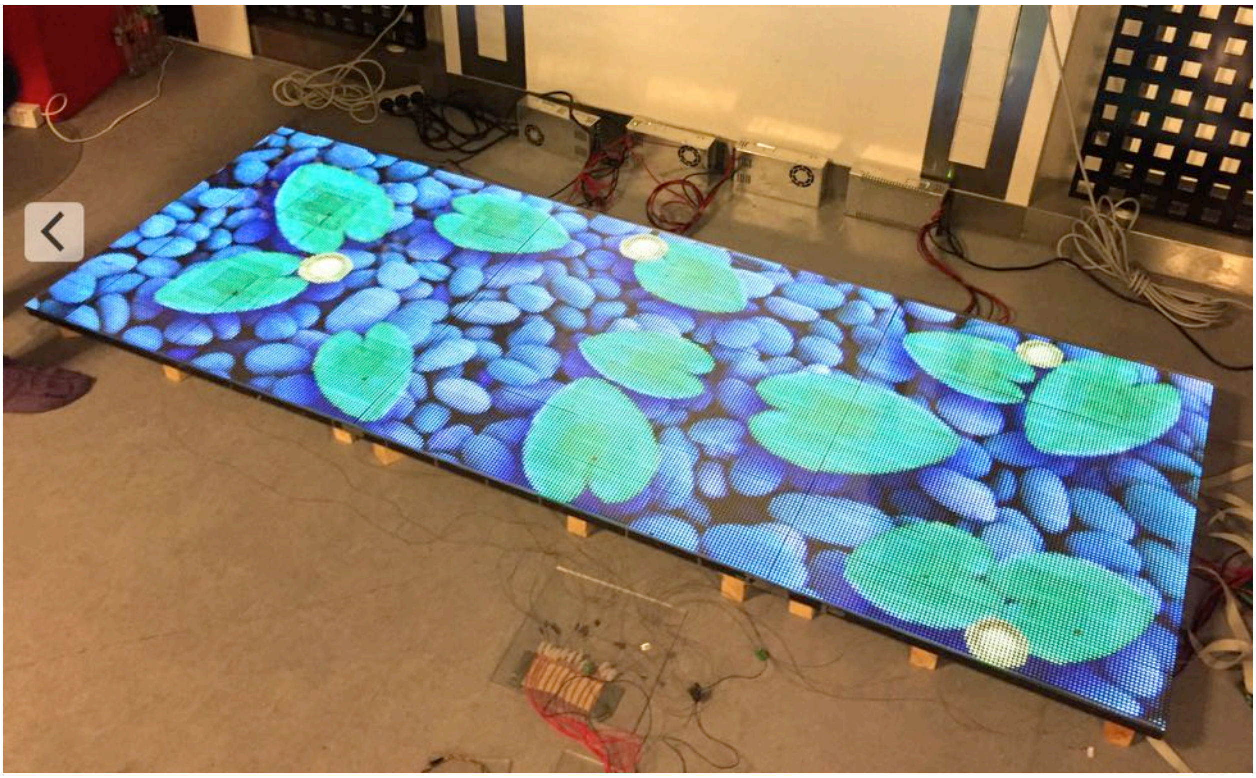


Figure 6: Overview of CapFloor setup.



Picture 1: Final prototype.

The following section describes our initial inquiry and identification of requirements.

4.1 Contextual inquiry

Through brainstorming and ideation, we found that using an interactive floor in fitness environments could be utilized to provide feedback and guidance to users through their floor exercises. In this section, we account for the process that resulted in identifying the requirements for the interactive floor.

We conducted a contextual inquiry to investigate:

- Specific use-cases.
- Conceptualize ideas.
- How to motivate and engage users?
- How to provide feedback and guide users during exercises?
- Requirements of sensing technology.

4.1.1 Observations and interviews

In this section we investigate how an interactive floor can be installed in a gym environment to provide guidance and feedback to users during their workout.

The inquiry was made by observing people and their activities in two different gyms. Furthermore, we conducted interviews with 3 users that use the gym on a regular basis but in different ways. Through observation we found that throughout the day, and especially between 16-21, the fitness environment is well visited. As a result, the people that inhabit the space and those walking from one exercise the other can influence the training activity. We also observed, that only a limited number of people exercised in groups whereas the majority went to the gym alone.

In relation to exercises, we found that floor exercises and stretching was the only time where gym users already had some kind of interaction or use of the floor. Many of the floor exercises were supported by other tools such as hand-weights, yoga-balls or abdominal rollers. Most of these exercises required a space of 2x1 meter to enable whole body movement.

In other exercises that were conducted on workout machines, the focus where directed to screens placed in the room, at the mirrors or in other cases in what direction the exercise gave possibility for. In between training exercises, people had a tendency to use their smartphone, talk with each other or getting ready for the next exercise.

Many of the observations were confirmed by our interviewees that in addition explained that their use of smartphones often was used to look at the exercise plan, switching between music tracks and documenting the training on social media. The exercise plan was in most cases made by the interviewees themselves at home before the training session or found on training sites and altered to fit their needs. In regards to floor exercises two of the interviewees incorporated this in the exercise plan but they all had to some extent used them for a period and still used floor exercises for stretching after the workout. One of the interviewees used floor exercises as her main way of exercising. The reason for this was because she had used it as a way to rehabilitate after an injury and subsequently used it for doing yoga every other week. In regards to conduct yoga exercises on an interactive floor she saw a lot of possibilities but were also a bit skeptical because she did not see an interactive solution with light in the floor and sensing that fitted with the yoga mindset and style. Although, she could see some benefits in using an interactive floor for her rehabilitation exercises and for yoga beginners. As a part of the rehabilitation the interactive floor could keep track of the different exercises. For instance, if they were executed the right way and in the right tempo and maybe could give some direction or alternative exercises if one exercise hurt or was too hard to do because of the injury. The same could be implemented for the yoga beginners but here it would also be relevant with some kind of time indicator so every stretch is maintained the right duration of time.

The other interviewees used floor exercises in a combination with training on machines and with free weights. The floor exercises were primarily used for core exercises. Furthermore, the interviewee had tried Freeletics [33], which is an exercise-form that have the floor in focus in the majority of the exercises. This interviewee thought, that a fit between his training method and an interactive training floor was good because it could be used without a lot of alterations from the way he already trains. One important aspect for him was that the floor should be able to count the amount of repetitions and keep track of the workout duration and rest in between sets. Furthermore, an interactive floor could be made to could help him push his limits by showing result from previous sessions and maybe make some of the exercises more interesting by games or by visualizations that could use ghost data from other peoples or one's own results. In addition, this interviewee was also interested in collecting as much data about the workout as possible, which should be accessible at home or in the gym on a smartphone app.

From the interviews and observations, we discovered that an interactive floor should comply with the following requirements to support gym users during their workout sessions:

- Primarily provide feedback and guide users during floor exercises
    - *Since - during floor exercises, users focus and look on the floor. In between exercises, user's attention is pointed towards other places*
- Support strength, flexibility and rehabilitation exercises
    - *Since - floor exercises mostly concern these areas.*
- Keep track of a user's workout sessions
    - *Since - it is hard to keep track of many things at the same time. Visualizing user data, such as number of repetitions can let the user focus on - breathing, tempo, counting, performance and motivation.*
- Take into account the influence of other people inhabiting the space
    - *Since - people use spaces close to each other*
- Size of floor should be approximately 2x1 meter
    - *Since - this is approximately the size required to perform exercises properly on the floor.*

- Take advantage of a user’s existing usage of smartphones
    - *Since - it can generate extra data about the user. Combining the floor with a personal item and connecting with personal applications can enhance the user experience.*

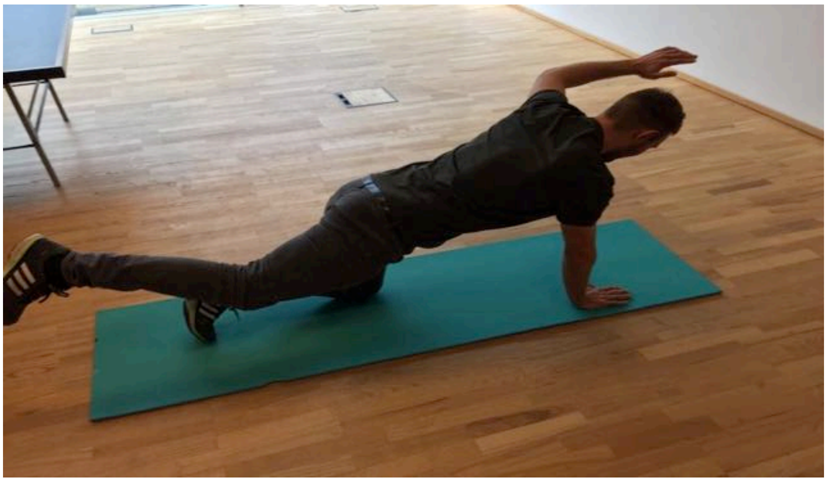
In the following section, these requirements are investigated further. In addition, we focus which data should be available to track users.

4.1.2 Bodystorming

After the observations and interviews, a bodystorming session with two participants, was conducted to further explore the findings gathered from the observations and interviews. The areas we were interested in was:

- How participants interact with an interactive floor.
- When and what type of feedback?
- What sensor data is needed to provide users with correct feedback?

The bodystorming was made by placing a mat that could be use as a stand-in for our interactive training floor (picture 2). The participants were guided through a pre-made set of exercises in which each exercise had different focus on how it could be represented visually on the floor. While the participants were completing our small task, they were told to think aloud and in some cases alter their exercise according to the dialogue with us.



Picture 2: Bodystorming with the participants.

Through the bodystorming session, we found that the most important thing for the participant was that they wanted to dedicate their focus on the different exercises and to get the most out of the training sessions. Some of the more specific suggestions we received was directed towards what information that would be best to show while working out. These suggestions included a repetition placed at the head position and a time indicator that could represent the total time of the workout, as well as rest time and the execution time for each exercise. For the stretching exercises a representation of the different muscle groups was suggested, it should furthermore be able to show what exercise to use for stretching the different muscle groups. The most important element for the engagement was the sharing of result and incorporating game elements such as score, time or another way to make the exercises more motivating. In addition, the building of the floor should be with as easy access as possible it should be as easy as using a treadmill. Furthermore, the top of the floor should be kept without any obstacles or scarp edges and direct contact with the LED panels should not be possible because it felt fragile and delicate.

For the sensing, we found that heart rate and other vital data was less important than the data about the exercise itself. Furthermore, the data represented should be shown during the exercise and be in regards to the current exercise. A representation of the total workout should be represented after the workout is complete.

4.1.3 Summary

Through this phase, we have found requirements for the sensors and the floor construction.

The sensors needed to meet the following requirements ordered by their importance:

1. Be able to recognize users from a distance and their body postures.
2. Register multiple inputs simultaneously.
3. Not obstructive and transparent (should not cover LED's and users should be able to walk and make exercises on the floor).
4. Robust to environmental changes.
5. Discern between distances.
6. Easy to install.

The LED-floor needed to meet the following requirements:

- The floor size should be 210cm x 80cm
- Be easy to assemble and move
- Robust build for users during exercises

In the following section we describe the assembly of the LED-floor and how it accounts for the relating requirements mentioned above. Hereafter, in section 4.3, we investigate sensing technologies and capacitive sensing methods that comply with the sensing requirements.

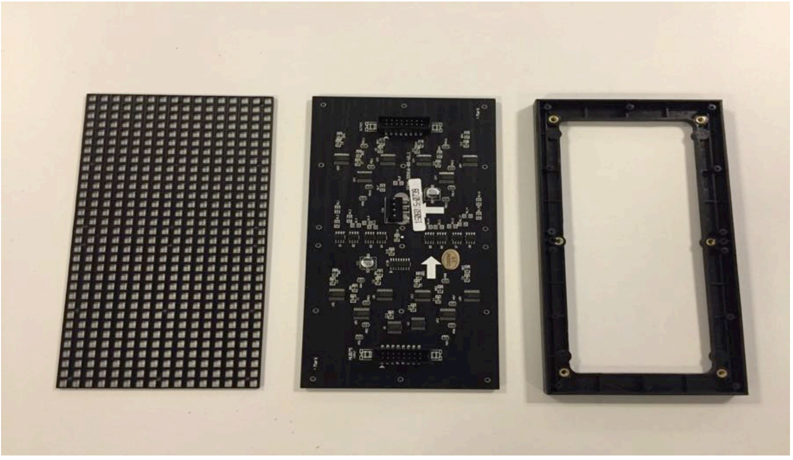
4.2 Assembling and building the screen

This section describes the process of building and assembling the screen according to the above requirements.

For convenience reasons we decided that the floor should be constructed of individual sections that could easily be assembled for future testing. Taking into account that people should be able to walk and conduct exercises directly on top of the LED panels, we decided to build an underlying structure that could hold the LED matrix panels together and support the weight of people. For this, we used MDF instead of using the metal connecting plates normally used with the LED matrix panels [34].

4.2.1 Display construction

The LED matrix panels used to construct the floor each have 512 RGB LEDs arranged in a 16x32 grid on the front. On the back there is a PCB with two IDC connectors, which can be chained together via the IDC input and output connectors. Each LED matrix panels measures 192mm x 96mm x 12mm (picture 3).



Picture 3: 16x32 RGB LED matrix panel

The 88 LED matrix panels we use are set up in a grid of 8 x 11. The total size of the floor measures 211,2cm x 77cm which satisfied our requirement. Our final screen resolution is 128 pixels X 352 pixels (picture 4).

Picture 4: Final screen resolution.

4.2.2 Constructing the floor

We made six sections, four 76,8cm by 38,5cm and two 57,6cm by 38,5cm to get the required size. Each section was made on a laser cutter by using Adobe Illustrator for the cutting files.

Each section was designed with small holes for the LED panel bolts and a pair of small squares with rounded corners for the 16-pin IDC's and one big hole for the power connectors (figure 7).

