Master’s Thesis in Interaction Design

Smart homes with smartphones

Creating a Smart home application for smartphones

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Abstract

The goal of this master thesis was to evaluate the field of Smart home applications run on mobile platforms such as smart phones. This was at the time a relatively new field that has attracted the attention of Smart phone giants like Apple and Google. This raised the question whether or not the users willingness to embrace the technology.

To evaluate the field, a literature study was conducted covering the Smart home technology, and Apple’s and Google’s Smart home solutions. The rendered in a prototype for a Smart home communication application which was run on the Android platform. The prototype was then used in user tests focusing on the usability of the application and the field of Smart home smart phone applications.

Even though the usability of the application was regarded fairly low, positive results were obtained regarding the evaluation of the field itself. This points to promising progress of Smart home applications run on smart phones.
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1 Introduction

Since the invention of computers, computing power has constantly increased each year [1]. Along with the increase in computing power a decrease in cost and size of computers has followed [2]. This trend has made it possible to create smaller, yet affordable computers without losing computational power. The trend has also enabled new inventions within the field of computers. For example personal computers, and hand held computers like smartphones and tablets. Bohn et al. [3] foresaw in their paper from 2003, that microprocessors soon would be embedded in everyday objects like, our clothes, watches, pens, and furniture. The microprocessors would make it possible for us humans to communicate with the objects, and also for the objects to be able communicate with each other.

In 1991 [4], Mark Weiser presented his vision that computers would be integrated seamlessly into our daily lives. The idea which Weiser called Ubiquitous computing, proposed that for information technology to be truly integrated with the human world it would have to disappear into the background. This way the users would be able to place their focus beyond the computer as a tool and instead focus on new goals.

Recently, more and more devices have gone through the transition to be in some sense a smarter device. This has been done by supplying them with computing power. For example, many television manufacturers have started making so called Smart TVs. These smart TVs use computing power and often network communication to offer its users more advanced functionality than what is available in an ordinary television. For example, passing content between the Smart TV and other smart devices like Smartphones and tablets, or executing applications on the Smart TV.

The trend of creating smart devices have helped push forward the Internet of Things (IoT) development. The purpose of IoT is to enhance things with embedded computers and sensors [5]. Things could be anything from machines and vehicles to clothes and creatures (even humans). The things monitors their environment and communicates with each other, which enables a network of these things to create environments, products, and services that are smart, attractive and helpful [6]. With these environments, products, and services, IoT can help increase the welfare through innovations within different areas and trades.

Smart homes or Home automation is an example of such an area of innovation [6]. The concept of Smart homes is about adding intelligence and sensors to objects and devices within a home environment [7, 8, 9]. This gives the Smart home users the ability to get information from, and control different parts of the Smart home. Examples of Smart home applications could be automatic light control and security surveillance.

Home automation has been researched for a long time, however the last few years big companies like Google and Apple has started to show interest of the technology. During 2014 Google bought the company Nest Labs which has created a smart thermostat and smoke detector. It was also during 2014 that Apple announced that they would launch their own framework for home automation called HomeKit. It is with these solutions that the companies will integrate home automation with their own products.
1.1 Purpose

The purpose of this project is to evaluate the novel field of Smart home applications on smartphones. The goal is to create a concept of a meaningful and rewarding Smart home application, which would then be used to evaluate the field. The evaluation will be performed with the help of the design proposal created in this project, which will be in the form of sketches, lo-fi, and hi-fi prototypes. Since the application would be run on a smartphone, the design concept would therefore conform to existing limitations and opportunities related to both Smart home, and Smartphone technologies and usability guidelines.

This project is performed in cooperation with the stakeholder The Mobile Life, who’s goal was to get information about what kind of Smart home applications they could develop in the future. A prerequisite from The Mobile Life was for the Smart home application to either use Apple’s HomeKit framework, or Google’s Nest Application programming interface (API) to communicate with its environment. Therefore the project was structured with the following sub goals:

**Research Apple’s HomeKit and Google’s Nest.** Find out what types of Smart home applications are suitable for these services.

**Create a Smart home application.** Use the knowledge about HomeKit and Nest to create a Smart home application.

**Evaluate the field of Smart home smartphone applications** Use the hi-fi prototype to evaluate the field of Smart home applications used on smartphones.

2 Background

The following sections contains the background of this project. Section 2.1 deals with Smart home and home automation in general, while section 2.2 and 2.3 contains information about Apple’s and Google’s Smart home solutions, HomeKit and Nest. Section 2.4 contains a subsection about tools needed when developing Smart home applications using HomeKit or Nest, and section 2.5 describes the programmable Philips Hue Light that was used in the project. The ending subsection describes the the stakeholder The Mobile Life and what their goal was with this project.

2.1 Smart Home

A Smart home is a dwelling containing interconnected components. The components could be things to control inside the house, for example lights or heating. They could also be things to get information from, for example the current temperature inside the house, or if windows and doors are opened or closed [7, 11, 12]. A Smart home uses these components to improve the quality of life for its users. However, a high tech-equipped house does not have to be a Smart home, Balta et al. [10, p. 364] distinguished Smart homes from high...
tech-equipped residence by "the network through which each of the technological components and information about them is connected and coordinated".

There are many definitions of Smart homes, Alam et al. [11] define the concept of Smart homes as an application of ubiquitous computing, with the purpose to provide user context-aware services. These services can be automated or assistive in the form of ambient intelligence, remote control, or home automation [11].

**Ambient intelligent services** uses sensors to monitor the user context, and then take actions to ease the user’s daily life. An example could be an automatic heating regulation that lowers the temperature when no one is occupying the house.

**Remote control services** lets users monitor and control devices inside the house. This could be done from within the house but also when the users are not at home. An example of remote control services could be to get information about which windows and doors are open, and even being able to close them remotely.

**Home automation services** are used for when the users want a schematic control of the house. This could be timer planned events like having the lights on during specified time intervals, or logical planned events like having lights on whenever a specific sensor is triggered.

