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**A System Supporting Analysis of Prototyping in Fab Lab
Education**

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ABSTRACT

Digital Fabrication Laboratory (Fab Lab) is an educational workshop that is open and easily accessible for personal fabrication. This workshop is equipped with tools for various aspects of technological materialization. In Fab Labs, makers and educators struggle to have proper documentation of their design process. Means for quick documentation are essential for supporting users' iterative prototyping, as well as analysis and reflection on design activities. This thesis aims to provide a solution to the lack of proper tools for documentation and reflection on design stages in the Fab Lab educational context.

To this aim, different interconnected systems for supporting analysis of prototyping in the Fab Lab are developed. These include a mobile-enabled client-server architecture and a web-based administrative dashboard for supporting managing and analysis of annotated visual data of prototype designs in Fab Lab. Concerning the supporting analysis, the focus is to establish an easy to use documentation tool, which comprises of a mobile application and a web administrator for better Fab Lab educational experience.

This thesis demonstrates the theoretical part of the lo-fi design, evaluation, implementation of Restful Web Services and implementation of the mobile-enabled system for properly documenting prototyping stages and an admin control panel.

A usability testing was conducted for the developed mobile application and the web application. The purpose was to understand users' feedback on the usability of the prototypes and the features in the applications that users find useful or the features that are required to be added or improved. The majority of the participants find the application useful.

Keywords: Fab Lab, digital fabrication, prototyping, making, documentation, images

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FOREWORD

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ABBREVIATIONS

API	Application Programme Interface
CSS	Cascading Style Sheets
Fab Lab	Fabrication Laboratory
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
NFC	Nearest Field Communication
REST	Representational State Transfer
WWW	World Wide Web
IoT	Internet of Things

1. INTRODUCTION

Documentation has been known to be highly crucial for effectiveness in the process of making and prototyping stages [1]. It is considered as one of the supporting analysis in creating prototype design because it supports the concepts of reflection-in-action and reflection-on-action [1, 8]. Herewith, this is the ability to reflect during a design process or at the end of the design process [1, 8]. For this reason, the goal of this thesis is to develop system designs that serve as a repository for storing information, ideas and knowledge from the various stages of developing prototypes in the Fab Lab.

According to Barhoush et al. [2], the illustration of possible taxonomy of reasons to document physical prototypes design, the aim to is achieve “Collaborate, Socialize and Motivate” [2]. Moreover, sharing of information plays a vital role in accomplishing these aims [2]. Documenting prototypes in the field of digital fabrication provides numerous benefits, which includes the taxonomy of reasons mentioned by Barhoush et al. [2]. For this reason, the aim for developing these systems is to facilitate reflection during prototyping amongst the users of Fab Lab. Moreover, users of Fab Lab can work together in a group, which improves collaboration and socialization skills. Further, when excellent communication is achieved through the aid of these systems, one can be sure of a proper learning environment and quality time saving [2, 3].

Furthermore, imbibing the tradition of knowledge sharing plays a huge role in the field of digital fabrication. The reasons for sharing knowledge differ. However, in Fab Lab, sharing knowledge helps to motivate and inspire other users of the Fab Lab [3]. This is so because Fab Lab demands a lot of critical and creative thinking for making brilliant prototype designs. It is worth mentioning that having the technology for sharing well-structured and informative documentation helps solve the issue of knowledge sharing in Fab Lab [4].

Sánchez Milara et al. argue that one of the significant challenges of students in Fab Lab is the amount of time spent on documentation, even though instructors always emphasize on the importance of documentation-while-doing [2]. The reason most students spend much time on documentation is that they often document at the end of the task. In fact, according to Ludwig et al., this form of documenting causes students to leave out necessary steps and machine configurations [4, 22]. In most cases, they generalize and omit some of the problems and difficulties they face while the task is ongoing [2].

In this thesis, the focus is to develop an interconnected platform of systems that tackle the difficulties of documenting-while-doing. Hence, contributing to the field of digital fabrication for providing a better environment in order to acquire creative skills. In this concern, the designs consist of implementing a Web API, a Web Administrator Application and a mobile application for users of the Fab Lab. These systems are interconnected and are extensible to the prototyping capturing system developed by Barhoush et al. [2].

This thesis is structured as follows. Chapter 2 of this thesis describes related works and a well-explained background overview on related topics such as Fab Lab, Prototyping, Making, Documenting, Web and Android Application technologies and development. In Chapter 3, a comprehensive illustration of the development of the system designs is provided. Then in Chapter 4, the general implication and outcome of the projects in this thesis are discussed, followed by the conclusion in Chapter 5.

2. BACKGROUND AND RELATED WORK

In this section, earlier research work and existing solutions in the light of supporting analysis for prototyping and documentation are discussed. This thesis is based on the coherent of different autonomous entities/technologies, which is used for the realization of supporting analysis in Fab Lab prototyping. The following sub-topics in the following sub-sections are based on the contextual background of Fab Lab Designs and the technological background, which aid better understanding of the technologies and the approaches that are utilized towards the realization of this thesis. It is important to note that these entities/technologies mentioned comprise of a smartphone application, web development/API(s), Protobooth (automated system for capturing images of prototypes) and NFC wireless connectivity.

2.1. Contextual Background of Fab Lab for Design

Fab Lab is a workshop that is open and easily accessible for personal digital fabrication. This workshop is mostly equipped with tools for various aspect of technology, thereby; it contributes to development phases such as fabrication, design, testing and debugging, monitoring and analysis, and documentation [1, 7]. It is claimed that FabLab is an alternative model of ICT for developments in the next stage of revolution in the light of digitalization, as there will be a transitioning from personal computation to personal fabrication [1].

The concept of Fab Lab began from an extension of educational outreach in the Massachusetts Institute of Technology Center for Bits and Atoms (CBA), to spread out research into digital fabrication and computation [6]. Herewith, it provides a platform for people to contribute to the world of science by technically prototyping for innovations and inventions, as a result of this encouraging people into adopting private enterprise [6]. Various achievements could come from the whole concept and existence of Fab Lab as it provides the students with the opportunity to learn and improvise [1, 6].

Moreover, it is considered a place to play, to create, to learn, to mentor, to invent, etc. [1]. One of the many fascinating attributes of the Fab Lab is that it is an internetworked workshop; thus, it provides connections with apprentices, instructors, professors, teachers, technologists, researchers, visionaries, renovators and innovators from different countries [1, 6]. It contributes to the research study of knowledge sharing. Fab Lab in different countries, share standard tools equipment and similar approaches to prototyping; the workshop/program is building a global network, independent laboratories that are working together for research and innovations [1, 6]. The next section consist of a tentative description of the various Fab Lab tools.

2.1.1. *Fab Lab Tools*

Presently, in most Fab Lab branches, some of the tools¹ that are available for prototyping include,

¹ <https://www.oulu.fi/fablab/about>

- Laser cutter (e.g., in Fab Lab Oulu, Epilog Laser Fusion) – for 2D and 3D design and fabrication.
- High precision milling machine (e.g., in Fab Lab Oulu, Roland SRM-20) – for making circuits and molds or casting
- Vinyl cutter (e.g., in Fab Lab Oulu, Roland GS-24) – for making flexible circuits and constructing out designs like adverts, etc.
- Electronics workbench – for users to sit and have activities such as brainstorming, programming microcontrollers and prototype circuits.
- 3D printer (e.g., in Fab Lab Oulu, Stratasys Fortus 380mc) – for printing professional 3D models/prototypes. There is also the Leapfrog Creatr, which is small compared to the aforementioned and it used for rapidly printing out 3D prototypes².
- Large wood routing machine (e.g., in Fab Lab Oulu, Rensi)
- CNC milling machine for milling grafting aluminum (e.g., in Fab Lab Oulu, Haas)

All these tools are utilized by Fab Lab users to learn and at the same time, design and create usable prototypes for either personal interest or instructions from their supervisors [6]. The “Do it yourself” approach adopted by Fab Lab has empowered student as they are challenged by the involvement of making something by the themselves [6]. In such case, they both learn and supervise; hence, they benefit from each other [1]. In this process, they gain “deep knowledge about the machines, the materials, the design process, and the engineering that goes into invention and innovation” [1, 7].

The Fab Lab approach of learning has come to strengthen the general educational settings, thus, instead of depending on a fixed curriculum where students are limited to learning what is provided by their instructors/teachers and not being able to explore and challenge themselves into innovation [1, 6, 7]. Now, it is safe to say that learning can now be achieved via a reliable, authentic, engaging, and personal context, whereby students face a personal phase of self-imagination, creative design, prototyping, reflection/peer reviews, and iteration as they work towards prototyping possible usable products [4]. Following the vital requirement of prototyping in Fab Labs, the next section provides complete illustration of prototyping in making and its significance.