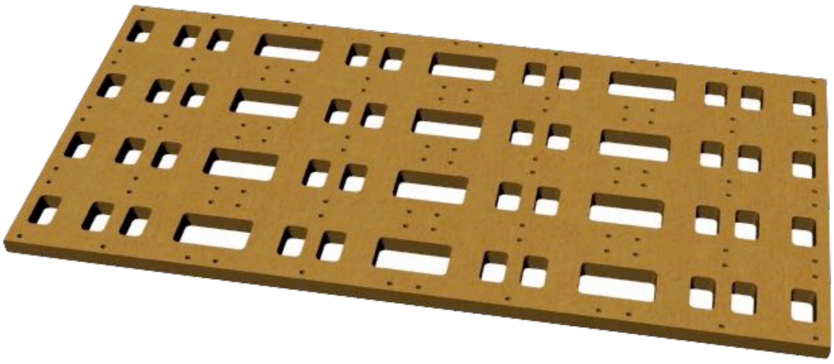
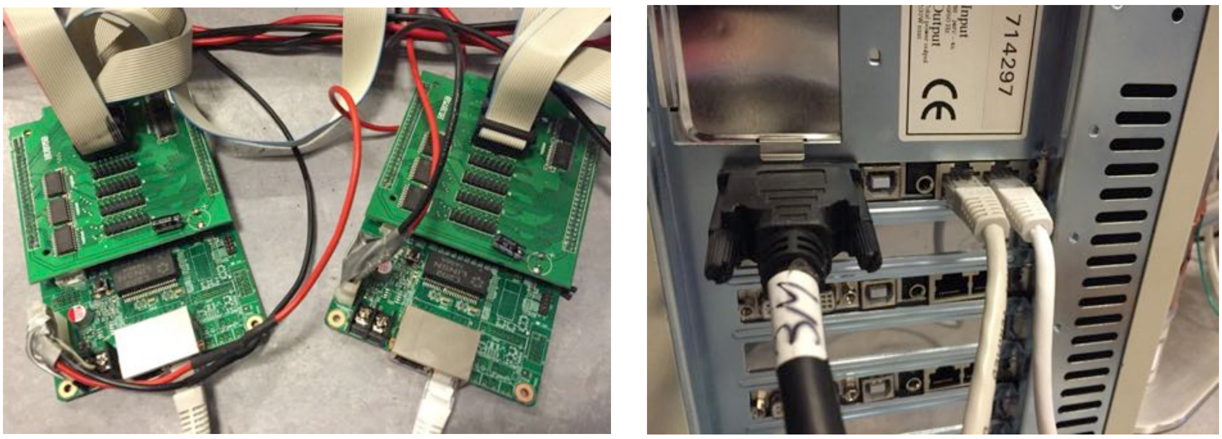


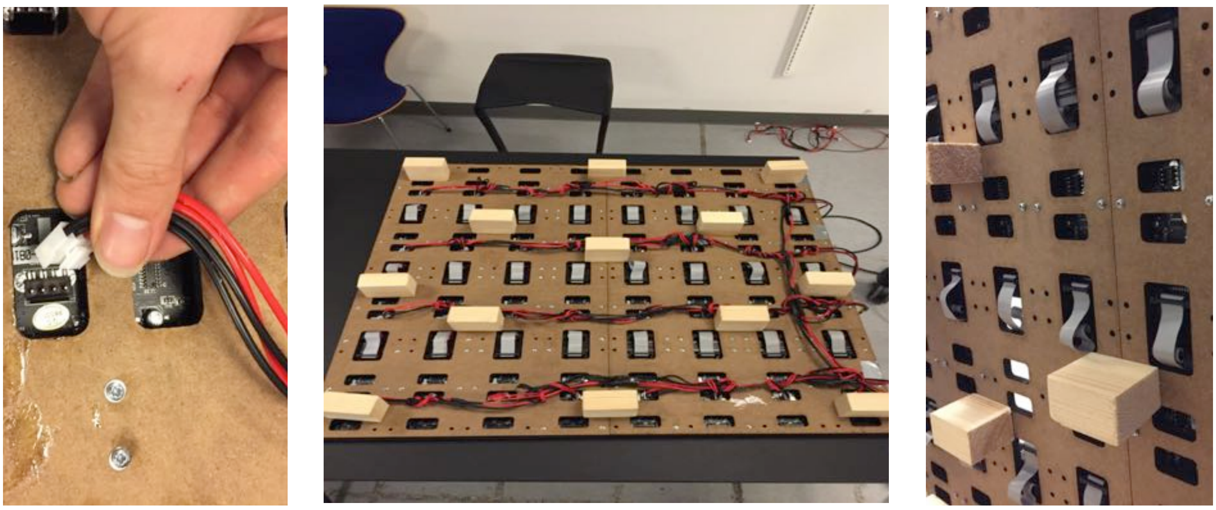
Figure 7: 3D model of MDF-section

Each panel row is connected to a 16-pin IDC that can be chained from one end to the end with the receiver card that has an IDC breakout board mounted on top. The receiver card is then connected via an ethernet cable to the sender card (picture 5).



Picture 5: Receiver card (left), with Ethernet-cables connected to the sender cards (right).

We are using eight rows of IDC wiring that connects to two receiver cards with IDC breakout board. These are then connected and controlled by the sender card. We use 6 power sources that are powering two sections each. Two of the power adapters are also powering the receiver cards.



Picture 6: Wiring.

To make room for the wiring, small pieces of wood was made to raise the floor 4cm over the ground, which made room for the power adapter connections (picture 6).

The video input was made using a serial connection to each of the eight rows. For this to work together, the sender card was controlled using a USB connection. The USB connection is only used for Sender/Receiver configuration whereas the rest of the video connection is split through the sender card to the receiver via the ethernet cable. To configure the sender card, we used LEDStudio12 [35] to split the video input to the right row sequence.

4.2.3 Setting up the display

For setting up the display we started by setting up the total LED-screen resolution to both the sender card and the receiver cards. This gives two identical screen displays that is just duplications of the same areas. Because the sender cards have two ethernet outputs we used them to send two different screen areas by calibrating each receiver card individually.

Under the “display connection” menu in LEDSTUDIO12, it is possible to divide each ethernet connections to display its own input size. We used this to make each ethernet connections display different screen areas by setting two different x,y points where the screens should start just with the same display area height and width.

4.3 Sensing exploration

Based on the results from the contextual inquiry, we decided to explore which sensing technology could fulfill the above requirements. Our experiment focused on comparing different sensing technologies to the findings from the contextual inquiry.

4.3.1 Sensing technologies compared to requirements

In this section we investigate applied technologies that has been used to create interactive floors. The objective was to find the technology that suits the above requirements. The technologies investigated were light sensors, camera-based tracking, foot-centric systems and capacitive sensing.

One of the primary requirements was that the floor should be robust to environmental changes. Implicit, this means that users belonging to the environment or users conducting exercises should not interfere with the tracking. As a consequence, issues with occlusion and shadows concerning front-projection ruled out this technology as a possibility. In addition, rear-projection was discarded due to the extensive space and construction it would require to install.

Concerning infrared and light sensors, we found that in order to incorporate these into our floor, it was required to break the pre-made LED panels apart. In our case, this was not a possibility. Even though the infrared sensor is able to recognize positions and proximity sense on the floor, it would be hard to integrate these into the floor without having them on top. Placed here, they would be visible, obtrusive and be prone to technical issues during user interaction. Placing them in a frame on the edge of the floor would require a more extensive construction and disable sensing of the distance between human limbs and the floor. Due to these reasons, the infrared and light sensors were neglected.

The two sensor technologies that provided the most suitable capabilities for our case were the FSR and the capacitive sensor. FSR sensor can be use for a variety of different things such as position, weight distribution and counter for repetitions - all important elements for guiding and providing feedback during workout. By putting the FSR sensors underneath each supporting leg on the floor, sensing the aforementioned things should be possible and make the floor unobtrusive and robust.

The capacitive sensing test show that capacitive sensing possesses similar qualities, but the position of the user would be more precise because it would not be measured by the weight distribution, but measured by direct touch with the surface. Furthermore, it would be possible to measure the distance to the user without direct touch, by using the capacitive sensors as a proximity sensor. In addition, the possibility of creating a transparent sensing surface eliminates construction issues that potentially would occur when placing FSR beneath the floor. Due to the results (table 6), capacitive sensing came out to be best fit suited for our floor.

Requirements	Capacitive sensing
Able to recognize users from distance and infer body postures	Relying on changes in capacitance we will be able to do so without experience issues with occlusion.
Discern between distances	Depending on the amount of change in capacitance, we can discern between various distances.
Robust to interaction and environmental changes	Capacitive sensing is limited in its robustness. This is due to, that the interaction takes places directly on the technology, and changes in the environment can impact sensor readings.
Easy to install	Capacitive sensing is relative easy to install and construct compared to other technologies.
Not obstructive and transparent	Using transparent conductive sheets, the sensing surface can be transparent and unobtrusive.
Multiple inputs	Using separate electrodes placed on dedicated positions, we can register multiple inputs simultaneously.

Table 6. Capacitive sensing in relation to identified requirements.

4.4 Requirements of capacitive sensing technology

In extension of the investigation above, we chose to further investigate which capacitive sensing method would be best suitable for creating the interactive floor and still fulfill the requirements. Hence, in the following section, we investigate:

- Different methods and procedures used in capacitive sensing.
- Capabilities belonging to capacitive sensing methods.
- Advantages and limitations of methods compared to the above requirements.

Based on our findings, we selected the capacitive sensing method for our initial experiments.

4.4.1 Capacitive sensing - methods and procedures

When taking existing capacitive sensing research into consideration, they all seem to have limitations and advantages when compared to our sensing requirements.

In general, some of the inherent properties of capacitive sensing already support the creation of an unobtrusive floor and interaction without direct touch. This is due to the technology's capabilities to sense through non-conductive material by detecting changes in the electrical field. Other capabilities come with a trade-off. For instance, the amount of distance for which the sensor starts to recognize an object depends on the area of the electrode, thus affecting the tracking resolution. In addition, some applications require more advanced constructions than others.

Those that explores transmit mode, like DiamondTouch [28] and Touche [29], offers great tracking resolution and are able to uniquely identify each user, although applying this technique would involve attaching the receiver to the user when exercising which would decrease the robustness and usability of the system. Touche and [30] have also explored more advanced systems to recognize hand position, gestures and how to generate a 3D map of the user fingers to enable other forms of interaction. These articles primarily explore interaction with small surfaces such as mobile screens and door knobs (Picture 7), hence, how they can be implemented successfully on larger surfaces on interactive floors are unknown.

Picture 7: Doorknob interaction - Touche [29].

In addition, these technologies are too advanced compared to what we intend to do. Less advanced and complex systems have also been explored and created like OpenCapSense [23] and the CapToolkit [26]. These toolkits allow easy construction, implementation and enables individual customization of sensors. Both toolkits apply loading mode and use separated sensors placed in arbitrary positions that reliably measure changes in capacitance and for instance recognizes a user's body posture on a couch. In addition, they explore how transparent conductive film can be used as an electrode, thereby enabling the construction of a transparent sensing system. These abilities match the requirements described above since a transparent sensing system enables the construction of a transparent surface, which does not interfere with visual guidance and feedback. Subsequently, this makes it possible to place the sensors above the LED’s and thereby increasing the distance of which we are able to sense resulting in additional user input. In addition, sensors can be placed arbitrarily on the floor depending on where we want the users to interact with the floor.

4.4.2 Summary

In this section we found the capacitive sensing toolkits to fulfill the majority of the requirements. Similar to the toolkits mentioned above is the CapSense library from Arduino and the MPR121 capacitive breakout board. These technologies possess the qualities:

- Sensors can be placed arbitrarily on the floor depending on where we want interaction.
- Enabling the construction of a transparent sensing system.
- Recognizes user's body posture
- Allows multiple inputs simultaneously
- Allows easy construction and implementation
- Individual customization of sensors

In the following section, we will address their technical specifications and implementation into our project.

4.5 Technical specifications - MPR121 & CapSense

This section describes the two capacitive sensing technologies tested in our experiments. Here among the technical specifications and how they are integrated into the test environment.

4.5.1 MPR121

The MPR121 [36] is a capacitive breakout board, which can control 12 capacitive touch pads simultaneously. The touch pads functions as the sensing electrodes by connecting a wire from the board to the conductive material. The capacitive system is based on *loading mode* and measures changes in capacitance by calculating the amount of voltage at the end of each charge and discharge cycle. Hence, depending on the charge time, amount of capacitance and current injected, the measured voltage changes (figure 8). The voltage is then converted through an ADC to a number that ultimately is sent to the Arduino.

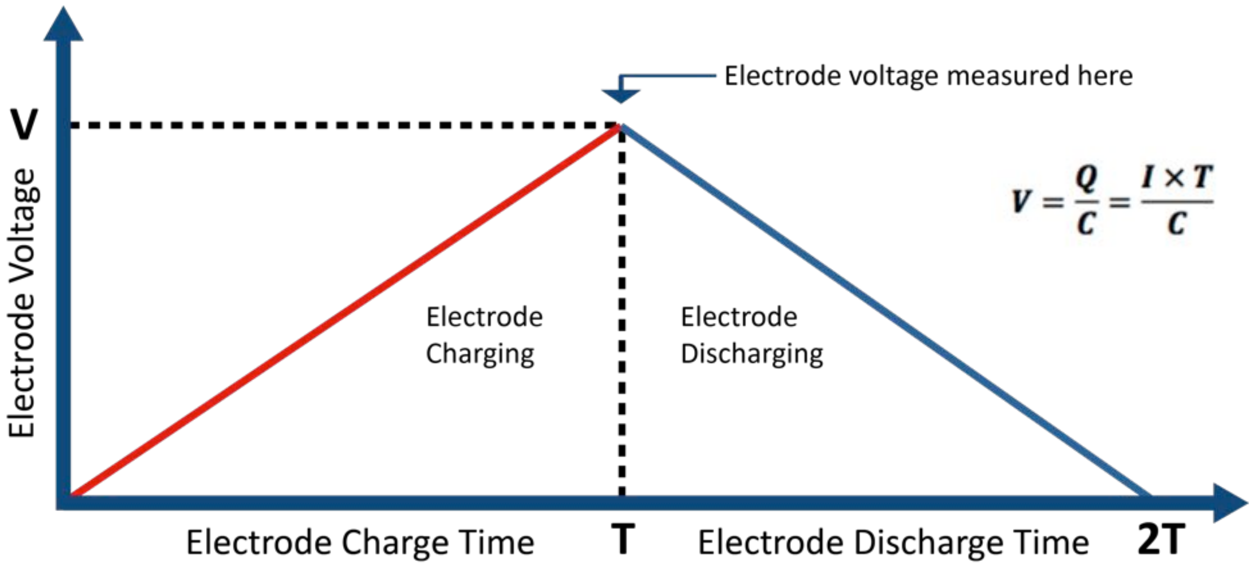


Figure 8: Charge time and voltage formula. I = charge current, T = charge time, V = peak voltage, C = capacitance [37].

The MPR121 comes pre shipped with software that detects change in capacitance. Before the sensing data is outputted, it is sent through a filter that accounts for environmental noise. This results in a stable output with low fluctuations. Finally, the output is then compared to a baseline value [38] and if the measured capacitance exceeds the baseline, an output of touch/untouched will be sent to the serial monitor.

In some circumstances a setup might require a different touch sensitivity than the touch/no touch. The mpr121 accounts for this by making it possible to manually adjust the baseline for each sensor and read the raw sensor values.

In regards to our installation, the code was adjusted accordingly to enable proximity sensing by surpassing the integrated baseline and instead sense the raw sensor value. As an electrode, we used OCF. The technical setup is illustrated in figure 9.