Based on a Smart home service main purpose, the service can be categorized into three basic categories; security, energy consumption and management, and lifestyle support [11, 12]. Most Smart home projects that have been conducted over the past decades can be categorized into one or more of these categories with respect to which user’s needs they targeted.

Balta et al. [10, 12] grouped Smart home services even further. As seen in Figure 1, the three broad yet interconnected groups; Safety, energy consumption and management, and Lifestyle support contains the Smart home service categories security, assisted living, healthcare, entertainment, communication, comfort and convenience, and energy efficiency.

**Figure 1**: Smart home services categorized into three broad interconnected groups. Image inspired by Balta et al. [12].
Safety
The Smart home environment can aid Smart home security solutions surpass conventional security solutions. This can be done by letting the house react to the different threats, for example in case of a fire, assess the danger of a fire and then automatically, send an emergency call, start fire sprinklers, and switch on all the lights [13]. Home automation services often have the effect of giving its users a peace of mind [10].

Healthcare
Smart homes are excellent facilities to provide continuous healthcare services to their users. Healthcare services can monitor its users and either generate health reports locally to the specific user, or send out data for a specialized work force to interpret in case of an emergency. This is why many Smart home projects have focused on creating Smart home services to aid patients, elderly people as well as healthy people [11].

Assisted living
An assisted living service monitors the user in order to provide aids based of user’s context. For example, a service that enables users to easily contact others in case of emergency, or a service that monitors the user’s behavior and signals incidence of potential accidents or illness [10].

Entertainment
Entertainment services are in some sense to maximize user comfort by tailoring the service to the user’s movements around the home environment. For example, a speaker system uses those speakers which are best positioned to give optimal sound based on the user’s location [10].

Communication
Smart home environments makes it easy to collect data that the users would want to share. This could be information about engagements and health, in order to enhance social communication [10].

Comfort and convenience
Most Smart home services could fit into the “Comfort and convenience” category, since that is the value of Smart home services that focus on making life easier and more comfortable for the user [10].

Energy efficiency
There are mainly two different types of energy efficiency Smart home services: one that lowers energy usage by shutting off appliances when they are not needed (e.g. heating, lights, etc.), and one that uses live tariffs of energy costs and then runs appliances when the energy price is low (i.e at night when there is low energy consumption) [14].

As with most new technologies, in order for Smart homes to have a public appeal, it has to address certain key technical, conceptual, and management issues [10]. These are issues that can limit the development of Smart homes. In both of the papers by Balta et al. [10] and Edwards et al. [15] these types of issues are addressed as follows:

Fit to the current and changing lifestyles
Both Balta et al. [10] and Edwards et al. [15] identified the importance of integration and the potential to evolve, as a central part for the concept of Smart homes to be successful. Especially because of a possible gap
between what the people developing the technology and what the users actually would want in their respective home.

**Administration**
As homes gets fitted with more and more technology, can the user be set responsible for installing, upgrading and maintaining the home’s software and hardware? Balta et al. [10] argues that the users will have to have a minimum level of expertise in order to have the environment to be set up in a way that is the most beneficial for the user.

**Interoperability**
For a Smart home to be successful, it has to be able to evolve and adapt to changing preferences, demands, and needs. This means that Smart homes have to be able to incorporate new devices, and that those devices have to be able to communicate with each other [10].

**Reliability**
It is important for Smart homes to provide the intended service that the user wants. Both unreceived and wrongfully received services will most likely lead to user discomfort [10].

**Privacy and security**
For Smart home services to be able to give the users the best possible service, the Smart home has to collect information about its users. Some Smart home services even takes care of parts of the house security. Therefore, the importance of Smart home security could not be overstated [10].

**Consumer perceptions of Smart homes**
Smart home technology have consumer barriers that have to be addressed in order for the technology to be socially acceptable. For example, the willingness to accept home automation, availability, and response fatigue [10].

### 2.2 Apple HomeKit

HomeKit is Apple’s home automation framework. It is used for developing Smart home applications for Apple’s iOS devices. The framework creates a bridge of communication between the iOS application and HomeKit integrated devices. With HomeKit, the applications can for example discover HomeKit accessories and configure them, or create actions to control those devices. These actions can be grouped together and triggered using Siri\(^1\) [16].

The HomeKit framework is compatible with both iOS programming languages, Objective-C and Swift. It provides seamless integration between HomeKit enabled devices and iOS devices [17]. Apple’s goal with creating a common protocol from which a public API is available for configuring and for communication with the devices is [17]:

\(^1\)Siri is Apple’s voice recognition input-service. It is used to control the device with voice commands.
coherent whole without those vendors having to coordinate directly with each other."

Because of the ability for accessories to be controlled from applications not created by its manufacturer, the possibility is enabled for applications to exploit all the connected devices in its services. This means that devices from different manufacturers can be used together in the same third-party application. HomeKit allows third-party applications to perform three major functions [17]:

1. Discover accessories and add them to a persistent, cross-device home configuration database.
2. Display, edit, and act upon the data in the home configuration database.
3. Communicate with configured accessories and services to get them to perform actions, such as turning on the lights in the living room.

On top of third-party applications, Apple’s own voice recognition input-service Siri, is also able to access the home configuration database. This allows users to control their HomeKit devices by giving voice commands to Siri. An example is, “Siri, turn on the lights in the living room.” If a user creates a home configuration with logical groupings of accessories, services, and commands, Siri can make it very easy to accomplish sophisticated operations with voice control [17].

The Smart home environment gets configured by HomeKit as a collection of home automation accessories in a home configuration database. The end user associates the accessories with containments within the database. By having a home configuration, the end user can describe the installed accessories with meaningful labels and groupings. The hierarchy of the basic data containers are [17]:

**Homes** are the top level container, and represent a structure that a user would generally consider to be a single home. Users might have multiple homes that are far apart, such as a primary home and a vacation home. Or they might have two homes that are close together, that they consider as different homes—for example, a main home and a guest cottage on the same property.