2.2. Prototyping in Making

Prototyping is one of the significant reasons Fab Lab was established. It allows students or any Fab Lab users to be able to brainstorm ideas and use the tools in Fab Lab to design prototypes for innovation [2, 8]. In other words, a prototype is known as an early stage, model or illustration of a product concept or an artefact to test the idea [9, 10]. The categories of prototype vary in about six ways, namely, Proof-of-Principle Prototype, Working Prototype, Visual Prototype, User-Experience Prototype, Functional Prototype and Paper Prototype [9, 10]. Herewith, these categories mentioned have general concept goal that is generally used to evaluate a new design for improving and boosting accuracy by both system analysts and

² <http://fab.academany.org/2018/labs/fablaboulu/>

targeted users of the design [9, 10]. Moreover, specifications for a real authentic system instead of just an abstract, imaginary or abstract idea are being provided by the involvement of prototyping [9, 10].

There are various features of prototyping which range from prototype for the software development process, to Horizontal and vertical prototyping [12]. Herewith, prototyping plays a significant role in design thinking; thus, it is one of the processes of design thinking. It is essential to know that design thinking is known as a non-linear process that follows a simple paradigm [8, 9, 10]. This starts from “empathy” and then follows by “define”, hence you first empathize with defining a problem, it then leads to “ideate”, after this is where “prototyping” comes in [8, 9, 10]. The different prototype design gives more insight into ideas because of that an individual can iterate between the “ideate and prototype”, and the last in this non-linear process is the “test”, where you must keep testing your design for better ideas until a satisfying final product is achieved [8, 9, 10]. There are two major types of prototyping, and they are as follows,

2.2.1. Types of Prototyping

- **Low-Fidelity prototyping-** This involves the use of essential mockups or representations. In this case, the features of the prototypes might only have a minute attribute of the principal or final design [8, 9, 10]. In most cases of the low-fidelity prototypes, the materials used are not going to be used for the final product [8, 9, 10]. Some of the materials that fall into this category are paper, wood, etc. All these materials could be utilized into sketching, storyboarding, card sorting, etc. This kind of prototyping gives room for quick and easy possibilities to make immediate changes. Thus, multiple iterations could easily be made between ideating and prototyping [8, 9, 10].
- **High-Fidelity prototyping-** This type of prototyping often occurs after a series of iterations between ideas and designing the lo-fidelity design prototype [8, 9, 10]. Besides, this prototype of this sort looks and operate as the final design imagined. Thus, providing concrete validation and user experience for an evaluation of the high-fi prototypes, with this, one can predict whether the primary goal of the final product or design would be achieved [8, 9, 10].

Prototypes could be said to have four drives, which are learning, communication, integration and milestone. Thus, because of the reasons stated for prototyping, one could eventually use these ideas to learn more by knowledge sharing such as asking and answering questions via communication, ensure compatibility with other apparatuses to have a proper integration and to determine whether there has been any substantial improvement [8]. Moreover, prototypes stand as depictions or illustrations of a design idea made before the completed final product [8]. In the process of creating prototypes, one could gain knowledge on the design process and the kind of decisions to make through exploration and communication of the design. For better understanding, communication and exploration of the design prototype, the idea of “Experience Prototyping”, where it is a reduced procedure, rather than just an attitude, that enables the designer to contemplate and reflect on the design problem in terms of designing an integrated experience [8].

The idea of prototypes is open to diverse new design ideas, from creating physical designs to software products, and many more. In [9] prototype is described as “the

means, by which designers organically and evolutionarily learn, discover, generate, and refine designs. They are design-thinking enablers deeply embedded and immersed in design practice and not just tools for evaluating or proving successes or failures of design outcomes” [8, 9]. As mentioned in [8], even prototypes are used to actualize and prove ideas to be either useful or not and afterwards classified into proof-of-concept, proof-of-product, proof-of-process and proof-of-production. Also, people that were naturally brilliant at design in the pasts went through rigorous training through an apprentice program in order for them to be highly competent in their field [8]. The approach used to come up with creative designs and the information of the field in which they worked were polished and polished through their time as apprentices. They gained most of their information and experience by conducting experiments whereby, they build prototypes and then iterating for improvement using any of the categories [8].

2.3. Reflection based on Documentation of Design Prototyping

The design process for a final prototype idea or concept is sometimes complex and complicated. According to [12], the process of design consists of various sub-activities such as listening, analyzing, brainstorming, evaluating, experimenting, evaluating, iterating, etc. However, these activities require a form of catalyst to boost the performances of the tasks [12]. Documentations such as sketches, notes inventories annotations, diagrams are vital when conducting a prototype design. In [12] they aim at designing a web site for documentation for design processes as it was proven that design documentation contributes via the facilitation of creativity and communication and numerous ways such as consistency of vision, insight, traceability and accountability [12].

It is essential to mention that prototype design is under the categories of interaction design, and many researchers have disapproved and express criticism towards poor adoption of structured documentation for design processes [8, 9]. One of this case is that lack of proper and structured documentation could cause a limitation of the worth or importance of research contributions because a design process that has poor documentation makes it difficult to properly conduct evaluation discoveries [8, 10, and 12]. For this reason, in [13], the authors introduced and discussed ‘Project Reflection Tool’ (PRT) system, which is a web-based system and open to all participants [13]. Herewith, this system allows a sound and easy design process because ongoing work can be easily documented to reflect on the design prototype [13] continuously.

According to [13], the PRT system elements are mainly the events, sub-events and notes, whereby time is a factor in the system for proper organization and accessibility. This is achieved by a simple interface that provides the features of documenting and reflecting on every design stage [13]. It is worth mentioning that the concept is achieved by including comments, descriptions, and actions taken, to their associated event. This tool supports the relationship between research and design [8, 14] as it relates to the concept proposed by Schön [4] that design process should be constructed as a reflective conversation between materials and resources. Thus, the PRT systems provide the designer to work with different tools, media and conduct various experiments while still able to reflect [13]. Besides, Schön’s concept on reflection-in-action and reflection-on-action are supported in the PRT [13] system is that anytime a design at a particular stage is added, they show that the design

process is still ongoing and proves the concept of design by Schön [4] discussed. These lead to the technological background for addressing the issues of proper documentation

2.4. Technological Background

In this section, related technological tools used for the realization of this thesis are reviewed for better understanding of the design methodology and problems encountered.

2.4.1. *WEB Developments and Servers*

Since the birth of web developments, so many sectors one can think about have improved drastically, especially in the field of information technology. According to [16], most developments in the field of IT have not been of more effect than the introduction of the World Wide Web by TM Berners-Lee in Switzerland [17]. San Murugesan et al. describes some cases of the development of web-based systems have missing systematic method, and quality control and assurance procedures, and for this reason, we have web engineering [17]. In recent years, the acceptance of the web in the various organization has risen substantially, including in the digital fabrication laboratory. For this reason, web technologies such as HTML, CSS, JavaScript, Python, Java etc., are used in order to be able to create an interactive and ease of use web applications [16, 18]. In a general sense, web development is known as the effort put in the production and development of a web application. This web application varies as it could just be a web site of the advertisement or it could be a sophisticated web application that comprises of network security, client/server-side application, e-commerce application, etc., [17, 18].

In web development, we have three aspects of production that in most cases, have linkages between them. They are as follows,

- Client-side: Most client sides are the web browsers, and of late, we are beginning to have mobile applications built on mobile devices, and this is considered the client-side [17, 18]. The technologies used in the client side are mainly for the users to be able to interact easily with the application and these web technologies consist of HTML, CSS, XML, JavaScript, Android programming, Swift, Dart, etc. [17, 18].
- Server-side: The server side, which is also known as the web server, is the server software or hardware responsible for running request made from the client side (could also be the WWW). In other words, one of the fundamental roles of the web server is to render services such as store, process and deliver data to the client [17, 18]. The provision of HTTP does this communication between the server and the client. It is important to note that this occurs over HTTP requests and responses, which is the intermediary between both sides.
- Database system: This system is often in the server side, and it serves as a storage system, whereby collected data are often stored in an organized manner [19]. Moreover, we have the Database Management System, which is a software system that helps users to be able to easily interact with the database [17, 18, 19].

All these mentioned above contribute to web developments, hence not limiting accessibility to everyone. In this new age of web developments, services on the WWW can easily be accessed on any IOT devices [17, 18, 19].

2.4.2. Restful APIs Design

This is a software architectural design that follows existing protocols for creating web services. However, for Web APIs, REST often utilizes the available HTTP methods, which are the GET, HEAD, POST, PUT, PATCH, DELETE, etc. [16, 20] This design was defined in the year 2000 by Dr. Roy Fielding [21]. REST is diverse; it allows the freedom to choose the format the client has requested. This means that with REST, one can returned formats such as XML, JSON, YAML, etc. [16, 20, 21]

Over the years, the growth in Web APIs have increased tremendously. Most systems are using this technology as we now have more client-server system [22].

2.4.3. Mobile Application Development

Mobile application development is an open platform of different technologies for development [18, 23]. The development of mobile applications for mobile devices have been existence for at least ten years, and since its birth, there has been a drastic development. Now, different mobile devices' brands permit an open environment for application production, such as Android devices, Windows phone, Nokia, Blackberry, iPhone, etc. [23]. Moreover, there are general-purpose, multi-paradigm, programming languages provided by these mobile platforms such as swift for iOS devices usually built on XCode package, and for Android devices usually on Android development studio that allows the compilation of android applications built with either Java or Kotlin [23]. In addition, there are platforms for Windows operating systems, Blackberry and many more. One of the importance of these mobile application development tools as programming language frameworks is that they provide ease of implementing tasks for the developments of a software [18].