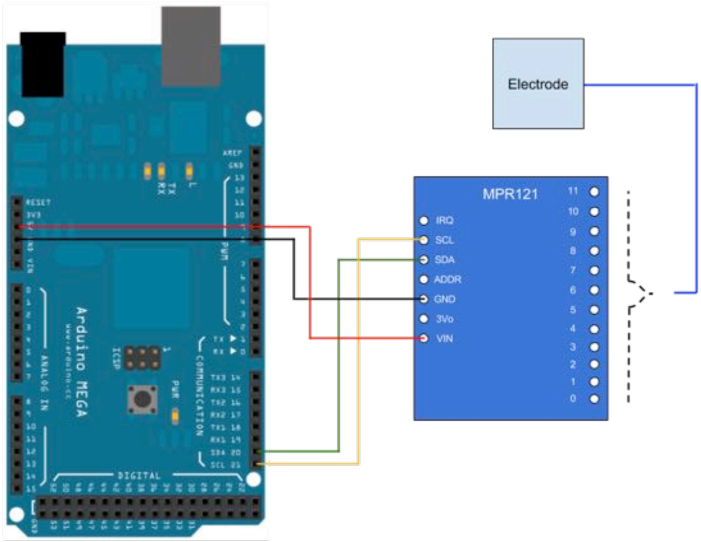


Figure 9: Technical setup of MPR121 to Arduino Mega.

4.5.2 Arduino CapSense

The Arduino CapSense library [39] is an open source toolkit for Arduino that enables easy integration of capacitive sensing into products.

The setup requires a simple RC circuit and inclusion of the library into the Arduino project. The send and receive pins are connected to the Arduino's digital signal. In between a resistor and electrode are placed.

As an electrode we used OCF due to its transparency low resistance where the electrode both functions as a transmitter and receiver. The change in capacitance is measured by calculating the time it takes to charge the capacitor. In this particular instance, the send pin starting state is high and outputs 5v through the resistor and into the capacitor. When the capacitor is fully charged, the receiving pin reads high and changes it state to the same as the send pin. This causes the state of the send pin and consequently the receiving pin to change to low. Thus the capacitor starts discharging. When the capacitor is fully discharged, the send pin changes its state to high and the procedure restarts. The output received is the delay between the send pin changing and the receive pin changing to the same state. The delay is determined by the value of the resistor and the amount of capacitance measured. Increasing the value of the resistor increases the delay but it also enables measurements from a longer distance. If the capacitance increases, for instance in the occasion of a human touching the electrode, the delay increases as well which forms the basis for user interaction for our interactive floor. The technical setup is illustrated in figure 10.

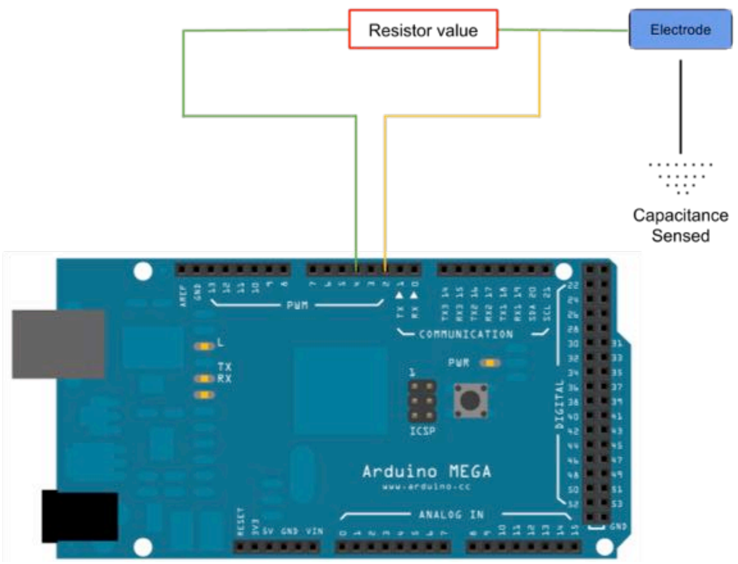


Figure 10: Technical setup of CapSense and Arduino Mega.

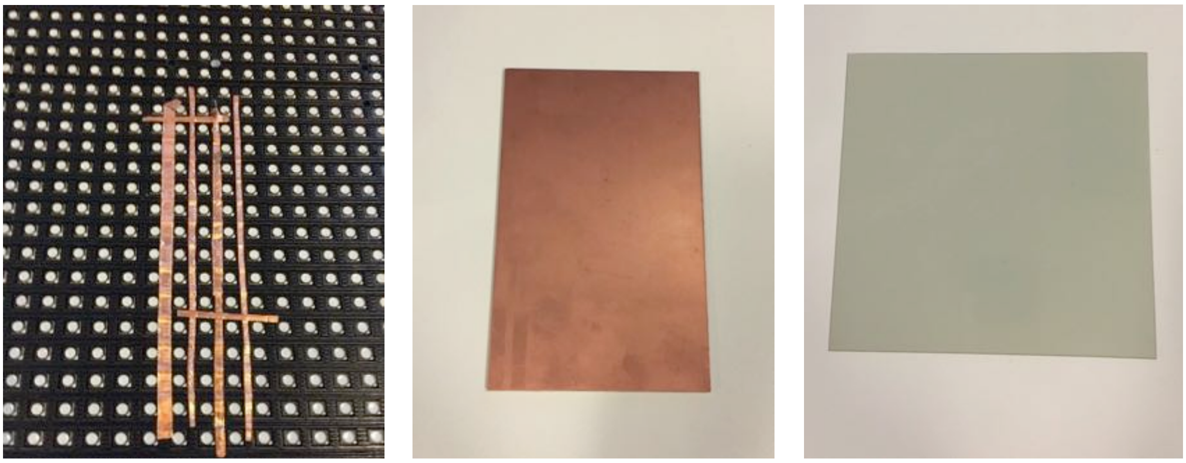
4.6 Experimentation - preliminary test

The first experiment was conducted to highlight the attributes of each technology and how they support touch and proximity sensing. Our experiments were aimed at finding:

- The optimal sensing material to use as an electrode
- Placement of sensors
- The amount of area covered of conductive materials for proximity sensing

The experiment contained a simple setup of the MPR121 and Arduino CapSense library to test how each system reacted to changes in capacitance when touched and sensing conductive objects in proximity. To avoid noise that occurred when touching the cabinet of the computer that was attached to the Arduino, we added a wire from the Arduino board to a ground connection which solved the problem.

As a part of the first experiment, we used both a copper plate that measured 10x15 cm, a copper grid measuring 3x8 cm and a sheet of OCF with the size of 15x15 cm to create our electrode (picture 8). When testing the CapSense library with both OCF and copper we were able to sense a human hand from distance and direct touch with no real difference between the two materials. The output received from CapSense were unstable and contained fluctuations in its output. Still, it provided sufficient data to differentiate between distances from direct touch to a distance of 15 cm.



Picture 8: Grid made of copper tape, copperplate and sheet of OCF.

The preliminary tests with the MPR121 yielded similar results in regards to sensing distance. In comparison, the MPR121 provided more stable outputs due to its pre programmed filter which eliminates noise from the environment.

We also found that the resistor size, area of the electrode and the object's capability to effect the electrodes capacitance influence the readings and the technologies abilities to proximity sense. These aspects both provide opportunities but also limitations. A general rule within capacitive sensing is that an electrode is only able to measure at a distance corresponding to its size. In relation to the requirement of a sensing system that can sense objects at a distance of 10 cm reliably, this size electrode causes the tracking resolution to decrease. Due to the large tracking resolution, issues with inferring correct distance of an object can occur. For instance, an output would be the same when placing a bottle directly onto the electrode as if a hand was held 10 cm above. Additionally, direct contact with feet provides the same output as direct contact with hands. As a consequence, inferring fine-grained body posture or the exact position of each finger or uniquely identify the user is not possible.

In relation to our project a very high resolution is not that important since we guide the user interaction through visual feedback. Hence, we only need a small amount of sensors placed at specific touch location based on the various exercises to meet the requirements.

4.6.1 Summary - capabilities of MPR121 and CapSense

Through preliminary tests, we found that capacitive sensing with the MPR121 and CapSense has the potential to fulfill our requirements. They provide the possibility to:

- Create a transparent sensing surface using OCF
- Enables proximity sensing
- Separate sensors and achieve multiple inputs simultaneously

In relation to technical elements we found that:

- Fluctuations by touching the laptop can be solved by connected the Arduino to earth ground
- MPR121 outputs more stable values than CapSense

Still, many aspects can influence sensor readings and their stability, including:

- Resistor size
- Area of electrode
- Area of electrodes and its impact on proximity sensing
- Environmental noise

After preliminary experimentation we found the need for further experimentation to achieve more knowledge about the sensors' advantages and limitations. As a result, a more thorough test was conducted. Here, OCF was chosen due to its transparency, easy implementation and conductive qualities.

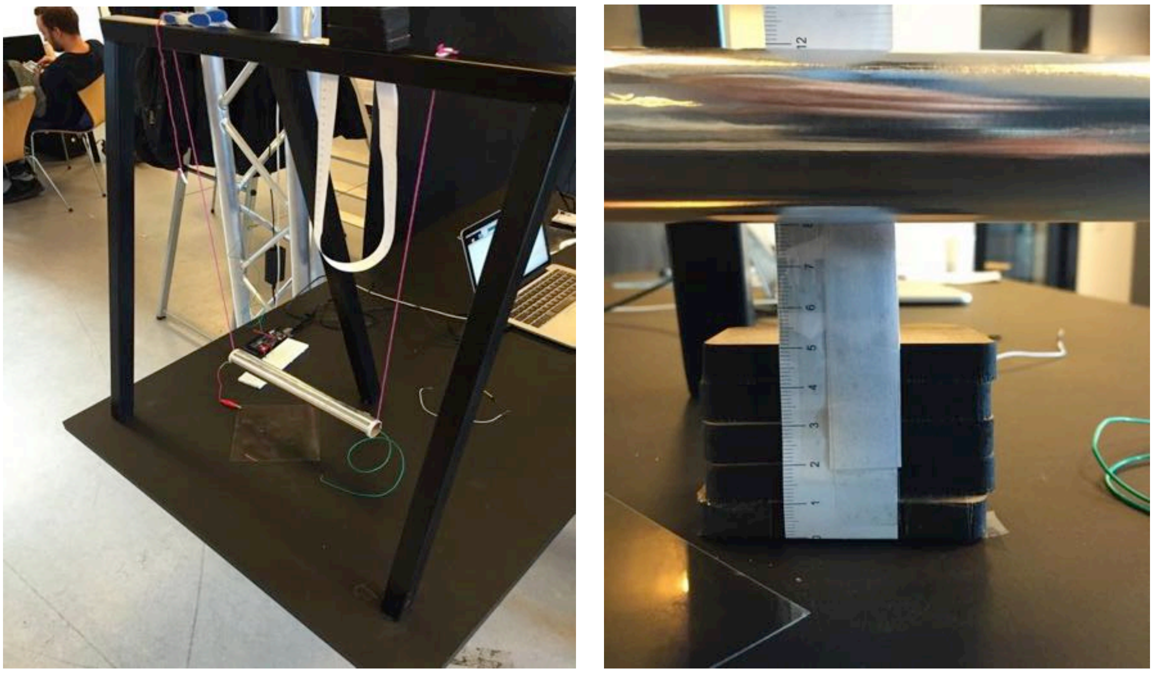
4.7 Experimentation in controlled environment

In this experiment, we further explored the CapSense library and MPR121. This was conducted to investigate the relation between:

- Resistor size
- Stability of sensors readings
- Proximity sensing

To achieve the most usable results, the test was conducted in a controlled environment to avoid as much environmental noise as possible.

The basic setup consisted of a roll of aluminum foil that acted as a surrogate arm. The aluminum foil was then placed above the OCF (picture 9). Depending on the investigated sensor element, different procedures were performed.

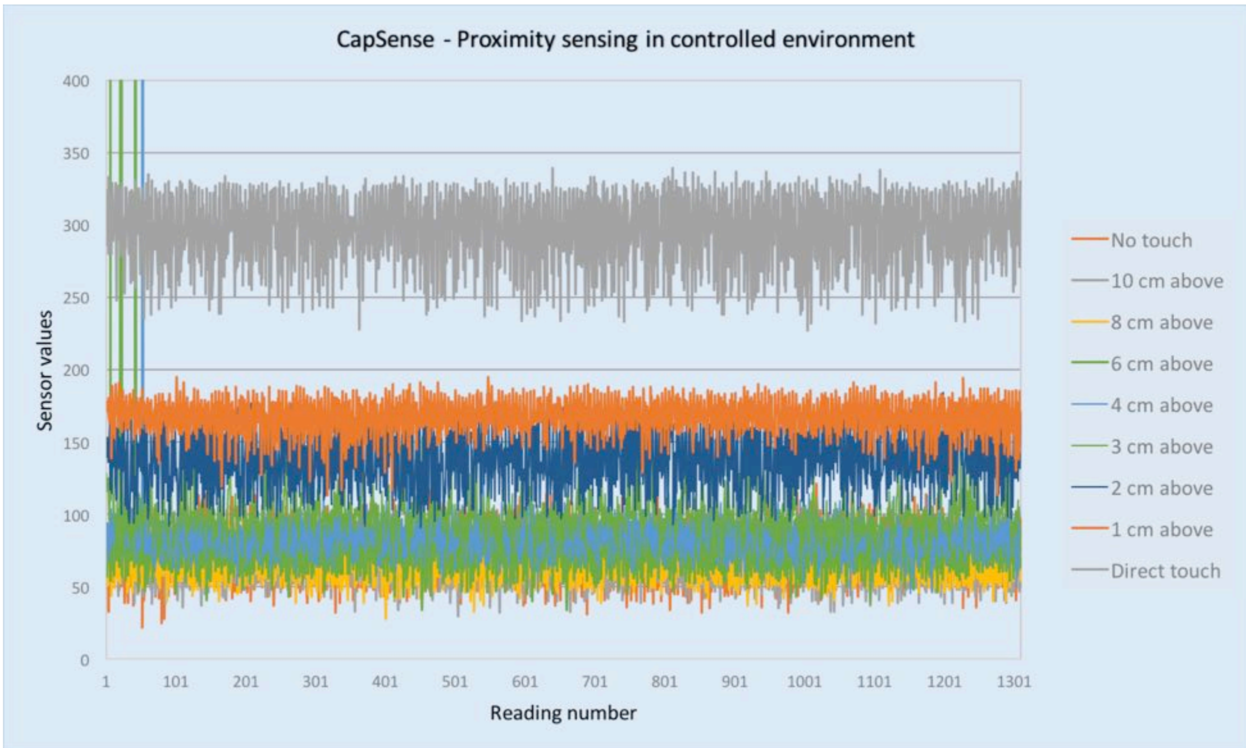


Picture 9: Setup of testing environment.

In the following section we will describe our findings. The first part investigates CapSense whereas the second part concerns MPR121. The data is visualized using graphs from which we discuss the properties of each technology. Finally, we conclude on our observations, and lay the foundation for the upcoming experiment.