**Rooms** are optional parts of homes, and represent individual rooms in the home. Rooms do not have any physical characteristics—size, location, etc. They’re simply names that are meaningful to the user, such as “living room” or “kitchen”. Meaningful room names enable commands like, “Siri, turn on the kitchen lights.”

**Accessories** are installed into homes and assigned to rooms. These are the actual physical home automation devices, such as a garage door opener. If the user doesn’t configure any rooms, HomeKit assigns accessories to a special default room for the home.

**Services** are the actual services provided by an accessory. Accessories have both user-controllable services, like a light, and services that are for their own use, like a firmware update service. HomeKit is most concerned with user-controllable services. A single accessory may have more than one user-controllable service. For example, most garage door openers have a
service for opening and closing the door, and another service for the light on the garage door opener.

**Zones** are optional groupings of rooms in a home. “Upstairs” and “downstairs” would be represented by zones. Zones are completely optional—rooms do not need to be in a zone. By adding rooms to a zone, the user is able to give commands to Siri such as, “Siri, turn on all of the lights downstairs.”

For applications to be accepted for Apple’s App store they have to follow the following guidelines [18]:

- Apps using the HomeKit framework must have a primary purpose of providing home automation services.
- Apps using the HomeKit framework must indicate this usage in their marketing text and they must provide a privacy policy or they will be rejected.
- Apps must not use data gathered from the HomeKit APIs for advertising or other use-based data mining.
- Apps using data gathered from the HomeKit API for purposes other than improving the user experience or hardware/software performance in providing home automation functionality will be rejected.

To ensure their users privacy [19], Apple uses both authentication to gain access to HomeKit devices, and encryption to protect the information being intercepted by a third party. The authentication is bi-directional, which means that both parties authenticates each other at the same time [20]. While the encryption key changes per-session to try and ensure protection of the information. Each HomeKit device also has an identifier, for the user to quickly identify the device.

### 2.3 Nest Labs

Nest Labs was Google’s opening to be part of the home automation market. Nest Labs had created their smart thermostat and smoke detector when Google acquired the company in 2014 [21]. Together with the smart thermostat and smoke detector, Nest Labs opened for other vendors to create devices that “Works with Nest” which together creates a Nest Smart home environment.

The central part of the Nest Smart home environment is the Nest service. All Nest products and applications are connected to the Nest service, which provides a data model of the home [22]. Nest applications and devices read data from the model to get information about the environment, and updates data in the model to reflect changes in the environment [22]. For example, both the current and target ambient temperature can be read from the data model, while as an example, the target temperature also can be set to new values. To ensure secure communication with the Nest service, Advanced Encryption Standard (AES) 128-bit encryption and Transport Layer Security (TLS) is used [23].

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2App store is Apple’s online market for applications to be used on Apple devices.

3Works with Nest is the stamp the products that works in a Nest home automation environment have.
The Nest service home model is stored as a JavaScript Object Notation (JSON) document. Clients (Applications and devices) registers for changes in the model, causing the service to push change notifications to the registered clients when states change in the model. The data in the home model is stored hierarchically, with devices and structures at the top level, and the specific device types are modeled under the devices object [24].

The Nest client applications are recommended to use the Firebase\(^4\) client library to subscribe to data values via the Nest API. Since the Firebase client library is available in the languages: Java, Objective-C, and JavaScript, Nest client applications can be built for most platforms. For applications built in languages where the Firebase library is not available the possibility to use Representational State Transfer (REST) or REST streaming to communicate with the Nest service.

As with Apple’s HomeKit, Nest devices can also be controlled via a voice recognition service. When a Google account is connected to a Nest account, the devices connected to that Nest account can be controlled using Google’s voice recognition service, Google Now. This allows for the Smart home environment to be controlled using a natural way of communication by only using the voice.

For Nest client applications to be approved they have to follow the Nest Developer Program guides for branding, user experience (UX) and marketing [25]. However, the application also has to follow the Nest Developer Terms of Service, where there are a list of the following prohibitions [26]:

1. Implement functionality that interferes with the core functionality of Nest products or services.

2. Collect, aggregate, re-syndicate, retain, log or store Customer Data (as defined below) received via the Nest API beyond 10 trailing days from the date when the data is received.

3. Aggregate control of Nest products, services, or Customer Data across multiple households except to the extent Nest permits control of multiple homes in a single Nest account.

4. Create a Client that performs demand response or other energy management programs such as those offered by electric, gas, water or similar companies or energy markets.

5. Offer or advertise a Client that provides emergency response, notification services, life-safety, or other critical use services that require notifications to be provided without interruption.

6. Create a Client or otherwise use Customer Data to evaluate end users or their property individually or in aggregate for insurance or other financial products and services.

7. Harm, defame, abuse, harass, stalk, threaten, endanger the safety, or violate the legal rights (such as rights of privacy and publicity) of any person or encourage any third party to do the same.

8. Upload, post, transmit or otherwise make available any inappropriate, defamatory, obscene, or unlawful content.

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\(^4\)Firebase is a cloud service used to save, store and update data in realtime. https://www.firebase.com

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9. Create a Client that functions substantially the same as the Nest API or other Nest Developer Materials and offer it for use by third parties.

10. Perform an action with the intent of introducing to Nest products and services any viruses, worms, defects, Trojan horses, malware or any items of a destructive nature.

11. Access or control any customer accounts or any devices linked to any customer accounts in a manner that could cause any harm, damage, or loss.

12. Use the Nest API to process or store any data that is subject to the International Traffic in Arms Regulations maintained by the Department of State.

2.4 Development

When developing client applications for Apple’s and Google’s Smart home solutions, tools have been supplied by both companies. Both solutions have their own developer tools for simulating devices on a computer. Apple has the HomeKit Accessory Simulator, and Nest has a Google Chrome extension that works as a simulator.

In Apple’s HomeKit Accessory Simulator the user can either add predefined devices or create its own. Each device consists of services and characteristics as defined by the framework. Devices that have been added to the accessory simulator can then be discovered in a HomeKit application running on the iOS simulator.