In recent times, mobile applications have become more multifaceted and are being adopted by many business sectors [18], it is crucial to accept the application of software engineering process to have an accepted application development that is of high quality [18]. At this moment, software engineering in this context is the process applied by an individual, or a group of people use in managing the creation of a software-intensive system [18]. Hence, to find the balance, the process of the software engineering must not only be aware of the properties of the mobile device, but it should address challenges of the project management.

According to [23], they described the development of mobile applications as a challenging task as a result of the specials demand required with a limited technical functionalities availability of the mobile environment [23]. Some of these challenges are the inadequate capabilities of mechanical devices, diverse and uniqueness of different mobile platforms, etc., and in terms of physical attributes of different devices, there are the size, weight, expandability, etc., [23] to consider, hence cause the challenges in developing a mobile application. For this reason, they introduced the MOBILE-D approach to overcome the challenges of developing mobile applications [23]. Moreover, this approach works for less than or equal to 10 individuals, and it has been tried and tested in software companies. It is worth

mentioning that this approach consists of five phases, which are the set-up, core, core2, stabilize and wrap-up [23]. In all these phases there, are development days that allow planning, working and releasing day [23].

2.4.4. RASPBERRY PI and NFC

A Raspberry Pi is a cheap and small sized computer [26]. A standard keyboard, mouse and monitor can be attached to it as peripheral devices, which means that a Raspberry Pi is capable of doing all that a desktop computer or a portable laptop can do. The Raspberry Pi setup is as follows:

- SD Card
- Display devices such as a TV screen or a monitor
- Keyboard and mouse
- Power supply

There are optional setups such as the Ethernet cable, Audio lead for speakers or headphones, etc. A Raspberry Pi is equipped with the technology that permits connectivity with external sensors such as an NFC technology. It is important to note that the NFC is a short-range wireless P2P connectivity technology [26]. In this paper [24], they used a Raspberry Pi, an Accelerometer and a Bluetooth Dongle to create a body secure sensor node for addressing the health issues. Here, it was stated that the NFC sensor could be used in place of the Bluetooth devices. Another case is in [25], where they used a Raspberry Pi for the Internet of Things prototype, in this concern, they tried to achieve communication between people and objects. In this case, they built the prototype with a Raspberry Pi and a mobile device with cloud storage between them [25].

2.5. Summary of Background and Related Works

The concept of Fab Lab as a “place to play, to create, to learn to mentor, to invent, etc.” [1] brings about interesting experience for students. In fact, it also contributes to the research study of knowledge sharing and prototyping. Moreover, as the goal of Fab Lab is to provide students with a more effective method of learning. It is important to highlight all the challenges student could experience in Fab Lab. One of the main challenges in Fab Lab occurs during prototyping.

As aforementioned prototyping is one of the major motives, Fab Lab was established. It allows students or any Fab Lab users to be able to brainstorm ideas and use the tools in Fab Lab to design prototypes for innovation [2, 8]. However, it has been realized by many experts that users of Fab Lab often struggle with taking proper documentations during the process of prototyping. Hence, utilizing the contextual background of design mentioned and the technological background related to this work this problem is addressed.

Concisely, the aim is to provide students the solution of lack of proper tools for documentation and reflection on design stages in the Fab Lab educational context and eventually aid easy analysis of prototyping in Fab Lab education. The next section describes the research problem and goal of this thesis.

2.6. Research Problem and Aim

This thesis aims to provide a solution to the lack of proper tools for documentation of design stages in the Fab Lab educational context. In this concern, the goal is to develop interconnected systems that support analysis of prototyping in the Fab Lab. According to the claims mentioned in [2, 3], there is need to tackle the struggles of makers and educators in having a proper documentation of their design process. Hence, the particular target is to develop a mobile-enabled client-server architecture and a web-based administrative dashboard for supporting, managing and analysis of annotated visual data of prototype designs in Fab Lab.

In the light of the supporting analysis, annotated visual data of prototype designs in Fab Lab is aimed as one of the features in the easy to use documentation tool. Hereby, this provides students with a means of reflecting on their prototyping phases, and they can also seek inspiration from another students' work. In this concern, the systems developed in this system will be interconnected with the system built in [2]. Further, as an extension of the prototype in [2] an NFC card support for identification of users of both systems. Moreover, with all these concepts mentioned it is believed that a better education environment for the student in the Fab Lab will be accomplished.

The following chapter describes the system design and implementations of the different applications involve in this thesis.

3. SYSTEM DESIGN AND IMPLEMENTATION OF THE APPLICATIONS

The system design in this thesis follows a two-tier client/server architecture. Herewith, the server side hosts the application logic and essential data. In the case of the client side, it is the presentation layer solely designed to assess the server for specific tasks. This system architecture supports the analysis of prototyping in Fab Lab in four different designs that are interconnected to one another such as:

- The Android Mobile Application
- The Administrator Dashboard (Web Application)
- The NFC tag reader for user's identification
- The Server side and Web APIs

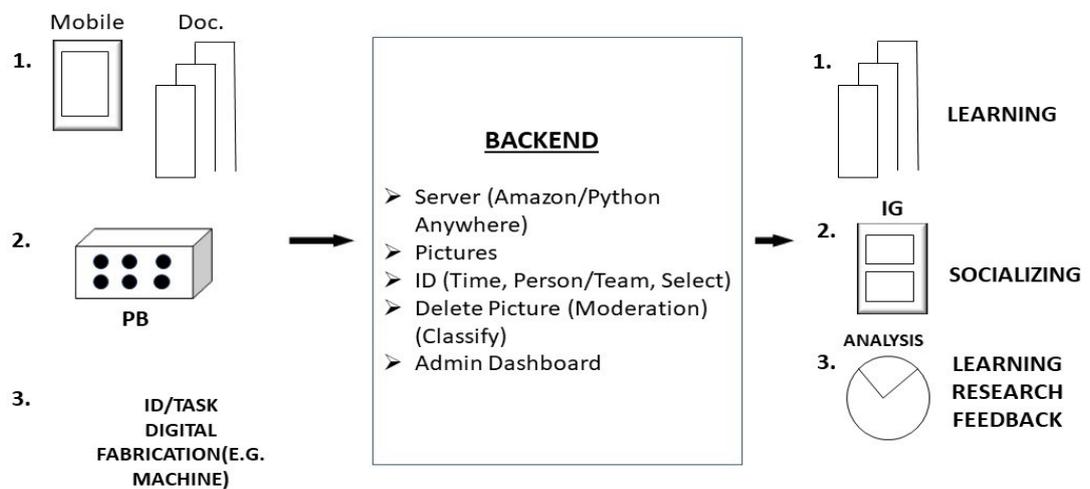


Figure 1. Components of the system supporting analysis in Fab Lab

It is imperative to mention that all system designs involve in this thesis follow a distributed system paradigm in other for them to be able to work as a single coherent system. Hence, in the light of this thesis, the client sub-systems consist of a Protobooth Oulu system, which is a physical design responsible for taking pictures of the prototypes from different angles and this is used to monitor all the stages of the prototype development. Another client system is the mobile application software that can run on an Android operating system. There is also a web application for administrative control of all data from the first prototype of Protobooth Oulu system designed in [2] and the mobile application. The data collected from all these client sides are persisted in the background of the system to a Python Anywhere Server over Hypertext Transfer Protocol Secure (HTTPS) channel and these data stream through a JavaScript Object Notation (JSON) format. The server side also has an SQLite database that is responsible for storing all the data. Figure 3 below gives an overview and a general idea of the system designs and architectures.

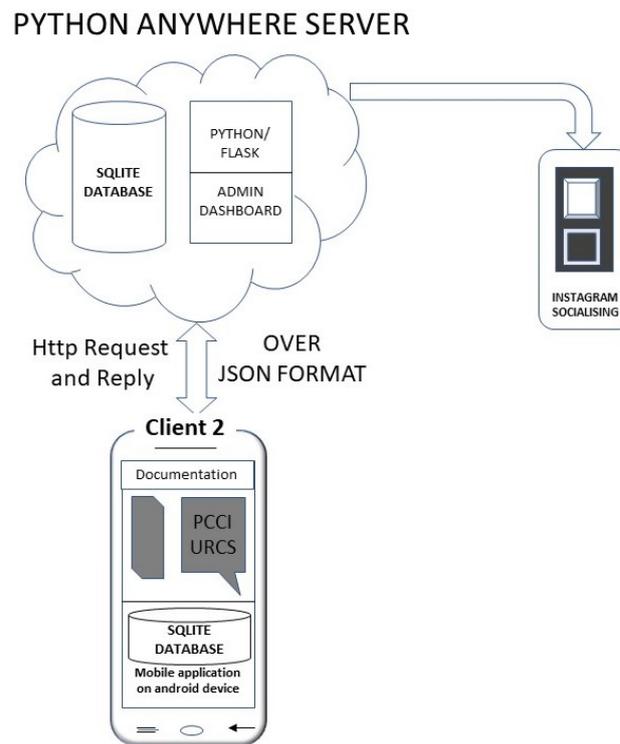


Figure 2. An overview of the System Design

As aforementioned, the Protobooth Oulu is a physical prototype designed by a group of research interns associated with the Center for Ubiquitous Computing and the Fab Lab Oulu at the University of Oulu, Finland. This system is an IoT technology because electronics, software and network connectivity are embedded for the collection and exchange of data (pictures). This physical device is stationed in the digital fabrication laboratory for easy accessibility. Moreover, it supports an NFC card reader for identifying students. Another overview of the first prototype of Protobooth Oulu system with the vital attributes of data is shown in Figure 4.