4.7.1 CapSense

To measure the distance of which the CapSense starts to react on changes in capacitance the roll of aluminium foil was gradually lowered. The values associated with each height were then collected and the stability and reliability of these readings was observed (graph 1). We used a resistor with the size of 6,1MegaΩ and a sheet of OCF measuring 15x15 cm.

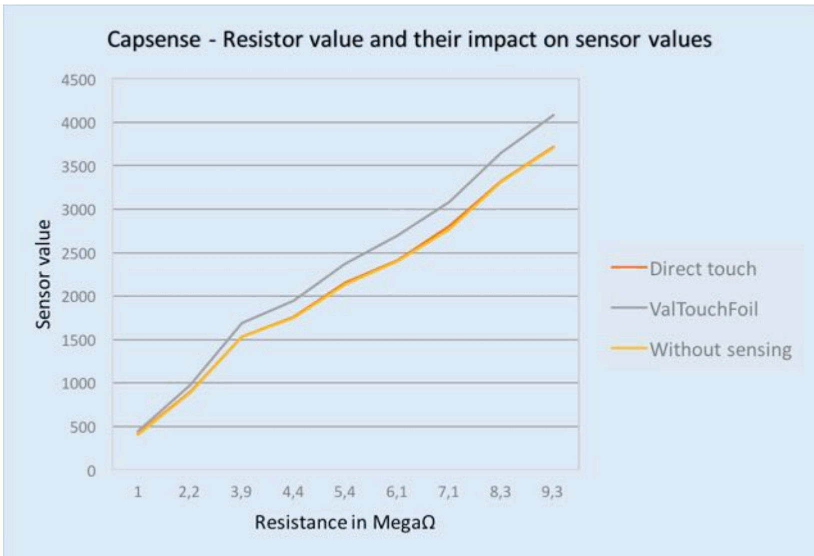


Graph 1: CapSense's capability of sensing reliable in a controlled environment.

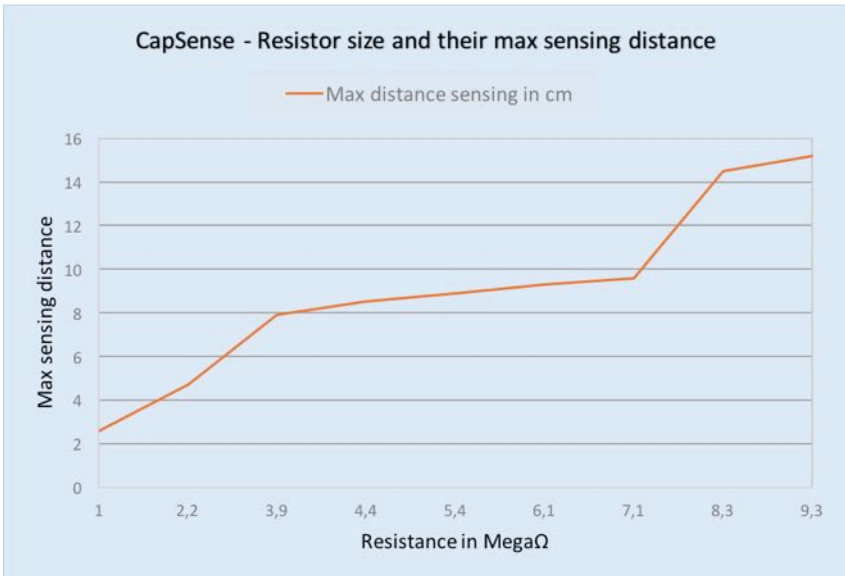
From the data gathered, we observe that there are some large spikes in the beginning of the measurements. We ignore these spikes since they only seem to occur when the Arduino starts. Hereafter the readings become more stable with only a few instances of irregular outputs. Despite the fact that fluctuations increase as the distance decreases and sensor values increase, it is when the distance is below 8 centimeters that we with least uncertainty can infer a specific distance from the electrode to the aluminium foil. The readings above 9 centimeters interferes with each other which makes it difficult to derive any exact distances from the the electrode to the aluminium foil. In addition, the sensing distance has decreased by 4 cm compared to the results from the preliminary tests. We believe that this drop can be explained with the size of aluminium compared to a user's body.

4.7.2 Test Resistance

To investigate the most favorable resistor value to apply to our sensing system, a range of different resistor values ranging from 1 MegaΩ - 9.3 MegaΩ were tested in relation to their ability to enable proximity sensing at various distances in the CapSense setup (graph 2, 3). We excluded resistor sizes of 10 MegaΩ and above since exceeding this limit would introduce multiple other factors that one way or the other could influence the sensor readings [40]



Graph 2: Test with CapSense experimenting with value of resistor and impact on sensor readings in controlled environment.



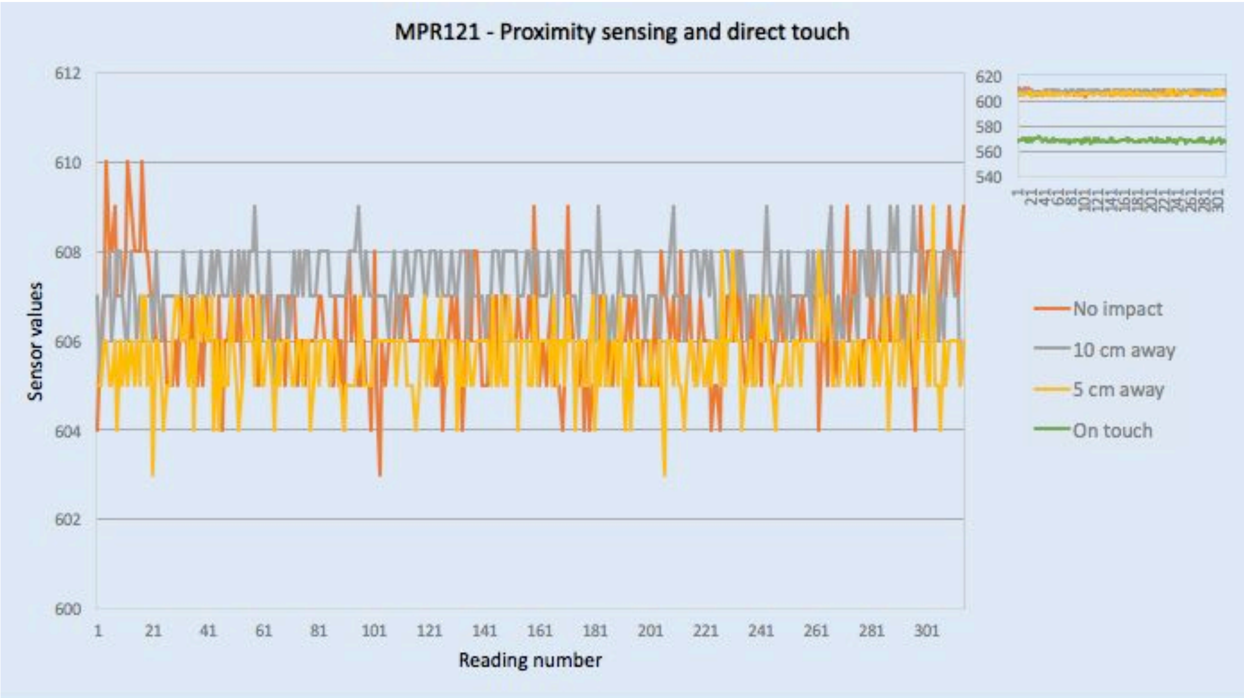
Graph 3: Test with CapSense experimenting with value of resistor and impact on proximity sensing in controlled environment.

The gathered data implies that there is a relative connection between the amount of resistance and sensing distance. The best results with regards to the proximity sensing was achieved by using a resistor value of 9,3 MegaΩ. This enabled sensing at a distance of 14,6 centimeters and the largest difference between direct touch and no touch. Although, the trade-off between using a large and lower resistor is that the readings are more prone to noise from the environment when the resistance increases. For instance, moving the body horizontally closer to the electrode instead of vertically, or simply touching the metal construction also affected the readings. Additionally, we noticed that the update rate of which the CapSense library measures the capacitance depends indirectly on the capacitance measured. Thus, if using a high resistor value and a large capacitor touches the electrode directly, the time between two measurements could increase to more than a few seconds thereby decreasing the update rate and disable reliable tracking of users. We did not experience this problem in our experiment, but depending on the use-case and amount of sensor electrodes, the system would have difficulty tracking a person regularly, thereby missing important interactions.

When comparing our observations of the sensor behavior and the data gathered with the initial requirements, a sensing system with a resistor value of 9,3 MegaΩ would enable proximity sensing at the desired distance.

4.7.3 MPR121

Following the same procedure used to test CapSense's ability to proximity sense with reliability, an experiment was conducted on the MPR121. Compared to CapSense, the MPR121 uses its own chip that handles electrode inputs. As a consequence, we solely tested its ability to proximity sense and provide reliable readings (graph 4).



Graph 4: Test with MPR121. Sensor stability and proximity sensing in controlled environment.

From the MPR121 test data, we observe that the readings fluctuate less than the sensor readings with CapSense. The sensitivity of the proximity sensing is lower and exact distances are more difficult to recognize when using the aluminum foil than we experienced when using a hand in the preliminary test.

Drawing on the experience from changing the size of the resistance in the CapSense circuit, we found that by adding 2,2MEGAΩ to the receiving pins between the MPR121 and the Arduino board made the proximity sensing increase and caused more diverse sensor data without affecting fluctuations in output.

4.7.4 Conclusion and next experiment

An advantage of the MPR121 compared to CapSense, is as follow:

- Only small fluctuations in readings can be used to infer that an object is within sensing distance.
- Implying a change in distance using CapSense requires calculating an average of a larger number of measurements or creating a noise filter.

The two technologies both recognize:

- Direct touch that are quite distinguishable from other readings, although
- They seem to have issues with providing data that with certainty can infer when an object is just within its sensing area. Hence,
- To efficiently track users, we have to rely on sensor readings that might be 1 or 2 cm beneath its actual sensing distance to have trustworthy readings that does not overlap.

In the following section, we will implement the changes and improvements from the results gathered through our experiments. These includes:

- A resistor with value of 9,3 MegaΩ,
- OCF with an area of 15x15 centimeters and
- A wire going from Arduino to ground earth.
- MPR121 will be tested as well with 2,2MegaΩ between pins

The next phase applies these changes and introduces a LED-floor to investigate how a combined sensing and floor system influences sensor readings.

4.8 Experimentation - first test with LED-floor

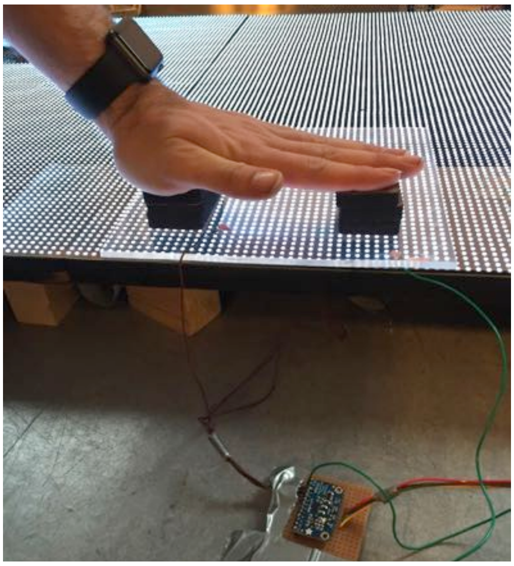
This experiment is conducted to explore how:

- The sensor system behaves when placed on top of the LED-floor.
- The stability of sensors readings.
- Impact of the amount of current running through the floor.
- The sensors ability to reliably detect objects at a distance.

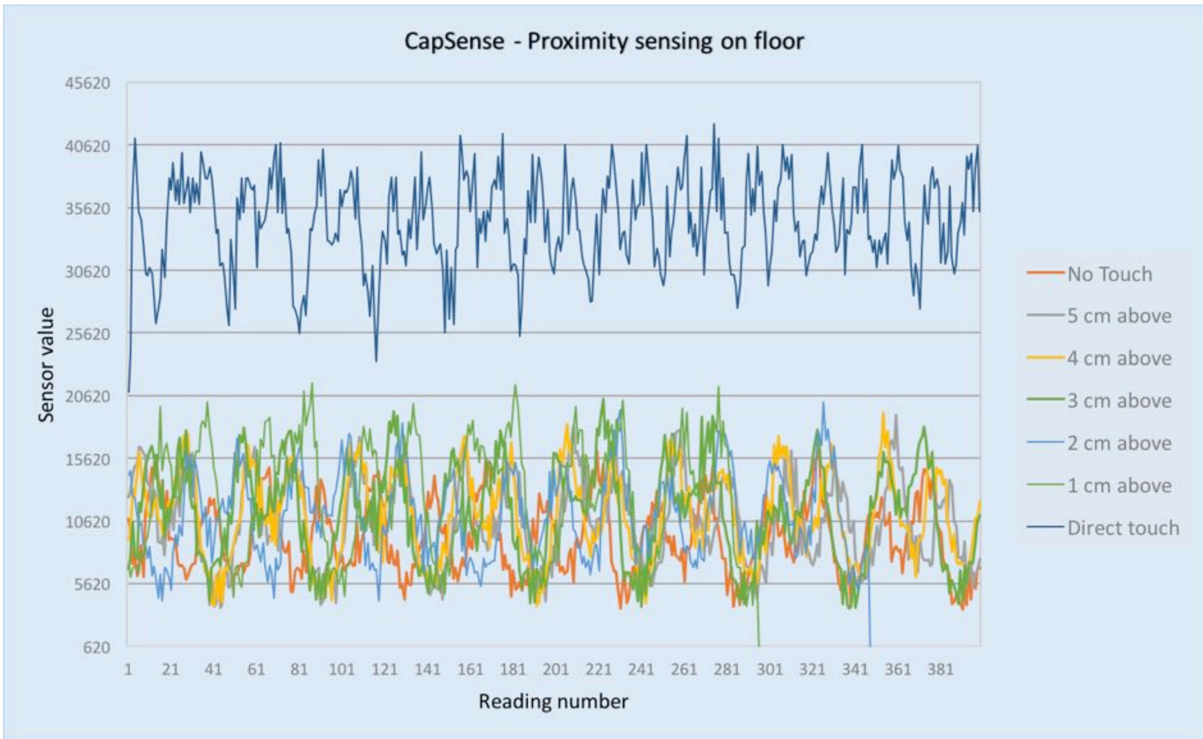
In contrast to the first experiment where a roll of aluminium functioned as the sensed object, we will in this experiment use human body as the sensed object. This is to simulate how senor would function in an authentic use-case. In addition, the setup includes a sheet of OCF placed on the LED-floor which functions as the sensing electrode. The test will both be conducted with the CapSense library and the MPR121. The results gathered will be used to choose the capacitive sensing technology best suited for our use.