The Nest Developer Chrome extension is run in the Chrome web browser. The user can add multiple smart thermostats and smoke detectors with the extension when it is signed in to the website. The user can then use virtual devices with Nest client applications connected to that Nest account.

2.5 Philips Hue

The Philips Hue is a lighting concept containing three basic parts, the Hue lightbulb, the Hue bridge, and Hue applications. The concept is to allow the user to change the hue, saturation, and brightness of each Hue lightbulb through different applications, e.g. the official Philips Hue smartphone application. The lightbulbs are connected wirelessly to the bridge, which in turn is connected through the home network where it communicates with the applications through a REST interface over hypertext transfer protocol (HTTP).

Each Hue lightbulb contains three types of light emitting diodes (LEDs). The LEDs are chosen to create a specific range of colors and intensities. These colors are possible to represent in several different ways. A popular way are by using hue, saturation and a value (HSV). In this project HSV was used to represent and manipulate the colors of the lightbulbs. For example, the color red would be represented by the hue value for red, with full saturation and value. To get

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5Google Chrome is a web browser created by Google.
6https://home.nest.com
a lighter red, the saturation would be decreased, and to get a darker red the value would be decreased.

The HSV color representation can be exemplified by using an HSV cylinder, like the one in Figure 2. The cylinder would have its angular dimension representing the hue, where red, green and blue would be located 120° apart and with red at 0° (and 360°) [29]. The cylindrical center would consist of the grey scale, with black at the bottom and white at the top. While moving out from the center increased the saturation of the color. Using the HSV color representation makes the task easy to gradually modify colors by changing the location inside the HSV cylinder.

![HSV cylinder](image)

**Figure 2**: A cylindrical representation of the HSV color space. Image by Michael Horvath (SharkD), distributed under a CC-BY 2.0 license.

### 2.6 The Mobile Life

This master thesis project was executed with the stakeholder The Mobile Life. Their goal was to find applications of use with the new field of Smart home applications run on smartphones. The Mobile Life has, since their start in 2005 worked with some of the worlds leading companies when it comes to create, design, construct, and launch products and services that are meaningful and rewarding to use. A sample of their creations have been an informational application for Sweden’s royal court, and a flight booking application for the Singapore based airline Scoot.

### 3 Method

This section describes the design process that was used during this project. The process was used as a method to design a Smart home smartphone concept application.

#### 3.1 Design Process

The design process was constructed towards the scope of this project. The process was based on methods from the design field researched by Lazar et al. [30] and Nielsen [31], and in particular Nielsens usability engineering cycle [32]. Nielsens usability engineering cycle is a modified version of the "golden rules"
created by Gould et al. [33]. The cycle [32, p.13] is focused on the development of new systems, and contains the following steps:

1. Know the user
   - Individual user characteristics
   - The users' current task
   - Functional analysis
   - Evolution of the user

2. Competitive analysis

3. Setting usability goals

4. Participatory design

5. Coordinated design of the total interface
   - Standards
   - Product identity

6. Guidelines and heuristic analysis

7. Prototyping

8. Empirical testing

9. Iterative design
   - Capture the design rationale

10. Collect feedback from field use

Nielsens usability engineering cycle was modified to satisfy the scope of this project:

1. Perform literature study

2. Formulate goals with stakeholder based on the results from the literature study

3. Iterative design
   - Sketch the internal structure and functionality
   - Sketch the user interface design
   - Refine sketches to a higher graphical fidelity

4. Implement guidelines and heuristic evaluation of the sketches

5. Implement a hi-fi prototype based on the final sketches

6. User test the prototype
3.2 Literature Study

The project started with a pre-study where basic information about the Smart homes was collected. The goal with the pre-study was to get an overview of Smart home technology in general. The pre-study also eased the search for material to use as reference in this thesis, such as information about Smart home technology. The information came largely from conference articles, and scientific papers about related to Smart homes and home automation. The main point of this research was to acquire a broad knowledge base to use as a foundation during the ideation in a later stage of the project.

Since the prototype being created in this project was a Smart home application that would either use Apple’s HomeKit framework or Google’s Nest API, information about these services were also gathered. Getting information about Apple’s and Google’s services were necessary to gain knowledge about how the services work. This information was also used to understand how the vendors intent their services to be used.

3.3 Smart Home Application

When the literature study was completed, the author and stakeholder The Mobile Life, together decided on what type of Smart home application that would be developed. It was an active decision not to involve the users in this stage, due to that the users does not always know what they want. This is pointed out by Rogers et al. [34], namely that the user’s imagination limits the answers when the user is asked what he or she wants. The Mobile Life was interested in an application which could decrease the perceived distance of their offices\(^7\). Therefore, it was chosen that the Smart home application would be a communication application, the type that is described in Section 2.1.

The application’s core features would be to share and display information about its environment. To read information about its environment, the application would connect to a Nest thermostat, from which it could read data like temperature and presence. The data would then be shared with other users of the application, which could display the data using programable Philips Hue lights\(^8\).

Since the application would be used in an office or home, the displaying of data would have to be performed in a most calm way [35]. This is because the application should not disturb the occupants of its environment. Instead, the application should display the data with smooth changes in the users periphery. This keeps the information away from the user’s center of attention when it is not needed.

Beside the applications core feature, it would also need to provide its users with the ability to choose which other users to follow, and to allow to be followed by. Without this function, the users privacy would easily be intruded by unwanted users. The user-following functionality would allow users to choose by themselves which information to share with which user.

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\(^7\)The Mobile Life have their two main offices in Stockholm and Singapore

\(^8\)The Philips Hue are lightbulbs which colors can be changed through an accompanying API.
3.3.1 Prototype Development

At this stage of the project, stakeholder The Mobile Life had decided that the application would be directed to use Google’s Nest API. The API is available for both Android and iPhone. However, The Mobile Life wanted the application to be built for Android devices. At this point, it was also decided that the application would use the Firebase cloud service as backend, which is the same cloud service that the Nest API uses for communication.