Figure 3. Initial Prototype version of Protobooth Oulu [2]

3.1. Implementation of the Systems API(s)

The system web API is an API that provides the interfacing with the Android mobile application, web administrator dashboard and the Protobooth system. This includes functionalities for documentation of prototyping phases in Fab Lab, providing some of the posts to the public, tracking documentation posts and history of the posts. Herewith, some of the features implemented to support the API full functionalities include:

- An admin being able to choose some of the posts that should be visible to the public
- Users being able to gain access to some of the public posts provided by the admin
- A quick and easy filtering system of the database tables
- Users and admin the possibility of checking information about the posts

It is important to note that the system web API communicates over HTTP request based on the Representational State Transfer (REST) architectural style. The API leverages the HTTP methodologies such as GET, PUT, POST and DELETE.

3.1.1. Database Design

The database design contains four main types of vital data; this includes users, projects, posts, and groups and each of this has a unique identity number, along with a selection of attributes. Below are the database tables described.

Table 1. Database Table for supPost

Column Name	Data Type	Description	Attributes
user_id	INTEGER	id of the user	Db. FOREIGN KEY, PRIMARY KEY, Table USERS
post_id	INTEGER	id of the post.	Db. FOREIGN KEY, PRIMARY KEY, TABLE Posts

Table 2. Database Table for supProject

Column Name	Data Type	Description	Attributes
user_id	INTEGER	id of the user	Db. FOREIGN KEY, PRIMARY KEY, Table USERS
project_id	INTEGER	id of the project.	Db. FOREIGN KEY, PRIMARY KEY, TABLE Projects

Table 3. Database Table for subGroup

Column Name	Data Type	Description	Attributes
user_id	INTEGER	id of the user	FOREIGN KEY, PRIMARY KEY, Table USERS
group_id	INTEGER	id of the groups.	FOREIGN KEY, PRIMARY KEY, Table GROUPS

Table 4. Database Table for Users

Column Name	Data Type	Description	Attributes
_id	INTEGER	id of the users	UNIQUE, PRIMARY KEY, AUTOINCREMENT
user_number	INTEGER	Number of the user. If the user is a student, the university assigned student number should be provided	UNIQUE, NOT NULL
nfc_id	INTEGER	user's personal NFC card identity	UNIQUE
user_email	TEXT	email of the user	UNIQUE
password	TEXT	password of the user	NOT NULL, UNIQUE, STRING (20)
is_admin	BOOLEAN	user status either True or False	DEFAULT is FALSE
usergroup		relationship with the Groups table	
course		Relationship with Courses table	
project		Relationship with Projects table	
post		Relationship with Posts table	

Table 5. Database Table for Projects

Column Name	Data Type	Description	Attributes
project_id	INTEGER	id of the users	UNIQUE, PRIMARY KEY, AUTOINCREMENT
project_name	TEXT	name of the project.	UNIQUE, NOT NULL
project_description	TEXT	description of the project.	NOT NULL, STRING (200)

Table 6. Database Table for Groups

Column Name	Data Type	Description	Attributes
group_id	INTEGER	id of the group	UNIQUE, PRIMARY KEY, AUTOINCREMENT
group_name	TEXT	name of the groups.	UNIQUE, NOT NULL

Table 7. Database Table for Posts

Column Name	Data Type	Description	Attributes
post_id	INTEGER	id of the group	UNIQUE, PRIMARY KEY, AUTOINCREMENT
post_title	TEXT	name of the title of the post.	UNIQUE, NOT NULL, STRING (100)
timeDate_posted	DATETIME	Date and time of post	NOT NULL, DEFAULT (UTCNOW)
pictures	JSON	Pictures posted for documentation	

The database design of the API(s) is design to support the other systems and it runs on MySQL. Moreover, all the tables are created using SQLALchemy. In addition, it is important to mention that the data gotten from the mobile application, web administrator and the Protobooth Oulu are synchronized automatically to the MySQL database, which is hosted on the PythonAnywhere server.

3.1.2. Resources, Relations and Uniform Interfaces

Further, the step-by-step process in designing the web API is to identify all the resources that should be exposed by the API. For this reason, an abstraction of the concepts and the state diagram of the API are shown below.

Table 8. Resources of the Web API

Resource	Resource Url	Resource Description
UsersList	documentation/api/users	Provides all the users that are registered in the system
UserRegistration	documentation/api//user	Allows a single user to create an account
UserLogin	documentation/api/userlogin	Provides the login authentication
New Project	documentation/api/addproject	Provides a single entry of a new project
Project List	documentation/api/projects/<studentNo>	Provides the history of projects that belong to a single user
All Posts	documentation/api/posts	Provides all the history of posts in the database table for Posts
Single Student Posts	documentation/api/posts/<studentNo>	Provides the history of posts that belong to any given particular student
Special Posts	documentation/api/posts/bool/	Provides all the history of posts that the admin has chosen to be seen by the public

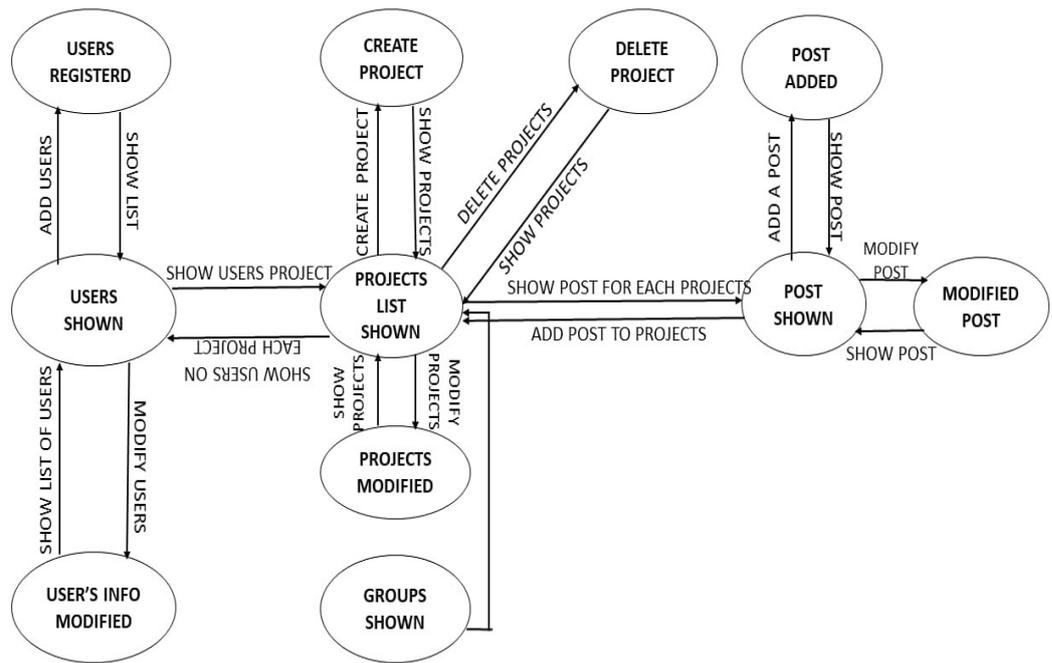


Figure 4. State diagram of the application

The Table 9 below describes the resources that are exposed to the uniform interface. It is important to note that the uniform interface consists of the GET, PUT/PATCH, POST and DELETE method. In other words, the table illustrates the actions that are executed in each request

Table 9. Uniform Interface

	GET	PUT	POST	DELETE
Users	Get the list of all the users in the applicaton			
User	Gets the information of a specific user	Modifies any of the specific information of a specific user	Creates and add a new user to te database of the application	Deletes the specific user from the app
UserLogin			Allows the user to login	
Project List	Gets all the projects in the application			
Project	Gets a specific project and the information required	Modifies a specific detail in a project	Post a new project to the application	Deletes a specific project from the application
Posts List	Gets all the posts in the			
Post	Gets a single and specific post in the application	Modifies a specific post in the app	Add a new post to the application	Deletes a post from the app
Group List	Gets and show all the groups in the application			
Group	Gets a single group in the application	Modifies the members of the group or the name of the group	Add a new group to the app or add a new user to the group	Deletes a specific group or users in a group

Following the implementation of the API design, it is required to ensure that the design meets the REST principles. For this reason, the next section briefly describes how the API meets the principles of REST

- **Resource Representation:** resources are one of the principles of a REST API, hence the resources in this case are built on MASON media type, thus, using the JSON data structure for the data format that are interfacing. Hence, the URI supports the MASON and JSON format as long as the right headers are used when requesting resources
- **Statelessness:** The API design falls under the stateless protocol because all the resources in the application have the information required to perform any action. As a matter of fact, in cases where sessions are to be

carried out by any of the client nodes, any of the standard HTTP protocols will handle it.