4.8.1 CapSense

In the following section we will describe our tests and observations in relation to the CapSense sensing system. The first experiment concerns the stability of sensor readings at various distances when placing the electrode above an LED-floor (picture 10).



Picture 10: Setup of test environment on LED-floor.



Graph 5: Test of CapSense. Stability of sensor readings and proximity sensing on floor.

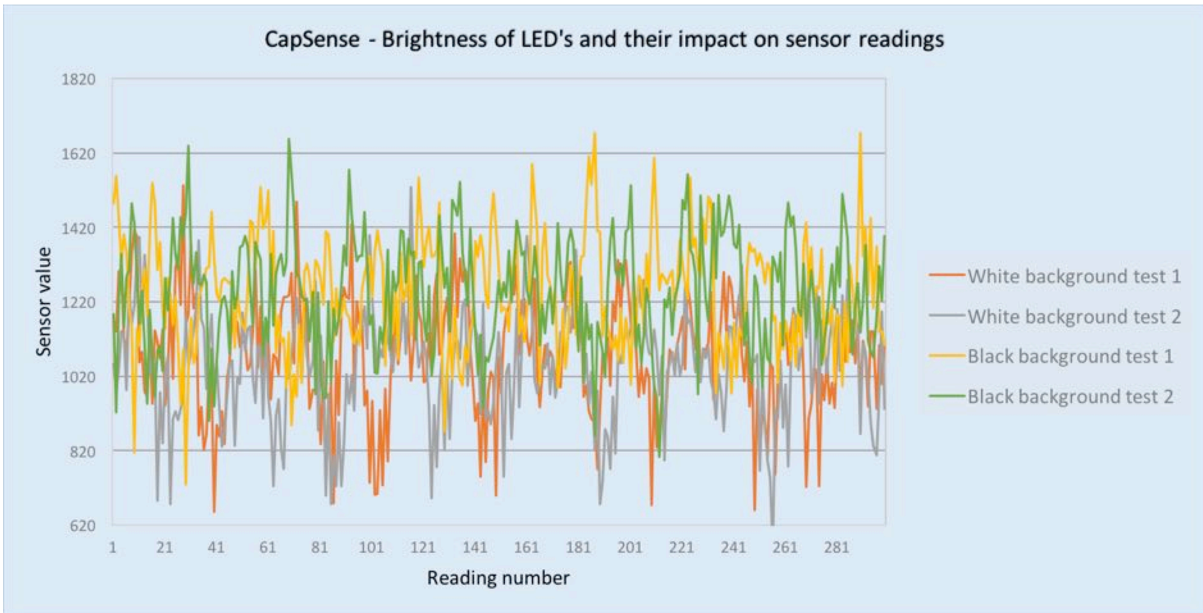
Comparing the sensor readings without the floor to those achieved with the floor, we observe that the fluctuations span a much larger range as shown in table 7 and graph 5.

CapSense	Without floor	On floor
Max distance	14,6 cm	3 cm
Output Span	+- 50	+- 7500

Table 7: CapSense- proximity sensing on floor.

The CapSense's ability to reliably recognize objects decreases from 14,6 cm to 3 cm and even then, there is only little difference between that distance and no touch. This is particularly due to the inherent lack of the CapSense library's inability to filter out noise, which causes the readings from different distances to overlap. As a consequence, the level of certainty of which one can imply that a hand is within a certain distance decreases. The only reliable readings occur when the hand is 1 cm above or touches the electrode directly.

To test whether the brightness of colors from the LED-floor caused different readings, we conducted two tests. One where the LED-floor was black, where the power supplies injected the least amount of current and another where the LED-floor was white, supplying the maximum amount of current (graph 6). The overall brightness of the LED-floor was also set to 15% of maximum capacity by using the LEDSTUDIO 12.



Graph 6: Test of CapSense. Impact of LED-brightness on sensor readings on floor.

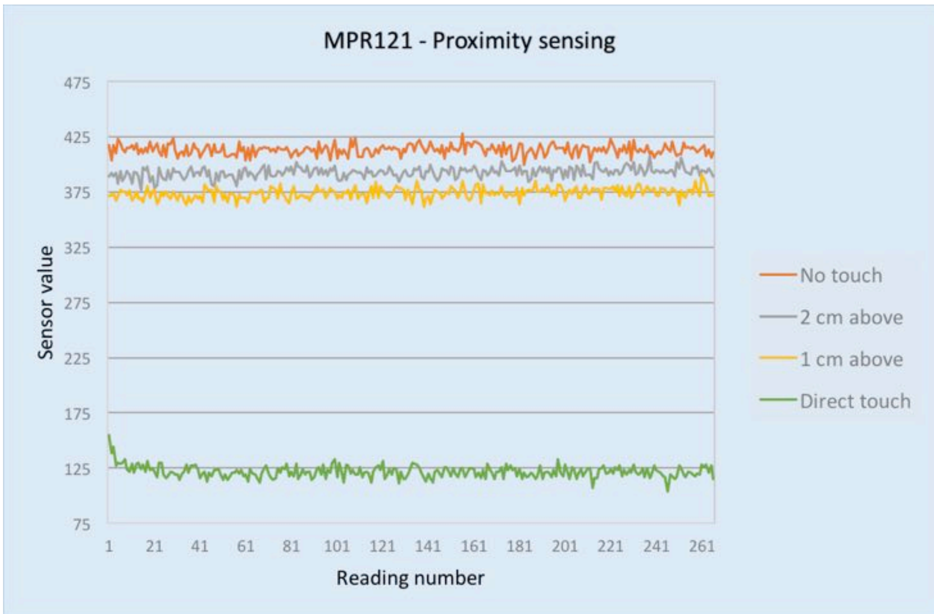
As the data reveals, there is a slight difference in the measurements. The outputs fluctuate at an equal amount as in figure 1, but the baseline of which the fluctuations evolves around is lower when the LED-floor is white than black.

Since there are no other influences on the readings except the floor, we find that the electric field that it generates is what causes the readings to vary. This is backed up by a short experiment where moving the electrode 4 cm above the floor caused the fluctuations to decrease. In addition, a short experiment was conducted in the controlled environment where the electrode was placed upon a table. By locating a hand beneath the same area of the table yielded the same observation, that underlying capacitive objects affected the readings.

The findings show the impact from the floor in relation to the sensor readings and consequently how slight changes caused by the level of brightness also can affect the readings. Hence, when applying this construction, we were unable to achieve readings that were sufficiently stable to infer correct user interaction with the floor.

4.8.2 MPR121

An identical test was conducted with the MPR121. The observations lead to an almost similar result. When testing the MPR121 without the floor, we achieved a reading caused by the aluminium foil up to 10 cm above, whereas with the floor we were only able to get a reading from approximately 2 cm above. Furthermore, as it was the case with CapSense, the fluctuations of sensor readings span a greater range (graph 7).



Graph 7: Test of MPR121. Sensor readings and proximity sensing on floor.

In contrast to the test results received from the CapSense system, the three measurements conducted from direct touch to 2 cm above, are quite differentiable and provide sufficiently reliable data to infer a distance with certainty. Graph 8 also provides reasonable data to believe that it can sense up to 3-4 cm above.

4.8.3 Conclusion and next experiment

These tests expose the impact from the environment, and in particular how the LED-floor impacts sensor readings. We found that both technologies:

- Provided less reliable sensor readings and a decreased ability to sense objects above 5 cm.
- Is affected by underlying capacitive objects, such as the floor.
- Sensor readings changes according to the brightness of the LED’s

Findings from the experiments with MPR121 includes:

- From direct touch to 2 cm above, readings provide sufficiently reliable data to infer a distance with certainty.
- Only minor increase in fluctuations concerning sensor readings.
- Were only able to get measurable reading from approximately 2 cm above.

Findings from the experiments with CapSense includes:

- Major increase in sensor fluctuations
- Ability to reliably recognize objects decreases from 14,6 cm to 3 cm.
- Only small measureable difference between 3 cm above direct touch.

Compared to the requirements, a sensing distance of 10-15 cm is most desirable. In the next section we will investigate how such a distance and more stable readings can be achieved by implementing a shield that limits the impact from the LED-floor.

4.9 Experimentation – shield test

To investigate how a shield affects sensor readings, a sheet of OCF connected to ground was placed between the electrode and the floor as seen in figure 11. A silicone mat was then placed in between the electrode and the shield creating a gap of 1 cm.

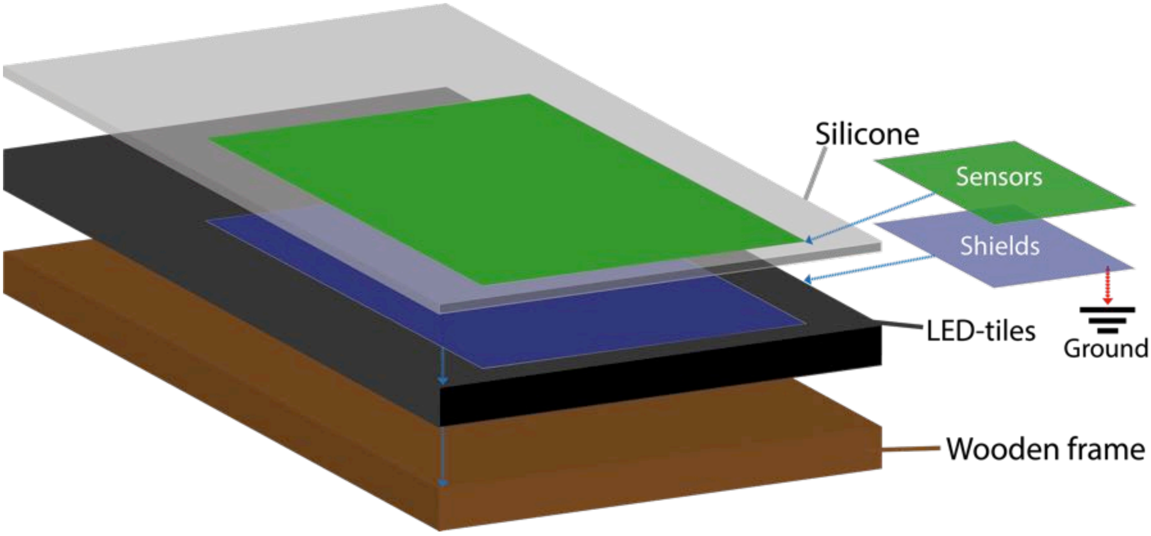
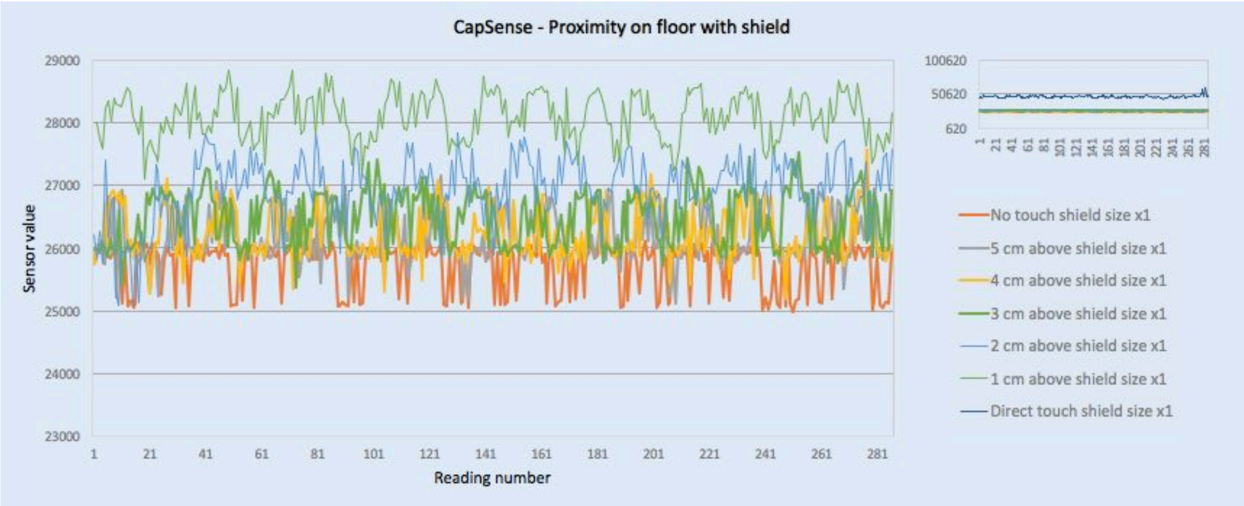


Figure 11: Overview of sensor setup.

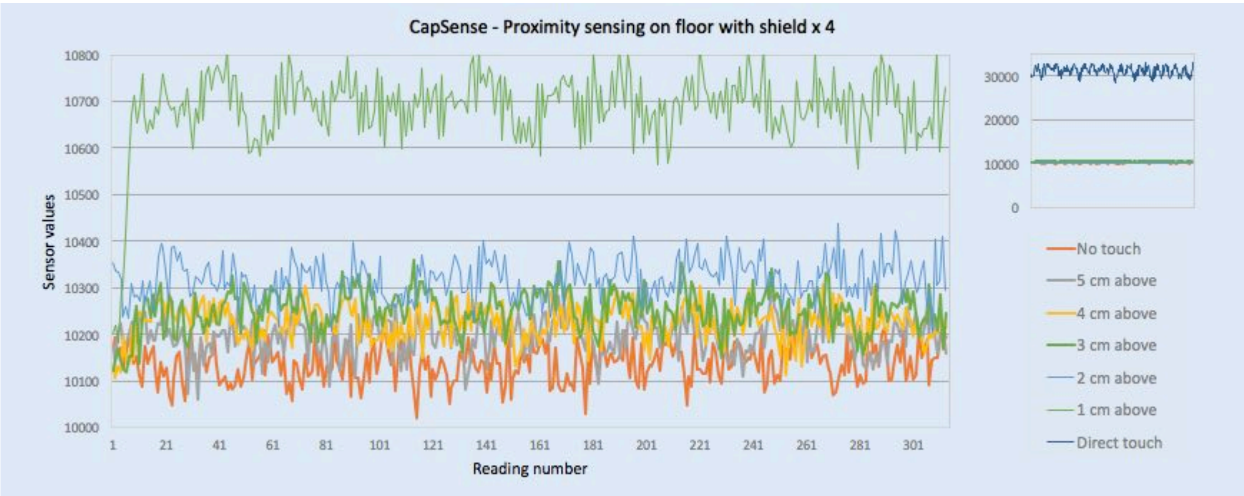
The results are described below and will be used to describe the specifications of our final sensing system and argue the design choices taken.

4.9.1 CapSense test

To measure the stability of readings from various distances, a series of measurements was conducted. The construction of the CapSense sensing system is identical to the one used in the experiments with the LED-floor, thereby only testing the implementation of a shield and its effect on sensor readings.