After the type of Smart home application and a basic use case was established, the structure and functionality of the application were elaborated through low fidelity sketches [36]. The sketches described how the application and its functions would work internally. By using sketches that easily could be changed or redrawn, many fast iterations could be used to help shape the concept of the application.

With the sketches completed, mockups of the graphical user interface and user flows was created. The mockups were also a method for making easily changeable design decisions, and refining them through iterations. This way a refined image of how the graphical user interface will look like can be used as a base when implementing the application.

Since it, at this point of the project was established that the application would be developed for the Android platform, design decisions were made to pursue the Android design principals [37]. The general structure of the application were to follow the Android applications structure hierarchy [38]. This structure hierarchy consists of three different levels. The first level is the "Top level views", which consists of the various view that the applications supports. The second level is called "Category views" which allows the user to discover more of the data in the application. And lastly, the third level is called "Detail views" which is the views where the user can consume and possible edit the data in the application. Table 1 shows the intended views for this projects prototype, the views purposes and which views corresponding to which hierarchical level.

According to the Android design principals, accessing prominent actions should be done from the top of the screen [39]. This was the reason for the buttons used to access the user activity and home views to be placed in the top of the screen. Android design principals also states to have buttons to the least frequently accessed views to the most right of the action bar [39]. This helped with deciding to have the user activity view to the left of the home view which would be positioned to the far right. The decision is also confirmed when compared to other Android applications with a similar functionality. For example, both the Android applications for Facebook [40] and Instagram [41] positions the button to access the home user profile (equivalent to the Home view) on the far right.

3.4 User Testing

When the hi-fi prototype of the application was implemented, user testing of the prototype was executed to evaluate both the design, and the field of Smart home applications on smartphones.
Table 1: The intended view for the prototype. The purpose of each view is described, together with the views hierarchical level.

<table>
<thead>
<tr>
<th>Prototype view</th>
<th>Hierarchical level</th>
<th>View description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote Users view</td>
<td>Top level view</td>
<td>A type of control panel containing followed users, and buttons to the &quot;Home view&quot; and the &quot;User activity view&quot;.</td>
</tr>
<tr>
<td>Home view</td>
<td>Top level view</td>
<td>A view containing the devices connected to the application, the user image and information.</td>
</tr>
<tr>
<td>User activity view</td>
<td>Category view</td>
<td>A view containing other users activities connected to the user.</td>
</tr>
<tr>
<td>Search users view</td>
<td>Category view</td>
<td>The view where the user searches for other users.</td>
</tr>
<tr>
<td>Setup device view</td>
<td>Detail view</td>
<td>The view which is used to setup devices connected to the application.</td>
</tr>
<tr>
<td>New user image view</td>
<td>Detail view</td>
<td>The view where the user updates its user image, which is seen by the other users.</td>
</tr>
<tr>
<td>User information view</td>
<td>Detail view</td>
<td>A view containing information about other users.</td>
</tr>
</tbody>
</table>

3.4.1 Test Scenario

In preparation for the tests, eight tasks that the test users would perform were created. The tasks were constructed with the objective to have the users examine all of the applications functionalities. Therefore, each task were designed to only test one specific function. The task ended up being:

- Add Philips Hue bridge
- Add Nest Home
- Select suitable environments to share
- Follow user Alice
- Accept a follow request sent from user Bob
- Connect user Bobs environments to own Hue lights
- Change light theme
- Unfollow user Alice
In order to evaluate the usability and user experience, a System Usability Scale (SUS) questionnaire was chosen. The SUS questionnaire was concluded to give the most reliable results by Tullis et al. [42] in their paper, A comparison of questionnaires for assessing website usability. Sauro [43] concluded mean value of 68 in his research with 500 SUS surveys. Sauro also stated the following limits:

0-51 is considered a failure.
51-74 is considered an acceptable result.
74-80.3 is considered a good result.
80.3-100 is to consider a top result.

The result of the SUS test is calculated by adding the user scores of each question, ranging from 1-5, and multiplying it with 2.5 [43, 36, 42]. Using a questionnaire generates some advantages when the data later is going to be collected. Stone et al. [36, p. 482] lists the following advantages:

- "The questions you want to ask are all written on the questionnaire, so there is less chance of forgetting to ask something."
- "The participants all see the same question, so there is more possibility of comparing answers from different participants."
- "You may be able to collect some quantitative data."

Four extra questions were also added to be asked after the SUS questionnaire were finished. These questions were meant to contribute data about the field of Smart home smartphone applications. The added questions followed the same pattern as the questions associated with the SUS questionnaire. The pattern was a claim that the user have to rate on a scale from one to five, where one equals strongly agree, and five equals strongly disagree.

When the test scenario was completed, a pilot test was executed conforming to the suggestions of Stone et al. [36]. The purpose of the pilot test was to get all details in order for the upcoming live tests. It is also always favorable to let the test supervisor go through the test at least one time before the live tests [36]. It was also during the pilot test where a suitable amount of time was established for the so called free browsing session.

To follow Nielsens guidelines for effective user testing [31] five test subjects were selected. Since the purpose of the project was to evaluate the field of Smart home smartphone applications, test persons with a variety of technical interest was selected. The test participants were selected to in some sense fill the scale from one to five, where one would be no technical interest and five would be high technical interest. This was especially interesting due to the administrative challenge, brought attention by Balta et al. and Edwards et al. [10, 15], and discussed in section 2.1.

### 3.4.2 Test Procedure

Before the test, each test subject was given a short introduction about the Smart home technology, Smart home applications on smartphones, and the purpose of
the application they were about to test. During the entire test the users were instructed to use the Think aloud method [44, 45, 36]. The idea with Think aloud is to have the users express what is on their mind during the test session. The users are encouraged to describe what they are doing and thinking during the evaluation [36]. This way, immediate feedback on the way that the users are thinking about the interface and any problems or surprises that arises [36].

The user tests were performed in an environment that each test subject felt comfortable in. Three of the tests were performed during the day, in an office conference room where these test subjects were employed. The other two tests were performed in the evening at the two test subjects respective homes. The intention was to perform each user test in the same environment that the user thought he or she would be using a similar application in.