- Addressability: The web API design meets the principle of REST in the light of addressability. This is so because, every API information can be accessed through a resource unique identifier (URI).
- The Uniform Interface: In order to establish an absolute HTTP communication, the standard set of operations for the protocol must be utilized. These standard HTTP protocols are GET, POST, DELETE and PUT/PATCH. Thus, in the design of the web API, the uniform interface as a principle of REST was put into consideration. The protocols in the design are invoked remotely through different URIs.

3.2. The Development of the Android Mobile Application

For the outcome of the mobile application, usability and enjoyable user experience are crucial goals worth achieving. It is crucial to have an application that is easy to use and user-friendly. For this purpose, the design process follows the design approached from Interaction Design development model, which are the conceptual and concrete design. According to [31], the process begins with the conceptual design, followed by the detailed design and lastly prototyping. Below, are the stages contributing to the development of the design,

1. Application requirement gathering – The requirements for the application are gotten from a series of literature reviews and related works that focus on prototyping and documentation. In order to conclude on the requirements of the application and the architect of the user interface of the application, an abstract drawing of the design plan is needed. Figure 5 gives an idea of the design flow of the application.

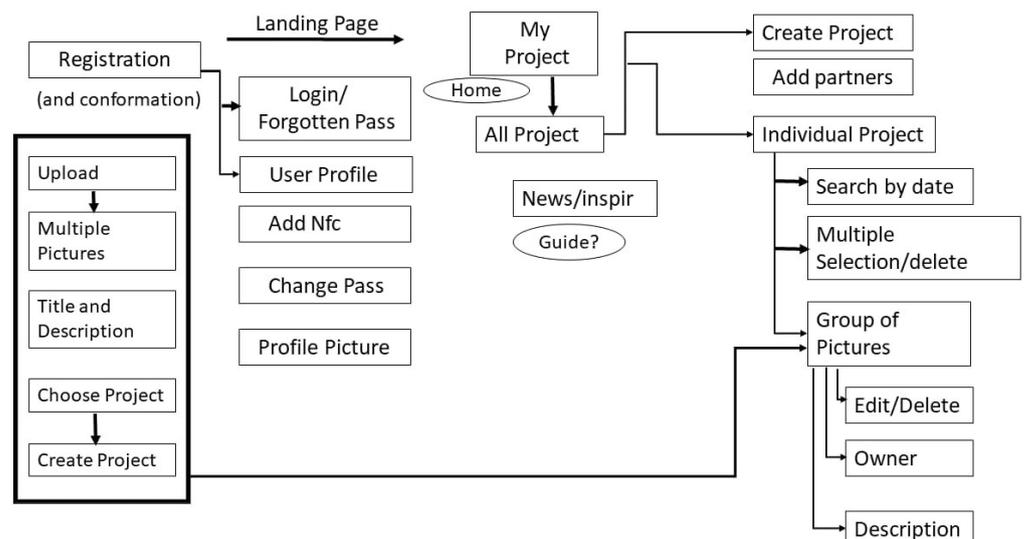
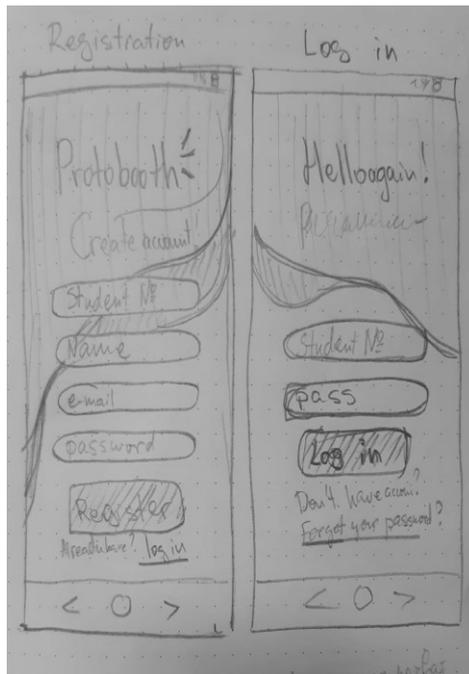


Figure 5. Flow chart of the mobile application

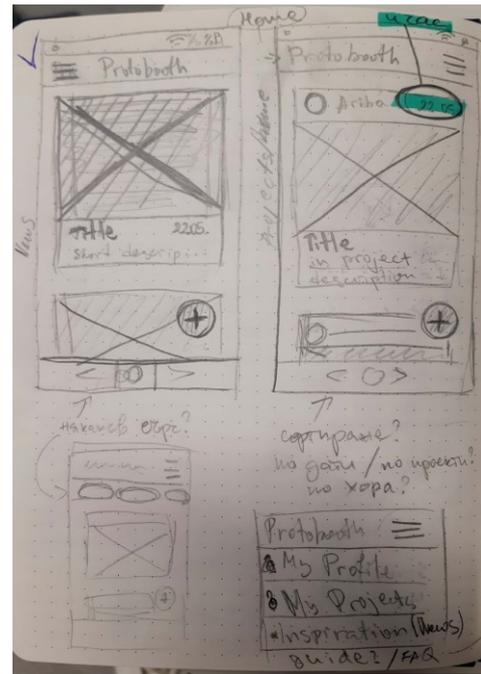
2. Prototyping stage - This stage consists of the Low-Fidelity Paper Prototypes and the User interface mockups
3. Implementation Stage – Using the ideas developed from the first and second stage

3.2.1. Low-Fidelity Paper Prototypes

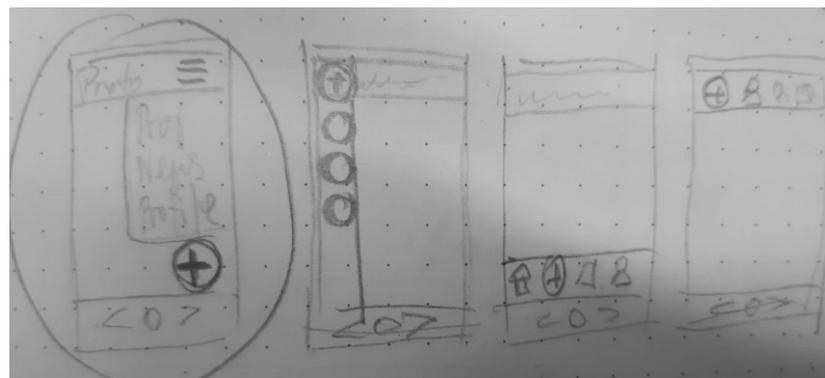
The results from the application requirement are then translated in to (UI) sketches using pencil and paper. Below are the outcomes of the sketches



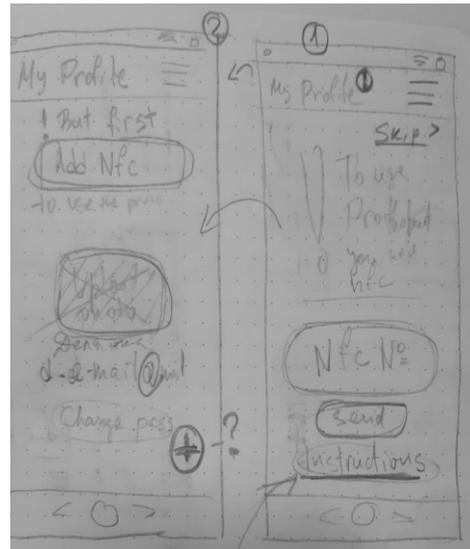
(a) Login and Registration view



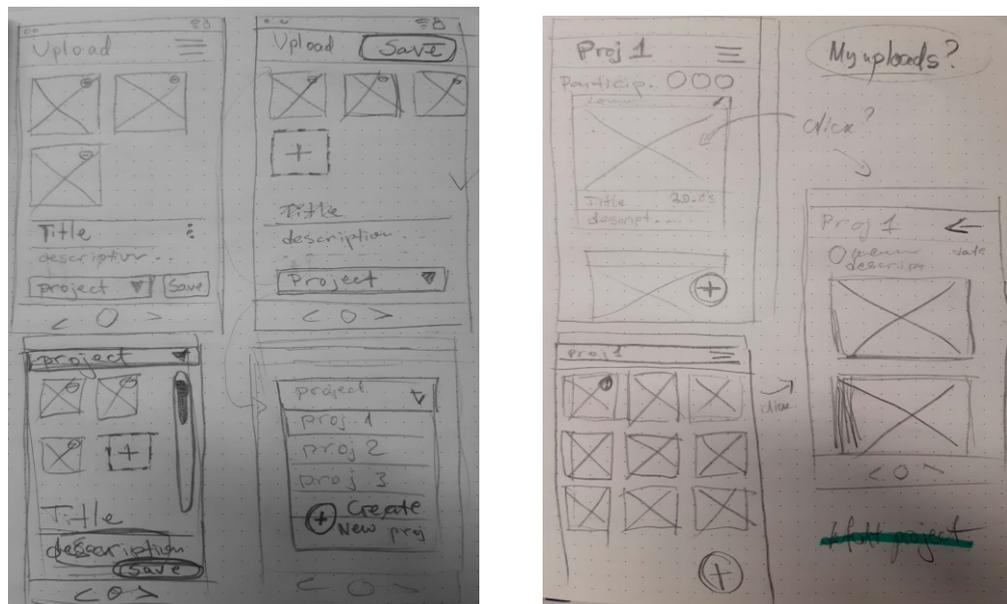
(b) Home view



(c) Menu bar view



(d) Users' profile view



(e) upload pictures, notes and create new project view

Figure 6. Paper sketches of the prototypes

Following reviews of the sketches for the UI of the mobile application, changes were made for better user experience. Hence, the following user mockups are designed.