Graph 8: Test of CapSense. Sensor reading and proximity sensing on floor with shield.

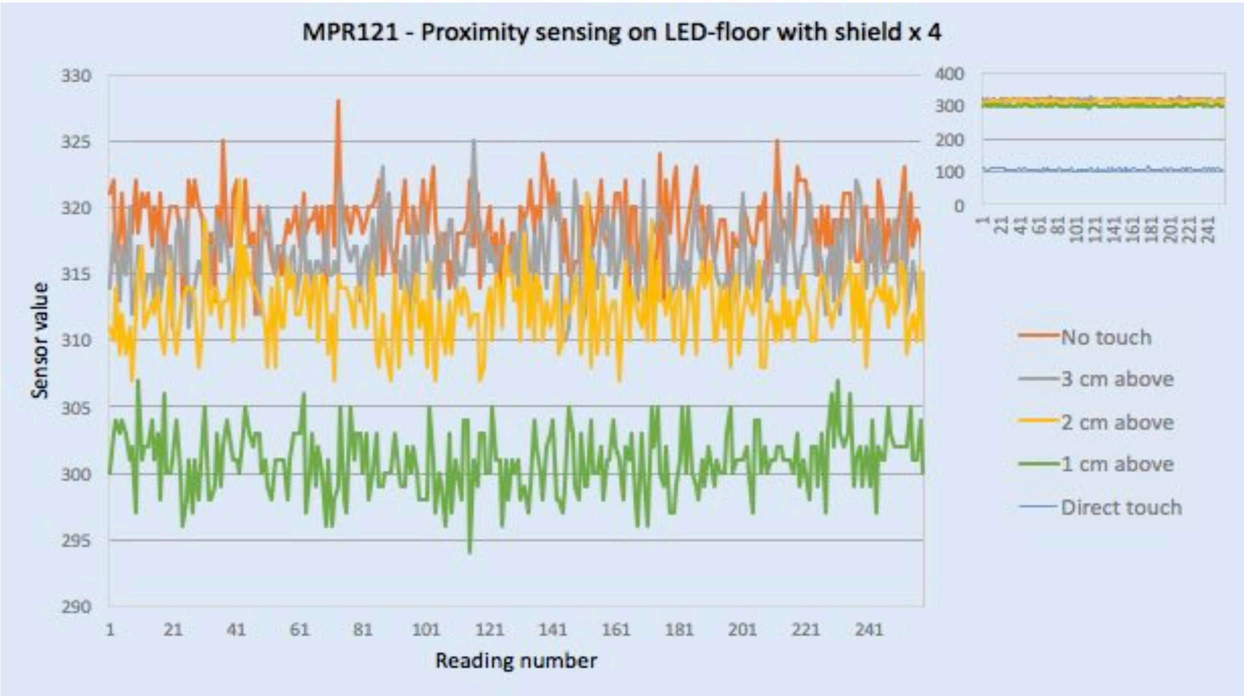


Graph 9: Test of CapSense. Sensor reading and proximity sensing on floor with shield x 4.

By observing graph 8 and 9, we notice that despite readings from each distance randomly overlapping each other, it is possible to make a reasonable separation of sensing objects from 5 cm above to direct touch. Although, when exceeding this limit, the sensing system is not able to sufficiently detect radical changes in capacitance. In addition, the certainty of which we are able to infer a certain distance could be enhanced by cancelling out noise and simply calculating the average for each distance. Furthermore, the fluctuations are pretty stable over time, which argues for a more robust sensing system that does not have to be recalibrated regularly. In relation to the results found in the experiment without the shield, the sensor values have increased stability and only varies between +- 1000. As a result, the sensor readings in relation to each distance are distinguishable from each other, which was not the case in the test without the shield.

4.9.2 MPR121

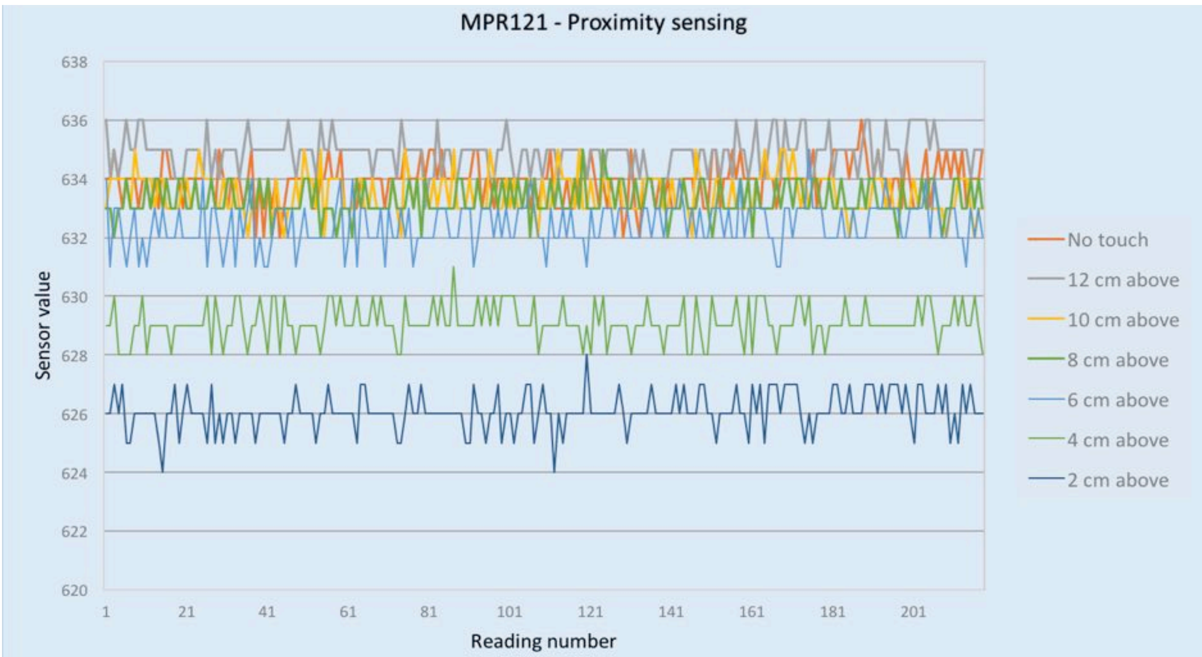
Conducting the same experiment with the MPR121 produces partially the same results - decreasing fluctuations in the sensor values and blocks out some of the noise produced by the LED-floor (graph 10). Although implementing a shield caused improved and more distinguishable readings than with CapSense, the same changes do not have any significant influence on the readings with MPR121 compared to the test without shield. Neither the distance of which we are able to sense from or in which degree of certainty we can imply how close the sensed object is to the electrode, improves substantially compared to the earlier results.



Graph 10: Test of MPR121. Sensor readings and proximity sensing on floor with shield x 4.

By implementing a sheet of OCF between the electrode and the LED-floor, we have decreased sensor fluctuations, thereby improving sensor stability by eliminating some of the noise produced by the floor. In spite of these results, the test yields no results that can lead to any conjunction that sensors are able to detect objects above 5 cm if they are placed close to the LED-floor. To test whether the distance between the floor, shield and electrode can be altered to fit our requirements further experiments was conducted. In addition, we applied more current to the electrode connected to the MPR121.

While changing the distance between the mentioned elements did not provide any considerable changes, the changes in current injected into the electrode increased the MPR121's ability to sense our hand at a greater distance. By drawing on the findings from earlier experiments, we explored in which degree we could decrease the size of the electrode while still maintain acceptable proximity sensing. Hence, to avoid as much influence from the LED-floor, we decreased the size of the electrode and incremented the size of the shield beneath. Multiple tests were then conducted until we reached an electrode and shield size that provided the best results.



Graph 11. Test of MPR121. Sensor readings and proximity sensing on floor with shield with increased current.

Graph 11 shows that the MPR121 starts detecting a hand at a distance of approximately 10 cm. When decreasing the distance between hand and sensor even further, sensor values keep decreasing towards the last reading at 2 cm. Observing the data, the difference in sensor values seems to be larger as the hand comes closer to the electrode. Thus, the most reliable results are achieved at a distance of approximately 4 cm and below, but as it was the case in earlier experiments, calculating an average of a few measurements would sufficiently imply that an object is within the maximum sensing distance. For instance, at no touch and when holding a hand 12 cm above the electrode, sensor readings stays within the interval of 632-636 with more readings above 634 than below. When holding a hand 10 cm above, the sensor output readings from 632-635 with the majority below 634. Thus calculating an average over a number of measurements would infer an object at 10 cm distance.

4.9.3 Conclusion and next experiment

In the test we ended up using the MPR121 connected to an OCF electrode measuring 5x5 cm and with a 3 x OCF-sheets with the size of 15x15 cm as shield. In between the sensor and the shield, a 1 cm silicone matt that was used as a divider between the sensor and the shield. The shield was placed directly on the LED floor with the non-conductive side facing the LED-floor.
In relation to the findings from previous experiments conducted on the LED-floor with shield, there is an improvement in sensing distance and electrode size. Especially compared to CapSense, these aspects enable higher tracking resolution and other forms of interaction that complies with our initial requirements.
Based on the experiments with capacitive sensing technologies, we find that the capabilities of the MPR121 best supports exercise guidance on our interactive floor. This is due to the following:

- System does not have to be recalibrated.
- Sense conductive objects reliably at a distance of 10 cm.
- Can use the transparent OCF as an electrode.
- Sufficiently stable readings over time.
- Detect multiple inputs simultaneously.
- Its capability to filter out noise from the environment.
- Able to apply smaller electrodes, thereby increasing tracking resolution.

The following experiment implements multiple sensors installed accordingly to the findings above. The electrodes are individually coupled to the MPR121 breakout board’s touch pads.

4.10 Experimentation - test with multiple sensors

The preliminary test focused on the sensing capabilities using one electrode. In the following section, we integrate multiple sensors into the interactive floor to investigate possible interaction procedures and if implementing multiple sensors impact the stability of sensor readings.

The construction used is illustrated in figure 12.

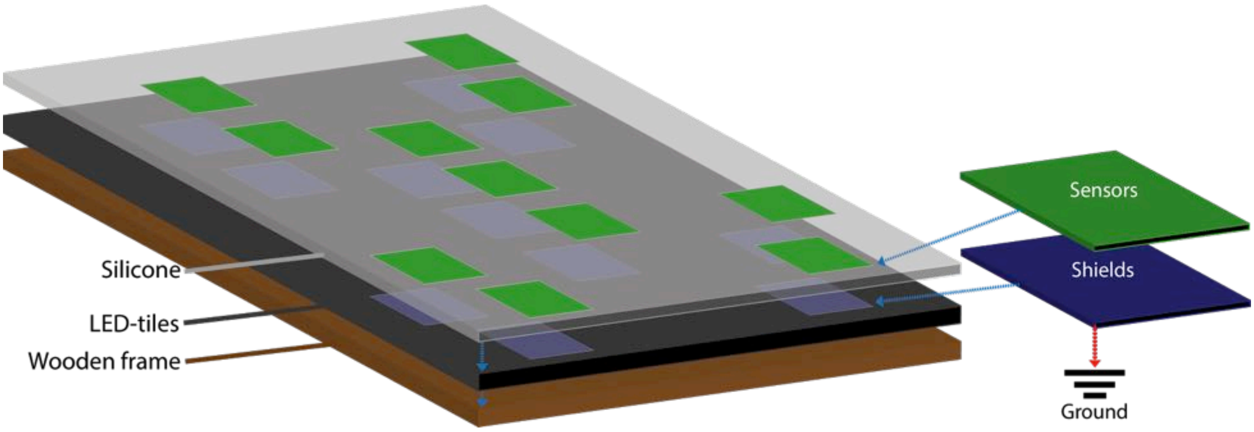
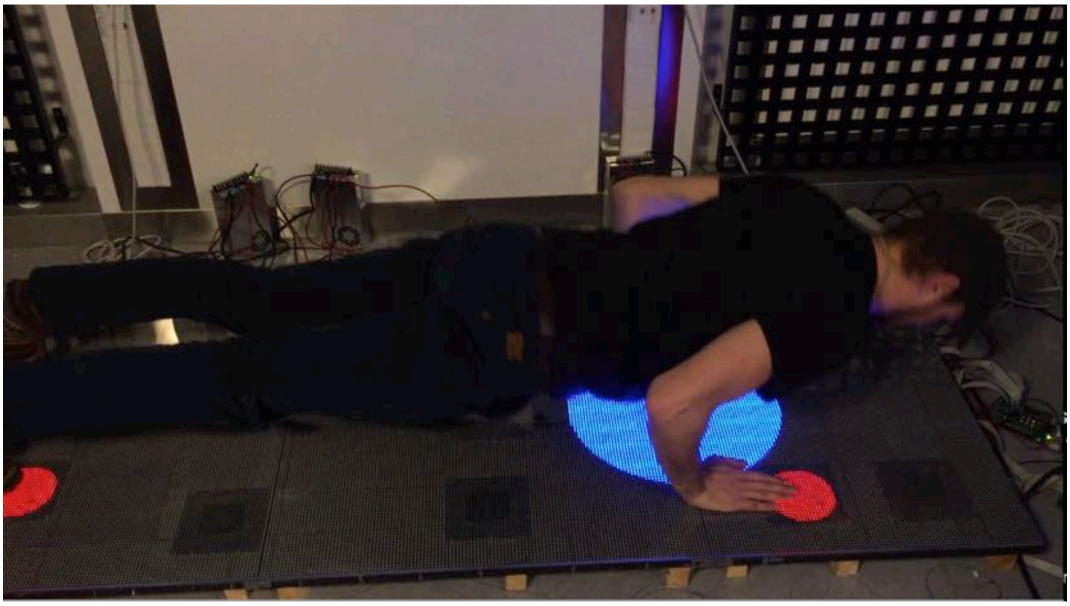


Figure 12: Floor implemented with multiple sensors.

12 sensing electrodes were implemented to investigate how a number of sensor readings could be combined to enable different interaction methods and recognition of body postures.
To illustrate the basic interaction, Processing was used to create visualizations that changed depending on the interaction. Three main methods of interaction was tested:

- Distance sensing on multiple sensors simultaneously
- Direct touch on multiple sensors simultaneously
- Direct touch and distance sensing simultaneously for recognizing body posture

During our test, we were able to interact via proximity sensing and direct touch. Additionally, by combining data from direct touch and amount of proximity, we were able to recognize a “push-up-posture” and increment number of push-up repetitions executed (picture 11).



Picture 11: multiple sensor test - Push-up

Concerning sensor stability, we observed that, placing sensors in the same circuit and close together, impacts sensor readings. The more impact one sensor gets, the more it influences the others. For instance, if one sensor recognizes direct touch, it influences the other sensors in higher degree than if it only recognized proximity. Even though direct touch only decreases the other sensor readings with a few values, it still impacts the overall possibility for proximity sensing. Another issue we experienced in our particular setup, is that wires running along the floor to the sensing electrodes can recognize small changes in capacitance when in direct touch with limbs. As a consequence, standing on a wire can imply that an object is in proximity above the sensing electrode, which is actually not the case.