Each test session started with a two minute free browsing. The free browsing was used to let the users get accustom with the application. Stone et al. states that it is usually when the user is allowed to explore the application on its own that the most information can be gathered [36, p. 478]. However, it was decided to have the tasks created to ensure that the users would test the entire application.

After each user had completed the tasks, they were asked to answer the questions in the questionnaire. The users were asked to rate the questions as best as they thought they could. The questionnaire was then followed with a short interview where the users was asked to share its own thoughts about the application and also the field of Smart home smartphone applications.

3.5 Boundaries

This project focused on usability, user experience and the field of Smart home smartphone applications. Initially in the project, the stakeholder The Mobile Life had restricted the project to only evaluate Smart home applications for Android and iOS. This was because the stakeholder mainly works with these two mobile platforms. Due to time constraints several other platforms for Smart home smartphone applications was rejected for this evaluation.

During the user testing of the application, all the external devices like the Philips Hue Lights and the Nest Thermostats were emulated through software on a computer. The simulators worked in the same way the physical devices would have worked, but had to be used because no physical devices were available. Although, the users would have to imagine how it would look and feel if it would have been real life devices.

4 Result

In this section the results from the project are displayed. Firstly displayed are the findings from the literature study, where differences between Apple’s HomeKit and Google’s Nest are stated. Secondly, the results from the prototype development presented. The results from the prototype development include sketches and designs created throughout the entire development process, and also system descriptive diagrams of the prototype.
4.1 HomeKit vs Nest

The literature study was not only the backbone for this project, it also provided information about the differences between Apple’s and Google's Smart home services. Even though they are both Smart home services, the two solutions diverges in functionality. Table 2 shows how the two Smart home services handles different Smart home functionality.

Table 2: This table describes differences in Smart home functionalities between HomeKit and Nest.

<table>
<thead>
<tr>
<th>Function</th>
<th>HomeKit</th>
<th>Nest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>A framework to manage and control Smart home devices [16]</td>
<td>A smart thermostat and smoke alarm used as hubs to work with other smart devices [24]</td>
</tr>
<tr>
<td>Communication</td>
<td>Applications use the HomeKit framework to connect and communicate with HomeKit enabled devices [17]</td>
<td>Applications connects and communicates with devices (including Nest thermostat and smoke alarm) through the devices own APIs. [22]</td>
</tr>
<tr>
<td>Automation</td>
<td>Require user actions to create events [18]</td>
<td>Can be triggered by events in background [24]</td>
</tr>
<tr>
<td>Voice control</td>
<td>Apple’s voice input controller, Siri [16]</td>
<td>Googles voice input controller, Google Now [22]</td>
</tr>
</tbody>
</table>

4.2 Prototype Development

This section presents the results from the different stages of the prototype development process. The results are aids created to help determine the structure, functionality and appearance of the application. The results consists of sketches, mockups, diagrams and an equation. The results are in chronological order of the prototype development process.
4.2.1 Structure Sketches

In the beginning of the prototype development stage, sketches and design proposals for the Smart home application prototype were created. These proposals were created to help determine the applications core structure and functionality.

Figure 3 shows how users of the application would communicate with each other through the Firebase cloud service. Users would upload their environmental data to the cloud service and receive callbacks when followed users would have done the same.

Figure 3: A sketch of how the communication between users and Firebase backend would work.
A Firebase cloud service stores its data in a Javascript object notation (JSON) document. The structure of this project’s Smart home application’s Firebase JSON document is described in Figure 4, where all users have the following attributes saved:

**accepted_users** - Is a JSON array containing UID of users that are accepted followers.

**environments** - Is a JSON array containing environment names which in turn contains its environmental data.

**following_users** - Is a JSON array containing UID of users that the user is following.

**name** - Is a JSON string containing the user’s name.

**other_users** - Is a JSON array containing UID of users that are following the user.

**user_image** - Is a JSON string containing a byte representation of the user image.

**username** - Is a JSON string containing a chosen username taken by the user to be identified with.

```
{
  "users" : {
    "<user UID>" : {
      "accepted_users" : {
        "<accepted user UID>" : "<STATE ENUM>",
      },
      "environments" : {
        "<environment name>" : "<environment value>",
      },
      "following_users" : {
        "<following user UID>" : "<STATE ENUM>",
      },
      "name" : "<user name>",
      "other_users" : {
        "<other user user UID>" : "<STATE ENUM>",
      },
      "user_image" : "<image in bitforms>",
      "username" : "<user username>"
    }
  }
}
```

**Figure 4:** The structure of the JSON document stored on the Firebase cloud service.
4.2.2 Mockup Sketches

When the basic functionality and structure of the application was established, mockups of the user interface were created. The mockups were refined through three iterations before reaching a desired appearance and perceived usability.

Figure 5 shows the two first mockup versions. The first mockup version, (a), was created to hold views which displays the basic functionalities of the application. These functionalities are the users, Nest thermostats, and Philips Hue lights. The next iteration of the mockup, (b), displays the followed users by thumbnails of their images. The mockup also has an "add user" button, used for searching for users to follow.

![Mockup Sketches](image)

**Figure 5:** (a) The first mockup of the application, displaying the fundamental parts of the application. (b) The second mockup of the application shows the followed users by thumbnails of their user image.

The third iteration of the user interface mockup, shown in Figure 6, added buttons to access the users home view, and the activity view. The home view would be where the user can overview the followed users, and connected devices. The activity view would be where the user gets information about user activities related to the user. The mockup also had the lists of devices merged to one single device list, and added the user’s image to the home view.
Figure 6: The third mockup of the application added buttons linked to the home and activity view. It also displays the user’s image and one single list for the connected devices.

When the mockups had been cultivated through the iterations previously described, new less rough mockups were created. The new mockups depicted the home view, the view to search for users, and the user info view. These mockups look more like the finished prototype. The new mockups are shown in Figures 7 and 8.
Figure 7: The new less rough mockup for the home view.
Figure 8: Mockups of the intended views of the application. Subfigure (a) is a mockup of the view to search for users. Subfigure (b) is a mockup of the user information view.
4.2.3 Functional Diagrams.