3.2.2. User Interface Mockups

Following the user interface pencil sketches, the user interface mockups are designed with photoshop for better understanding of how the mobile application should look.

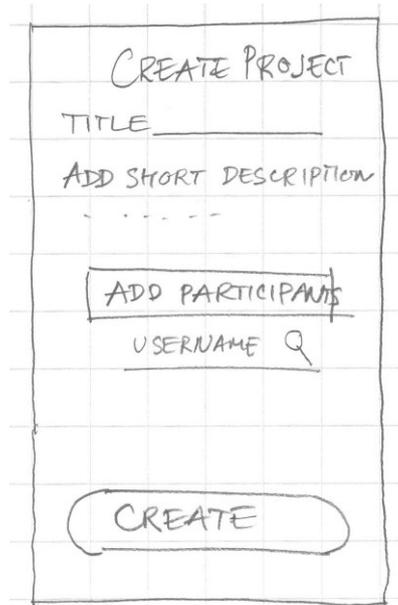
This gives more chance to continue brainstorming towards improved user-experience and usability.

The image shows two hand-drawn wireframes for a mobile application interface. Both wireframes are titled 'PROTOBOOTH OULU' at the top. The left wireframe is for the login view, featuring three input fields labeled 'STUDENT NUMBER', 'PASSWORD', and 'LOGIN'. The right wireframe is for the registration view, featuring four input fields labeled 'USERNAME', 'STUDENT NUMBER', 'EMAIL', and 'PASSWORD', followed by a 'REGISTER' button. Both wireframes have a 'REGISTER' button at the bottom left and a 'LOG IN' button at the bottom right.

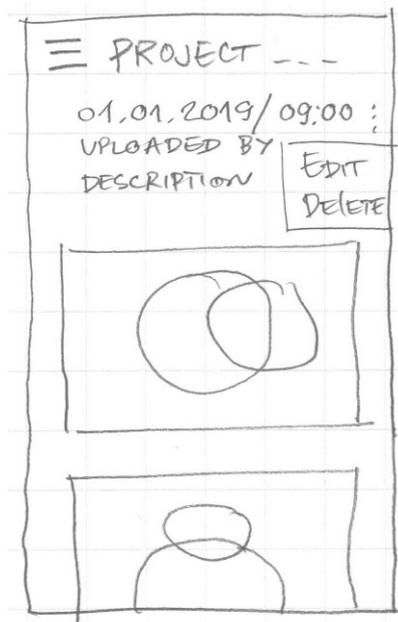
(login and registration View)

The image shows a hand-drawn wireframe for the 'Inspiration View'. At the top, there is a hamburger menu icon followed by the text 'PROTOBOOTH'. Below this, there is a list of menu items: 'HOME', 'INSPIRATION', 'PROJECTS', and 'MyPROFILE'. The 'INSPIRATION' item is highlighted with a shaded background. Below the menu, there is a large square placeholder for an image, containing two overlapping circles. Below the image placeholder, there is text that reads 'PROJECT 1 UPLOADED BY DESCRIPTION. ...'.

(a) Inspiration View



(b) Add Team View



(d) Single Post View

Figure 7. User Interface Mockups of the Mobile Application

3.2.3. Implementation and Architecture of the Mobile Application

For the Implementation of the mobile application, it was developed to run an Android operating system; for this reason, codes were written in Java Programming Language and Android Studio IDE. Herewith, the application follows a Model View Controller (MVC) paradigm, whereby the Model is responsible for the collection and the management of data; thus, data can be created, read, written or updated. The

View is responsible for revealing the data to the users in an understandable form. Thus, these are what you see on the application user interface. Last but not the least is the Controller, this plays a role of the connection between the Model and the View, in this stage, proper logics are defined to query the models and update the user interface accordingly (View). In Table 10 below, all the classes and their functionalities/descriptions for the mobile application are shown.

Table 10. Organization of the Mobile Application classes and functionalities

	File/Class	Description/Functionalities
Model	SQLitedb.java	This class is responsible for creating a standard SQLite database for creating and querying the database for the mobile application app.
	BgWorkManager.java	This class is responsible for data synchronization between the local SQLite database and the MySQL database on the PythonAnywhere cloud server.
View	LoginActivity.java	These classes handle the login and the registration view of the users
	FormRegisterActivity.java	
	ProjectFragment.java	These classes handle the other activities that concern documentations
	PostFragment.java	
	MainActivity.java	
	HomeScreenActivity.java	
	userProfile.java	
	AddUsersDialogFragment.java	
	ProjectPostFragment.java	
Controller	GalleryAdapter.java	This class handles the gallery views for pictures updated from the SQLite database

The mobile application for the documentation tool updates data to the PythonAnywhere server automatically on a periodic basis. This process is made to run in the background so as not to create conflicts while users are using the mobile application.

3.2.4. Mobile Application SQLite Database

The mobile application uses an SQLite database to store students' documentation posts. For privacy, the local SQLite database only stores the application user's posts, posts description and student's number. In table 11 below, the schema of the SQLite database table is described tentatively.

Table 11. The SQLite database schema for the Android Mobile Application

Column name	Data Type	Description	Attributes
student_id	INTEGER	Unique identifier for sorting posts	PRIMARY KEY, NOT NULL
student_number	INTEGER	Unique student number	UNIQUE, NOT NULL
_post	STRING	Base64 string of the pictures uploaded	NOT NULL
post_description	STRING	Description of the pictures uploaded to the database	UNIQUE
_timestamp	DOUBLE	Time the documentation was taken in milliseconds	DEFAULT 0

3.2.5. The Student Registration and Login Activity/View

The login and registration activity allow users to be able to have an authenticated account for themselves. Students can have access to his/her workspace via the login activity. Also, as shown in Figure 9, the "Don't have an account" leads a student to the registration activity.



Figure 8. Login Page

In the registration activity, a user can create an account with his/her student number, email address and password as shown in Figure 10.



Figure 9. Registration Page

3.2.6. Home Screen Activity

In this view, students can have access to some of the pictures uploaded by other students in other projects. However, these selected pictures are provided to the public by only the administrator. As shown in Figure 11 below, each post on the view, has the time and date features, description of the post and the student number for indicating ownership of the post.



Figure 10. Home page

In Figure 11 above, a menu icon shows the list of other views of the application. In the menu icon, a dropdown containing Home, Inspiration, Projects and My Profile are provided for easy navigation between all views. Actually, this icon is provided in all of the views/activities for a good user experience and usability.

3.2.7. *Project Fragment*

This activity allows a student to view his/her created projects and archived projects. This view is built with a native android ListView package for providing all the projects in a list in the order of the most recent post. Also, each project in the list has a dropdown icon that provides the Edit and Delete option. Herewith, at the bottom of the screen there is an icon that allows the student to create new project. Figure 12 below shows a screenshot of the ProjectFragment view.

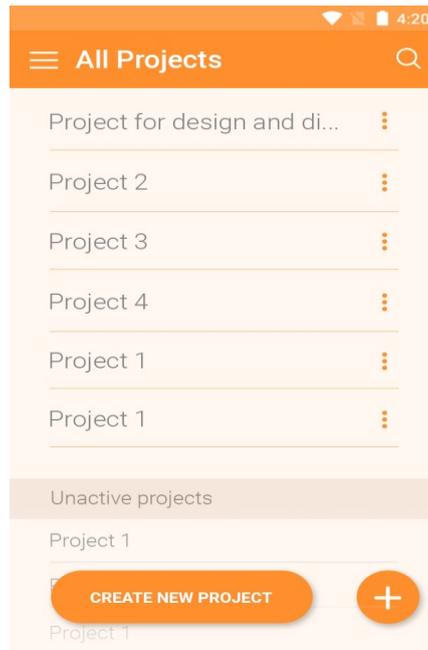


Figure 11. List of Projects Page

3.2.8. *Project Post Fragment*

Following the List of the projects shown in the ProjectFragment view, the system application also provides the possibility of navigating into each project. Hereby, the student can view all the recent documentation posts and add new posts to the project. The posts in this view also provides the user with one of the many pictures uploaded and the description. A recycler is used in building each post. For this reason, they have the capability of expanding to provide more information of the post when clicked.