One element to consider is that, since the impact is consistent, calculating the baseline for each sensor at startup, takes the impact into calculation. As a result, we altered the baseline value to take these drops in sensor readings into account. This led to a sensing distance of 5 cm Instead of 10 cm.

4.10.1 Summary - test with multiple sensors

During the test, we achieved a sufficiently reliable proximity sensing of 5 cm. This enables interaction procedures such as swiping and enables tracking of high-level posture and human limbs. Yet, without being able to differentiate between hands or feet.

4.11 Summary of results from experiments

Based on the experiments conducted in part 1 - 5 with capacitive sensing technologies, the most interesting results in regards to our interactive floor is as following:

From the preliminary test, we learned the following:

- Proximity can be reduced or enhanced at the cost of sensor resolution and stability
- Shields can be applied to reduce noise from the direction its places
- Capacitive touch works at stable at every sensor size
- There is a relation between proximity and sensor size
- Using filters with the MPR121 in relation to CapSense which has none - helps with stability but reduced to some extend the sensitivity
- CapSense is more sensitive to objects with less capacitance

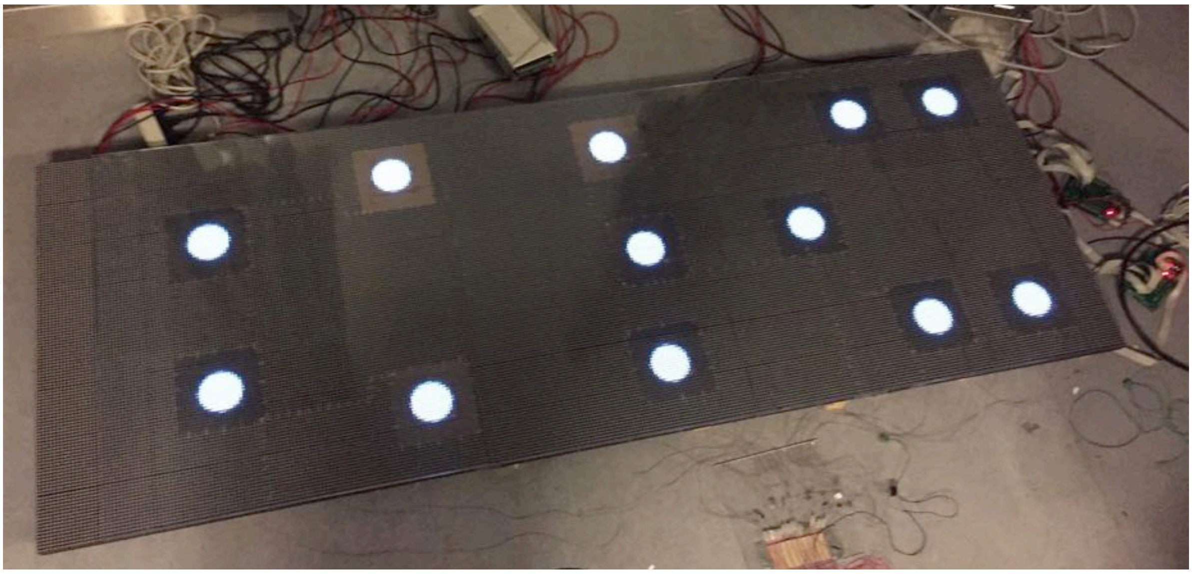
When testing the MPR121 and CapSense library with one sensing electrode, we achieved a sensing system capable of the following:

- System does not have to be recalibrated.
- Sense conductive objects reliably at a distance of 10 cm.
- Can use transparent OCF as an electrode.
- Sufficiently stable readings over time.
- Detect multiple inputs simultaneously.
- Its capability to filter out noise from the environment.
- Able to apply smaller electrodes without remarkable loss of proximity sensing, thereby increasing tracking resolution.

When implementing multiple sensors, we achieved the following results:

- Placing sensors in the same circuit and close together, impacts sensor readings.
- Wires running along the floor to the sensing electrodes can recognize small changes in capacitance when in direct touch with limbs.
- We achieved a sufficiently reliable proximity sensing of 5 cm.
- Enables swiping and tracking of high-level posture and human limbs.
- Unable to differentiate between hands or feet.

Our experiments ultimately accumulated in the creation of CapFloor- an interactive LED-floor based on capacitive sensing (picture 12).



Picture 12: CapFloor.

Table 8 summarizes the capabilities of CapFloor in relation to our initial requirements.

Requirements	CapFloor
Able to recognize users from distance and infer body postures	Able to recognize users within a distance of 5cm. Depending on the input, we can infer different postures if they take place within sensing proximity without problems with occlusion.
Discern between distances	Sufficiently discern between distances from 5cm to direct touch.
Robust to interaction and environmental changes	MPR121's integrated filter eliminates much of the environmental noise. A silicone mat and oilcloth makes it robust to direct interaction.
Easy to install	To some degree. Assembling the system from scratch takes time and is difficult. If the elements come pre-made, it is almost plug-and play.
Not obstructive and transparent	Using transparent conductive sheets, the sensing surface is transparent and does not cover the LED's.
Multiple inputs	Using separate electrodes placed on dedicated positions, we can register multiple inputs simultaneously.

Table 8: Comparison of initial requirements and the capabilities of CapFloor.

In the next design phase, we will test and evaluate CapFloor in accordance to guiding and motivating people during the workout.

4.12 Final interaction test

In this section we test how capacitive sensing and an interactive floor can be combined to provide guidance and feedback during various exercises. The test is conducted with 3 participants and contained two types of evaluation methods.

The first is a combination of *opportunistic evaluation* and *controlled setting involving users* [41]. Here, we tested CapFloor with a working training guidance system. Since not all of the exercises were developed for CapFloor, the second part of the test was made as a *Wizard of Oz* [41] where we could simulate these exercises. The reason for adding this test, was to obtain a more diverse evaluation of the system's capabilities with different exercises. Subsequently, additional information would lead to a more comprehensive comparison with other technologies and test of the identified requirements from the contextual inquiry.

During the test, the participants were asked to do a number of exercises on the floor. Meanwhile, the participants were asked to think aloud to provide feedback. Additionally, we video-recorded and observed how the participants reacted, interacted and responded to the tasks they encountered.

The primary goal of the test was to gain early insight about the usability of CapFloor and if users could see the potential of using it as workout and exercise tool. Secondary goals concerned:

- Use of CapFloor as a guidance and feedback system?
- Do users feel engaged and motivated?
- How do they experience the use of the floor?

In the following section, we describe our findings from the usability test. Table 9 illustrates the exercises involved in the test and includes related citations concerning the suitability of doing a specific exercise on CapFloor. Subsequently, we describe and comment on the feedback obtained concerning the general suitability of using CapFloor as a guidance and motivation system during user's workout.

The exercises included in the test opportunistic evaluation in a controlled setting, are push-up and core, whereas, lunges, bridges, sit-ups and squad are tested through simulation of these exercises.

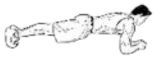
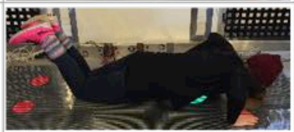
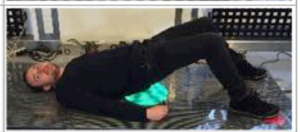
Exercise name	User comments	Postures	Suitable for CapFloor	Usability test
Lunges	"I think exercises like core, pushups and lunges works the best - exercises where i can see the impact on the screen"		✓	
Core	"I want to see what happens when I complete the exercise, so i push myself more than when just counting repetition"		✓	
Push-ups	"it is hard to reach the hands and feet position at the same time" "i can only make lady pushups is that possible"		✓	
Bridges	"If i could hear when i made a correct bridges repetition and when i was done it would still make me want to do it on this floor "		✗	
Situps	"There is not much to see when i make situps, but if the counter is between my feet i can see the counter but not when it registres a repetition."		✗	
Squat	"It is hard only to be able to do really deep squats, My knees are not happy about that"		✗	

Table 9: Overview of exercises tested

As table 9 shows, lunges, core and push-up exercises are the most suitable exercises for CapFloor. This is due to having the head directed towards the floor, which make it possible to see the feedback from the floor during the exercise. To incorporate less suitable exercises such as bridges and sit-ups, further feedback such as sound or vibration needs to be implemented to make these exercises beneficial as interactive floor exercises. Squat can only be incorporated with a loss of correct performance. Therefore, squats need to be avoided as an exercise or implemented through external sensor data such as smartphone.

Concerning the general use of the floor, we observed multiple aspects that could be improved. In relation to the construction, cracking noises occurred when people walked or in other ways interacted with the floor. In the beginning, this caused the users to interact gently and constrained, but as they got used to it, the interaction became more natural.

In relation to motivation, the participant felt more inclined to conduct more repetitions. This was mainly due to the counter keeping track of the number of repetitions or time elapsed.

- *"I want to see what happens when I complete the exercise, so I push myself more than when just counting repetition"*

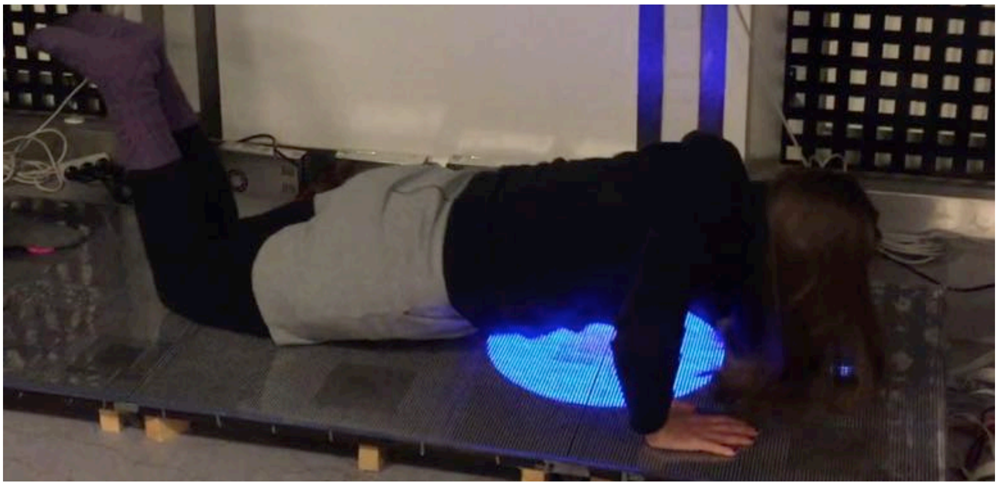
Another aspect that motivated the participants were the graphical guidance they were presented with.

- *"I feel I need to do the exercises when it tells me to do them - it's like when I do what my watch tells me for example when it tells me to stand up or move more".*

The graphical representations can also be improved. In the test, the graphical representations were static and this caused the participant to doubt if they conducted an exercise correctly, or if they conducted it at all. To solve this, they requested more feedback or more dynamic changes in the graphical representation depending on how close they were to do the exercise correctly. Subsequently, they felt that abstract representations of real world artifacts provided more interesting interaction instead of just using geometrical shapes.

- *"Maybe it would be more exciting if the dots could change color or if they were somehow animated like with the leafs - it could be like training on pillars similar to the Shaolin Monks".*

They also proposed, that games could engage and motivate them even further. In addition, they commented on the position of sensors and graphical guidance that the distance between them did not fit their body measurements, which resulted in awkward body postures when they, for instance, made push-ups (picture 13).



Picture 13: Usability test- lady push-up.

Even though we experienced some technical glitches during the test, the overall response to using CapFloor as a tool to enhance workout results was positive.

4.12.1 Summary of user-test

Through our usability test, we acquired knowledge concerning how and if CapFloor can be used to provide feedback and motivation during user's exercises. Even though it is a concept at an early stage, we found substantial reason to suggest that CapFloor can do so. Still, various improvements and further exploration has to be carried out before reaching a product that is qualified for implementation into a real use application.

The main findings from the user-test includes:

- Construction needs to be robust.
- Sensors need to cover the entire floor.
- Exercise programs needs to be made dynamic to fit body size.
- Guidance and diversity in feedback increase motivation.

In accordance to training exercises tested, we found:

- Lunges, core and push-ups were most suitable.
- Bridges and sit-ups need additional feedback.
- Squats need additional data – or should be avoided.

The following section summarizes the overall design process.

4.13 Summarizing the Design Process

We have in our design process been through an iterative process with several cycles, where we investigate how to create an interactive floor for training purposes. In each cycle, research and experimentation has been conducted to gather information about capacitive sensing, floor requirements or user interaction.

The design process was initially based on an interactive training floor idea from our early brainstorming sessions. This was investigated through observation, interviews and bodystorming in our contextual inquiry to set the requirements for the following phases. As a part of the next phases prototyping and experiments was made to investigate both the building of the screen and the choosing of sensing technology. An extensive exploration of capacitive sensing was performed in order to learn about how to use it together with LED panels. This involved splitting the experiments up in smaller experiment where only a few factors influenced the capacitive sensor at a time. The final prototype CapFloor was build with 12 sensors placed on top of the LED panels. To investigate if CapFloor had the potential to act as an interactive training guidance system, we made a usability test with 3 users.

Our usability test showed that CapFloor needs to implement sensors covering the entire surface so the programs can be made dynamical to the user's size. Furthermore, visuals representation and feedback needs to be investigated further to enable a diverse and motivating experience. Lastly, the construction needs to be made more robust for more extensive testing and use. Even though these aspects impacted the user experience and use of CapFloor, the overall feedback from the participants was positive.

5. Discussion

In this chapter we discuss how capacitive sensing can be applied to an interactive luminous floor and how such a floor can be utilized to provide feedback and guide users through training exercises. This includes discussions related to:

- Our findings compared to existing interactive floors that use capacitive sensing.
- General advantages and limitations between capacitive sensing and other alternative technologies.
- A more thorough discussion of the advantages and limitations between front projection and capacitive sensing.
- Suggestions on the opportunities future work for capacitive sensing

5.1 Advantages and limitations

Based on our design process we have found that capacitive sensing can detect conductive objects in proximity and direct touch. The data from the sensors can then be used to infer body posture and thus guide and provide feedback to users through their exercises. Compared to TileTrack [25] and Smart Carpet [24], it can be discussed in which degree these findings can contribute to the way they track and position people. Our research differentiates itself from these projects by providing visual feedback and integrating transparent sensors that make it unnecessary to install the sensor system beneath the floor. As a result, such a system can make any surface interactive, both luminous and nonluminous, without altering the environment. The shortcomings of doing so, is that the interactive surface becomes more vulnerable to technical errors. Particularly, if the interaction includes jumping or other stressful interaction methods. In relation to exercising, such problems also have the opportunity to impact sensor readings or cause other errors. By guiding the user interaction through visual feedback, such damaging behaviors can be avoided. Other limitations in relation to exercising and providing correct and motivational feedback is the distance of which we are able to sense a user's limbs. We achieved reliable measurements up to a distance of 5 cm, which in many exercises, predominantly those where the exercise is taking place close to the floor, is adequate to recognize correct body posture and interaction. Those exercises that require the limbs to move consistently above the maximum sensing distance are not suited for our interactive floor. In this case, sensor fusion techniques could provide the additional data needed for recognizing these gestures.