Figure 9 shows a sequential diagram of how the application communicates with the Firebase service when one user wants to follow another user. The application starts with registering a callback for when changes are recorded in the `following_users` JSON array on the Firebase service. Then User 1 registers a callback to receive the users from the Firebase service. When User 1 pursues to follow User 2, User 1’s unique identifier is added to User 2’s `following_users` JSON array.

User 2 receives a callback that changes have been made in the `following_users` JSON array. User 2 then has to decide to either allow or decline User 1 to be a follower. If User 2 accepts User 1’s request to be a follower, then User 2 adds User 1’s unique identifier to its `accepted_users` JSON array. At this point, User 1 has the ability to receive User 2’s environmental data through a callback.

![Figure 9: A sequential diagram showing the action sequence of User 1 requesting to follow User 2.](image)

The classes related to the devices used in this project are described in the class diagram shown in Figure 10. The classes are connected to the actual device via their individual software development kits (SDK).
Figure 10: A class diagram describing the classes related to the devices used in this project.
The structural design of the user interface is shown in Figure 11 and consists of a "Remote users view" and a view holder to populate with the other views. The remote users view works like a toolbar, and is always visible and contains information about which users are followed. The remote users view also contains the buttons which are linked to the home and activity view.

**Figure 11:** The user interface structure. With the remote users view always showing, while the view holder is containing the home, activity, and user info subviews.
The view holder is populated with the view currently used by the user. As shown in Figure 12, the home "user activity", and "search users" views are all access from the "remote users" view. The "setup devices" and "new user image" views are accessed from the "home" view, while both the "user activity" and "search users" views can be used to access the "user information" view. The "user information" view of followed users is also accessible from the "remote users" view.

The environmental data is stored in double-precision floating-point format on the Firebase cloud service, and is cast to match the interval $I = [0, 1]$. The environmental data from the Nest thermostat has the following meaning:

**Temperature** compares the ambient temperature to the target temperature of the thermostat. A value of 0.5 implies that the target and ambient temperature is equal. Equation 1 was used to reduce oscillatory values when the target and ambient temperature are close to equal. The equation is plotted in Figure 13, where $x = (a$ predetermined temperature span) and $y = (output value)$.

**Estimated time to arrival (ETA)** compares the current time to the ETA. The value of 0 represents that the time to ETA is larger than the predetermined maximum set to 2 hours. The value then changes linearly to 1 as the time to ETA reaches 0.

**Away** is a binary environment model, where 0 represents that the user is away, and 1 represents that the user is home.

$$y = \frac{\arctan(10x)}{\pi} + \frac{1}{2}$$ (1)
Figure 13: A plot describing equation 1 used to model temperature values from the Nest thermostat. Where $x$ = a predetermined temperature span and $y$ = output value.
4.2.4 Screenshots

After the Smart home application had been implemented, screenshots of the different screens were taken. Figure 14 shows the implemented version of the applications home view. While Figure 15 contains images of the other views that were implemented in the application.

![Figure 14: A screen shot of the implemented home view.](image-url)
Figure 15: Screenshots of the implemented views: (a) The search view, (b) The activity view, (c) The followed users view, (d) The Hue device view, (e) The Nest device view, (f) The user information view.
4.3 User Testing

The results from the user tests are displayed in the following subsections. The results are divided into three parts, the SUS questionnaire, the questionnaire about the field of Smart home smartphone applications, and the feedback and observations from the Think aloud session.

4.3.1 SUS Questionnaire

The SUS questionnaire rendered scores with a mean of 58.5 from the five test subjects. Figure 16 shows the results from each test subject. The users listed in Figure 16 are listed in order of the technical interest given by the test subjects. Figure 16 shows that there were no correlation to the SUS score and the technical interest given from each test subject.

![Figure 16](https://example.com/figure16.png)

**Figure 16:** A bar graph showing each test subject’s SUS score with a mean value of 58.5.
4.3.2 Smart Home Smartphone Applications

Figure 17 and Figure 18 shows the rating that each test subject answered to the claims given to them about Smart home smartphone applications. The results from the questions about Smart home smartphone applications are also analyzed in Table 3.

Table 3: This table contains the mean value for each claim about Smart home smartphone applications.

<table>
<thead>
<tr>
<th>Claim</th>
<th>Mean value</th>
</tr>
</thead>
<tbody>
<tr>
<td>I would like to use Smart home applications on my smartphone</td>
<td>4.8</td>
</tr>
<tr>
<td>I think it would be cumbersome to get started with Smart home smartphone applications</td>
<td>1.6</td>
</tr>
<tr>
<td>I think I would find a similar application meaningful to use</td>
<td>3.6</td>
</tr>
<tr>
<td>I think I would find a similar application rewarding to use</td>
<td>3.8</td>
</tr>
</tbody>
</table>
Figure 17: Bar graphs of the test subjects' ratings to the claims "I would like to use Smart home applications on my smartphone" and "I think it would be cumbersome to get started with Smart home smartphone applications". The results have been recalculated to have five signify strongly agree and one to signify strongly disagree.
Figure 18: Bar graphs of the test subjects ratings to the claims "I think I would find a similar application meaningful to use" and "I think I would find a similar application rewarding to use". The results have been recalculated to have five signify strongly agree and one to signify strongly disagree.
4.3.3 Think Aloud

The overall user satisfaction from using the application can be deemed good. However, there were eight comments that came up during the Think aloud session. The compiled results from this session can be seen in Figure 19, which shows the number of users that highlighted each comment. Table 4 describes each comment in more detail.

**Figure 19:** A bar graph containing the number of users who commented on each of the feedbacks and observations made by the test subjects.
Table 4: This table contains detailed descriptions of the comments given by the test subjects during the think aloud sessions.