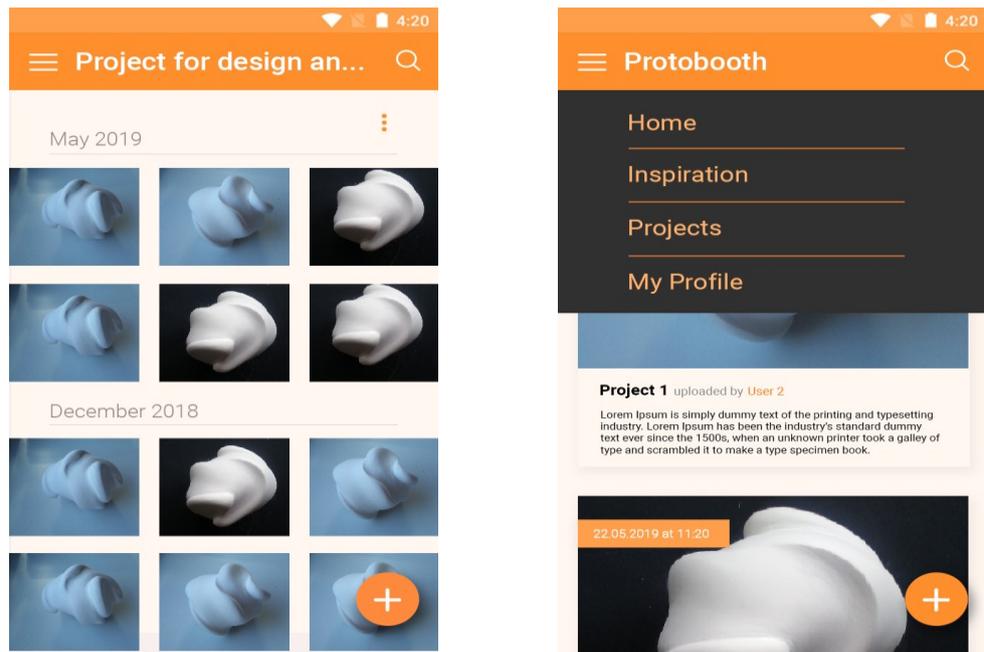


Figure 12. Documentation Post Page

3.3. The Development of the Admin Dashboard (Web Application)

The web admin dashboard is built to run on a Python cloud-based system environment using web technologies such as Python (Flask), Bootstrap, HTML, CSS and MySQL. In this concern, the web application utilizes the web API designed for interfacing and populating data. In other to achieve this system, similar procedures in developing the mobile application were taken into consideration.

3.3.1. Application Requirement Gathering

Following the significant goal of the thesis, a proper brainstorming was carried out. Hence, to decide on how to manage the data (documentation process posts) gotten from the students. Concisely, the web application tool provides an admin with the benefit of selecting pictures and posts that will be viewed by the public. There is also a control panel where the admin can view/manage all the students and their projects that are registered.

The web application system provides the admin with the privilege of making some useful database tables managements, such as Create, Delete and Modify.

3.3.2. Low-Fidelity Paper Sketch of the Web App

Subsequently, to obtain substantial concept for the Web admin dashboard, long process of brainstorming and deliberating was carried out with pencil and paper sketch. These procedures provide insight into the usability of the web application. Figure 10 depicts some of the web application tool provided for the administrator. Figure 10a shows the Home view of the web admin page, where all the recent student posts are collated and shown in the form of different blog posts. As you can

see from the picture that there is an icon on the side of each post, on click, the icon changes, whereby the goal is to give the admin the privilege of accepting or selecting the posts that should display to the public and in the HomeScreenActivity mentioned in section 3.1.6.

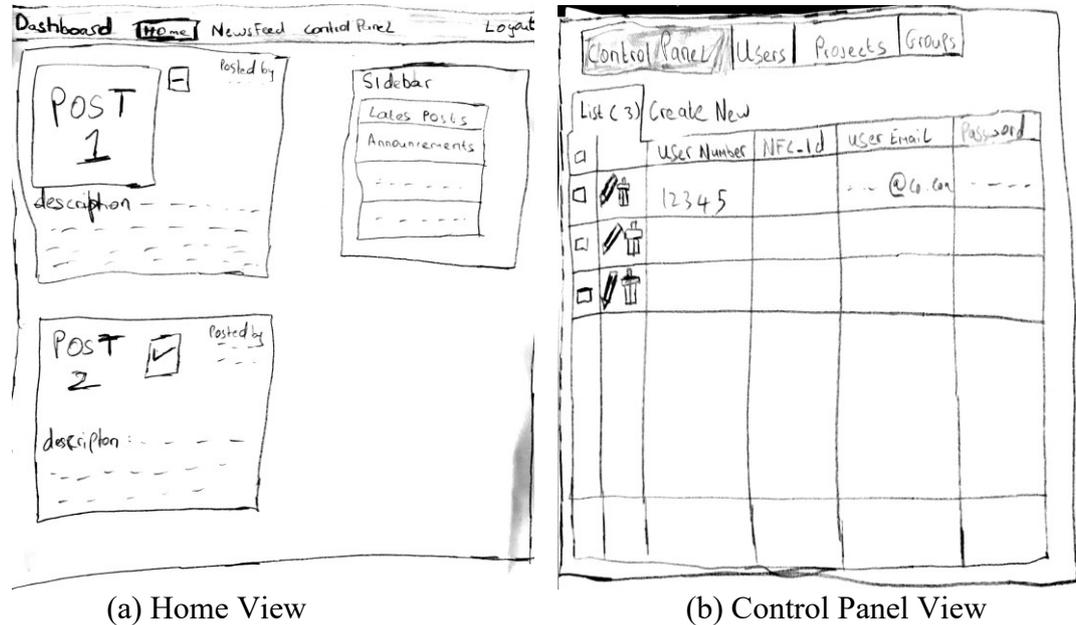


Figure 13. Paper sketches of the Web Admin pages

Further, Figure 10b illustrates an administrative control panel for displaying all the students' record to the admin. In this view, an admin can navigate to each section. For Instance, when the admin navigates to Projects, he/she gets to see all the projects that have been created, or when the admin navigates to Users, he/she gets to see all the students that have created an account to use the documentation tool. Following the results of the paper sketch, the actual design was implemented. Herewith, the next section contains brief explanations and overview of the features and components of the web administrator.

3.3.3. Overview and Features of the Web Application

The web application consists of several screens (see Figure 15, 16 and 17). The login screen for an admin (Figure 15). Once the admin logs in, he/she gains access to the home view, where students' posts are visible. The home view provides the navigation access to the other views/parts of the web application. Note the icons that surrounds each post on the page. The plus and minus icon allows the user to choose which of the posts shall be available to the public. In addition, there is also a delete button for each post for deleting a specific post.

Flask Admin Documentation Dashboard [Home](#) [About](#) [Login](#) [Register](#)

Please log in to access this page.

Log in!!

Email

Password

Remember Me

[Log in](#)

[Forgot Password?](#)

Our Sidebar

You can put any information here you'd like.

- Latest Posts
- Announcements
- Calendars
- etc

Figure 14. Login Page to the Admin Panel

Control Panel [Home](#) [Users](#) [Courses](#) [Groups](#) [Projects](#) [Posts](#)

List (10) [Create](#) [With selected ▾](#)

	Project Name	Project Description
<input type="checkbox"/>	Documentatiow Prototyping	In this project we develop prototypes
<input type="checkbox"/>	Documentation For Prototyping	In project we develop prototypes
<input type="checkbox"/>	A good robot	In this project we create a robot
<input type="checkbox"/>	A good way to study	we do a research on this
<input type="checkbox"/>	let's do this	good project
<input type="checkbox"/>	creating a phone	we use this to create a gadget
<input type="checkbox"/>	For Prototyping	In project we develop prototypes
<input type="checkbox"/>	rectangular box	solar powered box with traffic lights
<input type="checkbox"/>	Telecom software	A tool for softwarizing telecommunications
<input type="checkbox"/>	Fab test	testing project