5.2 Comparison with present interactive floors

Despite the shortcomings, the general advantages of using capacitive sensing with luminous floors seems to eliminate some of the properties that limits both interaction with, and the construction of present interactive floors. Based on table 5, front projected floors, such as the Wizefloor, generally suffers from occlusion and shadows when the users enter the surface. This is especially the case when the user is standing just beneath the tracking camera and projector or when multiple users use the interactive surface simultaneously. Such installations can potentially benefit from applying a capacitive sensing surface and a LED-floor, thus eliminating the aforementioned issues. Additionally, this would enable new methods of interaction and eliminate some design problems (picture 14).

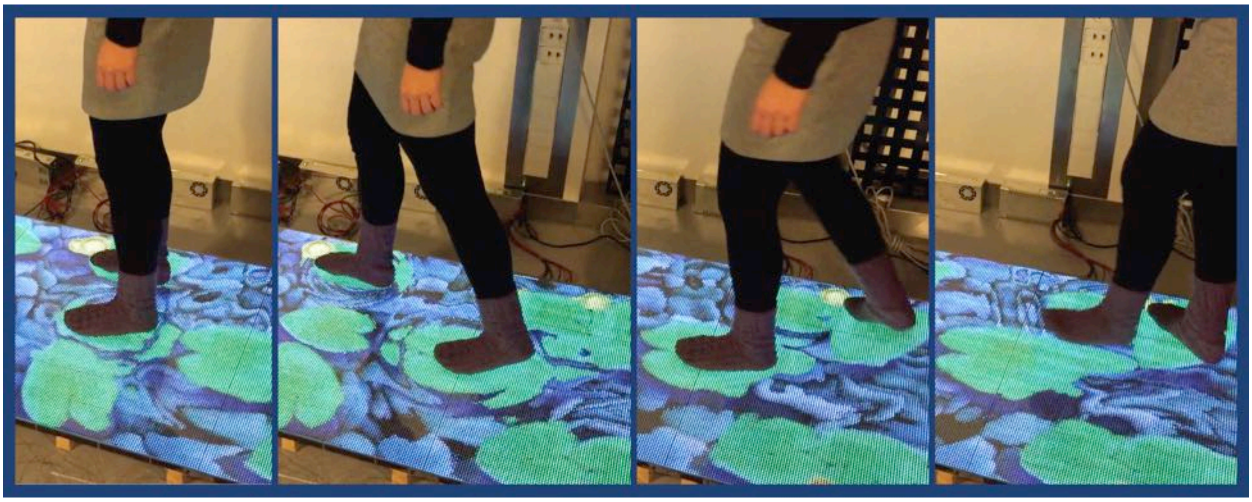
Picture 14: Left: interaction with Wizefloor. Video-link: https://youtu.be/3GBx9kIvSmg.
Right: interaction with CapFloor. Video-link: https://youtu.be/gHZzgFhhzCM

For instance, the games or learning applications offered by Wizefloor are designed specifically to avoid problems with occlusion and shadows. As a consequence, the graphical elements users interact with are placed along the edge of the projected surface. Thus, to avoid problems with occlusion, users have to stand outside of the interactive surface. From there they can use their feet to interact with the graphical representations by either hovering over or touching the surface directly. To “select” an element on the graphical surface, the users then have to dwell their feet above the element they want to choose. In CapFloor, interaction can be achieved by using the same delimiter, but it also enables using tapping as an additional delimiter.

A consequence of using dwelling-time, is that, walking across the interactive surface can cause unintentional selections of elements. As a result, applications where the entire interface has to be used, users have to walk around the projected surface to successfully interact with the desired element. Solving these issues using front projection would require installing multiple cameras and projectors that each have to be calibrated in relation to each other. Another solution could for instance be accomplished by using back projection, but compared to capacitive sensing, the construction of this is extensive and greatly influences the environment.

Above, we have discussed some of the advantages of applying our proposed approach to Wizefloor. In the following, we will discuss the shortcomings and potential issues in regards to this.

As it is now, a front-projected floor, like Wizefloor, offers a stable and reliable technology. Additionally, much software already exists and the area of full body-interaction with games has led to advanced tracking technologies such as the Kinect. Thus, successful integration with interactive floors and further into environments is a feasible task. Subsequently, by drawing the technology away from the floor and into the ceiling minimizes the risk of technical issues. In contrast, our technology is directly involved in the user interaction. This causes a potential risk for system failures and broken electrical circuits, especially when dealing with interaction from children and young adults. Problems also add up when taking into consideration the amount of sensors and LED's integrated into the construction of CapFLoor. Another issue that potentially could impact the user experience and interaction is the resolution of the LED's which constrains advanced graphics and text. Although when evaluating computer games one aspect concerns their ability to create trustworthy animations, it is vaguer how resolution impacts interaction and user experience with interactive floors. Taptiles [6] implements a low resolution display of LED's with a lower density compared to ours and explores user interaction. The majority of their study concerns user interaction with the floor and how text is perceived. Their results show, that users intuitively use their feet for selection and that changes in LED density do not appear to have an effect on reading accuracy. Subsequently, they advise that Taptiles is more suited for casual and brief interaction than more complex interaction processes. Applying these results to our findings results in an interactive floor that, in regards to the interaction with front projected floors, does not seem to fall short (picture 15).



Picture 15: Interaction with CapFloor and an example of screen resolution. Video-link [https://youtu.be/gHZzgFhhzCM]

A comparison between the graphical elements used in Wizefloor and how users perceive text in Taptiles is difficult to conduct. But following the general guidelines from Taptiles, it appears that in complex interaction applications used in Wizefloor, a LED floor would be insufficient and decrease user experience while a LED-floor in less complex applications would be sufficient. Yet, this is something to explore in future work.

5.3 Capacitive sensing and its opportunities

Based on the discussion above and table 5 it is clear that each technology contains advantages and limitations. Thus, when choosing the right technology there are multiple considerations. In this section, we will discuss different constructions that can alter the sensing capabilities of CapFloor and its shortcomings. Consequently, we propose usage applications where we find CapFloor most suitable.

Throughout the design process, we have investigated and tested capacitive sensing. This has been carried out to meet our initial requirements, but the experiments conducted and previous work on capacitive sensing shows supplementary opportunities. Amongst these is the possibility of altering the size of electrodes. As a result, the floor can be adapted to support multiple forms of interactions. For instance, integrating smaller electrodes increases the tracking resolution but decreases the distance of which the system is capable of recognizing objects. Thus, when the user is in direct contact with the floor, it is possible to achieve a footprint that uniquely identifies that particular user. In contrast, lower resolution results in increased proximity sensing that can infer high level body postures and support other kinds of interaction. Lastly, integrating different sizes of electrodes can be used to create diverse areas where each support a different kind of interaction. As a consequence, a capacitive sensing interactive floor can be customized to use applications where different interaction procedures are required. Additionally, using OCF or other transparent conductive sheets, makes it capable of being placed above screens or put onto walls. That would in turn require a robust glass to protect the display.

The limitations with the technology occur when integrating it into constantly changing environments and applications. For instance, the level of air humidity can impact readings and users' doing fitness wearing a wet t-shirt or drop sweat on the floor, can also cause false readings. Another aspect to consider is the form of interaction. As mentioned earlier, jumping or other similar movements that concentrates pressure on the surface can cause technical issues. This is in contrast to both front and back projection, foot-centric systems and optical tracking that can withstand more rough interaction procedures. In addition, more simple applications with few requirements can be less expensive and easier to construct by using other technologies.

Therefore, choosing the most suitable technology depends on the use, the environment where it has to be installed, pixel resolution required and the complexity and methods of interaction.

5.4 Summarizing discussion

Through our discussion we have illuminated how CapFloor can be applied to future interactive floors. Each technology has advantages and limitations compared to one another, and so it is in this instance as well. CapFloor can potentially eliminate many of the existing problems that these current floors suffer from. It does this by providing:

- An independent and transparent interactive surface that can be placed above any surface, thus, avoiding problems with occlusion.
- Capable of proximity sense up to a distance of 10 cm.
- Size of the sensors can be altered depending on the requirements for interaction.

Use of CapFloor is limited by:

- Vulnerable construction.
    - *Although, in future work, a more robust construction can be made.*
- Low pixel resolution.
    - *Due to the speed of the technological advances, a higher resolution can be achieved within a reasonable amount of time.*
- Incapability to sense pressure and recognize fine-grained interaction and body postures.
    - *These constrains are the most difficult to enable*

6. Future Work

The study conducted in this thesis has focused on two aspects. First, the technical advantages and limitations of applying capacitive sensing to a luminous interactive floor and secondly, how such a floor can be used to provide feedback and guide users through their training exercises. In this chapter, we will comment on future work that can contribute with additional knowledge to the area of capacitive sensing and luminous floors. The section is divided in two, the first part concerns the technical aspects and the second part concerns interaction and user experience.

6.1 Technical future work

One of the primary shortcomings of our prototype is the vulnerable construction. Further investigation into an even more robust floor can resolve potential interaction and construction issues. Beside a sturdier floor the sensing surface could potentially be made of two sheets of OCF that covers the entire surface. One of these sheets should then be placed above the LED-tiles and act as shield. The other should be placed above the silicone mat and function as the sensing overlay. To enable this, it would be relevant to investigate the possibilities of laser engraving sensing areas into the overlay. Further exploration into such a system could eventually enable a plug-and-play solution that not only applies for luminous surfaces, but also to normal surfaces and other structural elements such as walls.

Concerning sensors and their capabilities, CapFloor is capable of sensing human limbs reliable up to a distance of 5 cm with an electrode size of 5cm x 5cm. More thorough testing and use of other capacitive sensing systems could enhance the proximity sensing which would make the system able to recognize fine-grained interaction and body postures. Additionally, combining the capacitive sensor readings with machine learning, sensor data from smartphones or smartwatches could enable new interesting applications.

6.2 Interaction and experience

Through our study, we have only scratched the surface of using CapFloor for an interactive training device. How to provide graphical feedback using colors, dynamic geometrical shapes or text needs to be investigated further through user studies. Additionally, different sources of feedback such as sound or vibration could be examined.

One area that in particular demands attention and further exploration concerns how to provide feedback and guidance to enhance user motivation and engagement. Subsequently, other fitness related use-cases could be explored even further to expand the list of applications. Among these is using the CapFloor for rehabilitation purposes, which probably would demand another set of requirements.

An interesting experiment to conduct in future work would be to implement the technology into, for instance, Wizefloor and observe how it could change the user interaction with the floor. From the results, a proper comparison of the advantages and limitations of capacitive sensing in relation to front-projection could be done.

7. Conclusion

In this thesis project, we have investigated how to create an interactive floor that can guide and motivate users during their workout.
Progressing from the accumulated knowledge gathered throughout the design process, we set forth an interactive luminous floor, CapFloor. The floor consists of LED-tiles to provide graphical visualizations and a transparent capacitive sensing surface. The main purpose of CapFloor is to provide fitness users with a tool that ultimately can enhance their workout results. To test its potential ability to do so, CapFloor went through a series of real-world user tests. The participants in the user test were optimistic and displayed great interest in using the floor as an integrated tool in their workouts.

Additionally, the knowledge gathered from the design process also resulted in an overview of the limitations and advantages of a selection of applied technologies in interactive floors, as well as a thorough exploration of capacitive sensing. As a result, we are able to propose that a transparent capacitive sensing surface has many potentials that can be applied to other applications than just fitness guidance. For instance, it can eliminate issues with occlusion and shadows in relation to front projected system. Additionally, the sensing surface can be applied to not only floors, but also screens and walls - potentially making any surface interactive.

To successfully use CapFloor to guide and motivate users during their workout, further studies concerning user experience and interaction have to be conducted. Similarly, the impact on interaction and experience when using a transparent sensing surface instead of other tracking technologies, has to be carried before reaching a system that is qualified for real world usage.

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Appendix

A.1 Findings from final test with CapFloor

Summary and categorization of the final interaction test 4.12 with users. Our categorization is the first point; second point is the user quotes.

- Users initially walked gently and with a lot of self-restraint
    - “it is weird to walk on a screen”
    - “it sounds like it could break”
    - “some places it gives in”

- In the end users was less careful and was acting without self restraints
    - “HIGH CRACKING SOUND” - when user moved quickly to core posture
    - Comments about construction stopped

- Sensor position and program not made dynamic
    - “it is hard to reach the hands and feet position at the same time”
    - “I can only make lady pushups is that possible “

- Motivation enhanced when a counter
    - “I want to see what happens when I complete the exercise, so I push myself more than when just counting repetition”
    - “I can’t to the exercise half because then it does not count.”
    - “in the beginning counting the repetition is more exciting than a count down because I don't know when and what will happen. But I imagine this could be demotivating when I get more exhausted”

- Premade exercises and exercise directions helps engagement.
    - “I feel I need to do the exercises when it tells me to do them - it's like when I do what my watch tells me for example when it tells me to stand up or move more”

- Possibilities of more feedback feedback.
    - “it would be nice to get some additional feedback during the exercise, I would be nice to see my tempo and pulse. or an overview over my total exercise time”

- Exploration of functionalities help motivation
    - “it is exciting to see what happens - but when I know it the excitements drops, so maybe it could surprise you like if it was game”

- Graphics matters
    - “it is more fun to look at the leafs and the waves than, small circles, it just looks more cool and interesting. “
    - “maybe it would be more exciting if the dots could change color or if they were somehow animated like with the leafs - it could be like training on pillars similar to the Shaolin Monks”

- Training exercises most suited for CapSense
    - “I think exercises like core, pushups and lunges works the best - exercises where i can see the impact on the screen”

- Not all Training exercises works well on CapSense - sound or other types of feedback could help.
    - “There is not much to see when I make sit-ups, but if the counter is between my feet I can see the counter but not when it registers a repetition. “
    - “If I could hear when I made a correct bridges repetition and when I was done it would still make me want to do it on this floor”
    - “It is hard only to be able to do really deep squats. My knees are not happy about that”

A.2 Video links

1. Final test of CapFloor. Interaction and screen resolution - https://youtu.be/gHZzgFhhzCM

2. Interaction with Wizefloor - https://youtu.be/3GBx9kIvSmg

3. Final prototype, test with push-up - https://youtu.be/xk4FcmWiWAk

4. Collection of user-tests - https://youtu.be/nAxhVI7O8xM

5. Interaction test with particles. Showing direct touch and proximity sensing -

https://youtu.be/s2Q0Ysk4X2U