<table>
<thead>
<tr>
<th>Comment</th>
<th>Detailed description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unintuitive interface</td>
<td>The test subjects commented that the interface was unintuitive to use. They had a hard time navigating to the views they wanted to visit.</td>
</tr>
<tr>
<td>More feedback</td>
<td>The test subjects wanted more feedback of events both in foreground and background.</td>
</tr>
<tr>
<td>Unclear what themes are</td>
<td>The test subjects did not understand the use and function of the themes that were used to change the appearance of the Philips Hue Lights.</td>
</tr>
<tr>
<td>Back button</td>
<td>The test subjects wanted back buttons to exit popup views.</td>
</tr>
<tr>
<td>Unclear user image</td>
<td>The test subjects did not understand the use of the user image connected to the user profile.</td>
</tr>
<tr>
<td>Unclear icons</td>
<td>The test subjects did not understand all the icons used in the user interface.</td>
</tr>
<tr>
<td>Use more popups</td>
<td>The test subjects wanted more popups to give feedback of events taking place.</td>
</tr>
<tr>
<td>Keyboard does not hide automatically</td>
<td>The test subjects wanted the keyboard to automatically be hidden after typing.</td>
</tr>
</tbody>
</table>

5 Discussion

The purpose of this project, as stated in section 1.1, was to perform an evaluation on the novel field of Smart home applications on smartphones. To perform this evaluation, a prototype of a Smart home application implemented for the Android platform was created. Returning to the subgoals that were stated at the beginning of the project (in section 1.1):

- Research Apple’s HomeKit and Google’s Nest
- Create a Smart home application
- Evaluate the field of Smart home smartphone applications

This section discusses the results from these subgoals.
5.1 Research of HomeKit and Nest

The research of the Smart home solutions created by Apple and Google rendered in some interesting results. Not only was the intended use of both solutions researched, the differences between what can be considered two future giants in Smart home solutions for smartphones were also highlighted. The research showed that HomeKit and Nest actually are two widely different solutions. HomeKit is used to interconnect Smart home devices from HomeKit compatible vendors, while Nest instead is used as a hub that in its turn can be used together with Nest compatible products.

To be approved by Apple, applications using the HomeKit framework will be obliged to have HomeKit as their primary purpose. At this point of time, HomeKit applications will also be restricted to only interact with devices through user actions. This means that automated behavior is limited, which limits the possible area of use in terms of Smart home applications for HomeKit applications.

Nest applications are more independent in terms of the area of application. Although, Smart home applications using Nest devices will need to use dedicated applications created for their specific use. This might worsen the association between the different devices that could be used together in a Smart home environment. It could potentially be a reason for the Nest Smart home solution not to be adopted by the general public.

5.2 The Smart Home Application

The results from the usability tests gave a clear representation of the Smart home application created in this project. The mean SUS score of 58.5 shows that the application was not very well received in terms of usability. However, given a design iteration to attend to the comments given by the users during the user testing, the SUS score would most likely rise to a more acceptable level.

The SUS scores from the five tests subjects differed 50 points from the lowest to the highest score. The two highest SUS scores even reached grades where the prototype could be considered “acceptable” to “great”. It is most likely that another design iteration and more user testing would create a more reliable result with lower variance.

The comment given by most of the test subjects was that the user interface was unintuitive to use. This can be seen as a big or maybe not very specific issue to fix. However, by taking care of more specific comments given by the test subjects, the interface intuitiveness would certainly increase. Besides an unintuitive interface, the three most received comments were, to have more feedback, that the themes used by the Philips Hue lights was unclear, and the need of a button to escape popup views. For example, to guide the user with more feedback would certainly create the feeling of a more intuitive interface.

It should be noted that the prototype application was well received by the test subjects. Even with the considerably low SUS score. It was also important that the test subjects did not have any issues understanding the purpose of the application. Since the purpose of this project was to evaluate the field of Smart home smartphone applications, and not just the prototype itself. With this in mind, the application should be deemed successful of reaching its goal.
5.3 Evaluating the Field

The results from the user tests were very promising for the field of Smart home smartphone applications. All test subjects answered positively about using Smart home applications on their smartphones. The test subjects also gave positive answers to if they thought that they would find similar applications meaningful and rewarding to use. Although these results came from the only five participating test subjects and can not be statistically proven, the results are promising for the field of Smart home smartphone applications.

The test subjects stated that they did not think it would be cumbersome to get started with Smart home applications on their smartphones. This is especially remarkable because the prototype application they used for testing had a low SUS score. The positive results from this evaluation also helps ease the concerns raised by Balta et al. [10] about the average user being discouraged to embrace Smart home technology.

6 Conclusions

This section contains the conclusions from the project, and suggestions for future work.

6.1 Smart Home Applications on Smartphones

The field of Smart home applications on smartphones appears to have a bright future. The feedback received about the field was positive, even though the usability of the prototype that was used for evaluation was considered to be low. The fact that the field was well received by all the users shows that even users with low technical interest might be interested in adopting the technology. This points to that Smart homes has the possibility to be a familiar integration to our future homes.

The usability of the prototype created in this project affected the evaluation of the field of Smart home smartphone applications since the evaluation was conducted with this prototype. Since the usability of the prototype was considerably low, new user tests and field evaluations should have been performed if there had been more time available in this project. The results from the later tests could be compared with the old results to get a measure of the improvement of the prototype and how it correlates with the acceptance of the field of Smart home smartphone applications.

6.2 Future Work

When contemplating about future work in the field of Smart home applications run on smartphones, an important thought to consider is if the field is still in an early stage. The field was at the time of execution of this project right at a point where exciting happenings were about to happen. The biggest one was definitely the release of HomeKit compatible consumer products, which is said
to reach the public during June 2015. At the same time more and more Nest compatible devices are being released, widening the Nest product catalog.

After the field of Smart home smartphone applications has reached some state of maturity, a more extensive evaluation of user willingness could be performed. The field can also be further evaluated through other types or categories of Smart home applications. There are also possibilities to redo a similar evaluation with a similar communication application on other platforms like HomeKit or SmartThings10.

References


10SmartThings is a Smart home platform that can be run on Android, iOS, and Windows phone [46].