Figure 15. Users' Project Page

Control Panel							
Home		Users		Courses		Groups	
Projects		Posts					
List (14)	Create	With selected ▾					
<input type="checkbox"/>	<input type="checkbox"/>	User Number	Nfc Id	User Email	Password	Is Admin	Is Teacher
<input type="checkbox"/>	<input type="checkbox"/>	0	0	admin@yahoo.com	\$2b\$12\$STZldgJ3RypXw3wOhaRgeullApxM4vAvkNVNz2zAUFUHu0foG5IkJm	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	75942569		jobico124@gmail.com	jobico124	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	2557768		adeegbe@gmail.com	adeegbe	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	12345		adeegbejoshua@gmail.com	\$2b\$12\$JeAbjOVV4smm.ntxkDq5Nu2sT852LUoPep2ei87xclMm0PadbS84Sy	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	2557292		sabbir.ahmed@student.oulu	\$2b\$12\$M5py1P3YBb6.XnKDrVQ/4OwGdUrbuW542xldGcZnFgljrku1.1H.	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	525625		adeegboshua@gmail.com	\$2b\$12\$yB2UgB9RFPXTJvVyzg2nl.yEZI3Pwcolp1IeBANZSZVnjXID9vXuG	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	59682		gjujh@rst	\$2b\$12\$5Fm/TJ.e66Sh210Anjs.ZArJdnF00B07jwQNh.o.AXIBqOrrUBK	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	123456		polo@gmail.com	\$2b\$12\$8Lq26dq0mc1.sgJcSI1D.D.eryXToPTGQp5Cmrry2w9t6EEAGyhm	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	1234567		jobi124@gmail.com	\$2b\$12\$5gHb304n.VFgfCC4oQmupOrDXYXi4I96D3WXRW4UGhrgUG8BFbL0S	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	1010	0	ds@gmail.com	\$2b\$12\$quRbttn.rifqOHGexs8COIIRQwVbQuM5tXIKsaqdiIHBrTsVv72m	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	1111		qqqqq	\$2b\$12\$UXJ3z.JaVMkaRk1ACe3/cTux6r9AsggvqvoE.mWXLrqZpsvOYXNasS	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	2365565		adeegbejoshua@jkh.com	\$2b\$12\$8z.JaRtzeLICBwCXsppDTHu3/D317Kubm1.p1ICPb9uD3r5Xr1pnpe	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	2573357		bozzfeedz2@gmail.com	\$2b\$12\$IGcOWNI5WMB0iIW/clpNeOW5KHJPZ4bBVKT2U6dChgLTCKjexhS8C	<input type="checkbox"/>	<input type="checkbox"/>

Figure 16. Control Panel for all users

On clicking the Control Panel in the home page of the administrator web app, the admin is redirected to the admin control panel. In this page, there are various tables that contain information on the Users, Groups, Projects and Posts. The admin can make various changes to the information in each table such as Create, Modify and Delete. It is important to note that whatever changes are made in this administrator control panel, have automatic effect on each user's information and this automatic update the users (student) mobile application.

Following the implementation of the Web API(s), the mobile-enabled client-server architecture and the web-based administrative dashboard. An evaluation study was carried out. The next chapter provides the description of the evaluation and results of the study.

4. EVALUATION AND RESULTS

4.1. Prototype Evaluation

This section provides the result of a usability testing conducted on the mobile application and the web application. The purpose of this study is to understand users' feedback on the usability of the prototypes and the features in the applications that users find useful or the features that are required to be added or improved.

The study was carried out in Fab Lab Oulu with 15 participants of ages ranging from 20 to 35 years (mean age = 28) are recruited and an ongoing project for every participant. Afterwards, the concepts of the applications are shown to the participants. A consent form for every participant is also made available before each participant commence the study. The consent form is a formal proof of a voluntary agreement that shows that based on his or her rights, every participant willingly agrees to take part in the study. It also provides the purpose of the research study and the potential possibilities and benefits of participation.

The usability testing consists of two main exercises from each participant. In the first exercise, each of the participants is asked to perform some specific tasks on the mobile application and the web application, after that, each participant is provided with a System Usability Scale (SUS) questionnaire for the next exercise. The tasks for the applications are as follows,

Tasks for the Mobile Application:

1. Create an account for yourself using the mobile application
2. Login into your account
3. Create a new project
4. Form a group by adding other students to the project using their student number
5. Upload new pictures of an ongoing project in Fab Lab like it is your own and write a short documentation on them
6. View your personal documentation
7. Delete a post
8. Log out

Tasks for the Web Application:

1. Login in as an admin (Admin login credentials are provided)
2. Create an account for 5 users (students)
3. Create a new project
4. Form a group by adding students to the project using their student number
5. Delete students' post
6. Log out

The SUS questionnaire provides us with a rapid and dirty usability scale [30]. The questions in the SUS is as follows. It is important to mention that this same questionnaire is used in evaluating the web application, though, different results were generated.

1. I think that I would like to use this system application frequently
2. I found this system application unnecessarily complex.
3. I thought this system application was easy to use.
4. I think that I would need assistance to be able to use this system application

5. I found the various functions in this system application were well integrated.
6. I thought there was too many inconsistencies in this system application
7. I would imagine that most people would learn to use this system application very quickly
8. I found this system application very cumbersome/awkward to use.
9. I felt very confident using this system application.
10. I needed to learn a lot of things before I could get going with this system application.

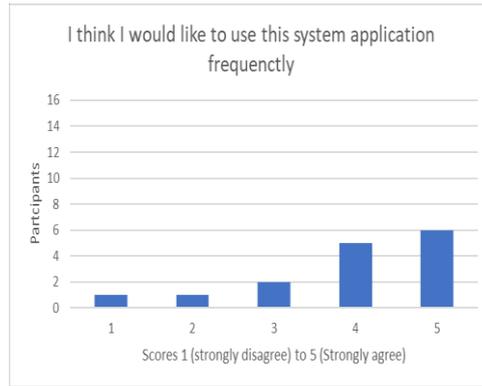
Note that for each SUS question, there are five choices of responses ranging from strongly agree to disagree strongly. Thus, the results are interpreted via the method of normalizing to obtain a percentile ranking [30].

After all the steps mentioned are carried out, the participants are then engaged in a semi-structured interview, where fundamental questions, follow-up questions, and open-ended questions are discussed [31]. The questions asked, provide us with every user's profile. The following are the questions:

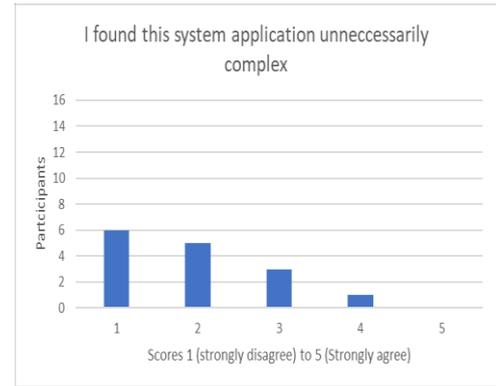
1. How often do you work on projects in Fab Lab?
2. How often do you take documentations?
3. What is your opinion about an admin providing some of users' documentation post to the public?
4. Apart from Fab Lab, where else would you want to use the application?
5. Do you find any features in this application irrelevant?
6. Do you find any features in this application difficult?
7. How else would you want this application to be built?
8. What other features would like to have access to in this application?
9. Have you ever used a similar application in the past?
10. Do you prefer to use book and pen or mobile devices?
11. Gender
12. Age
13. Level of education
14. Occupation

4.2. Analysis of the Results

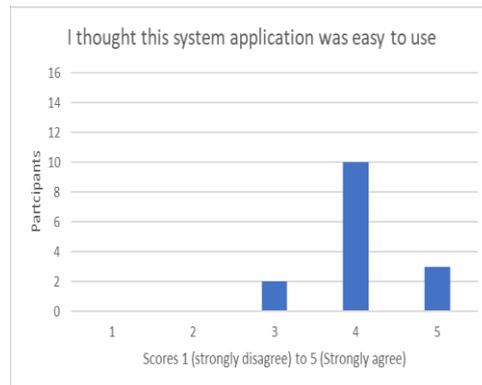
At the end of the user study, it took an average duration of 18 minutes for users to complete the study. In the case of the SUS questionnaire feedback, the analysis of responses from all participants gives an average SUS score of 78.5, in the SUS standard scale of 0 to 100. Figure 10a to 10j depict the complete descriptions of the SUS responses.



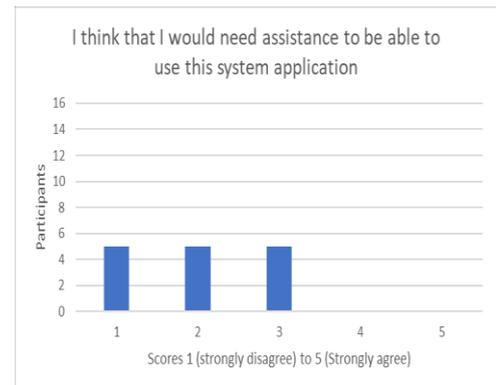
(a) Q1 Response



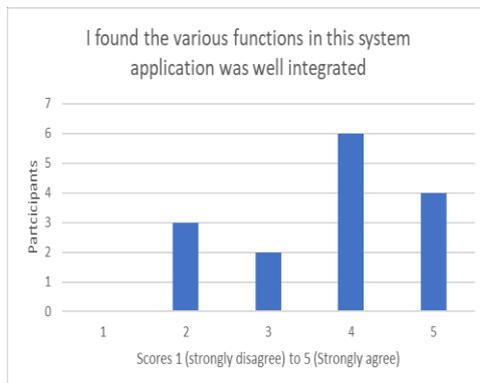
(b) Q2 Response



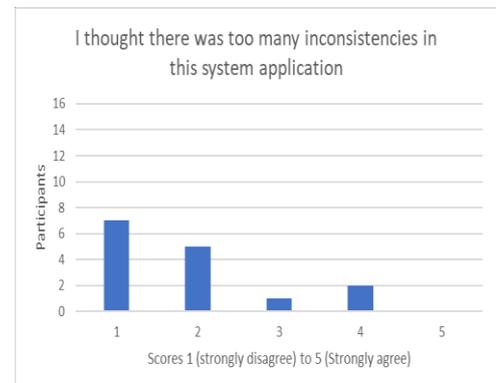
(c) Q3 Response



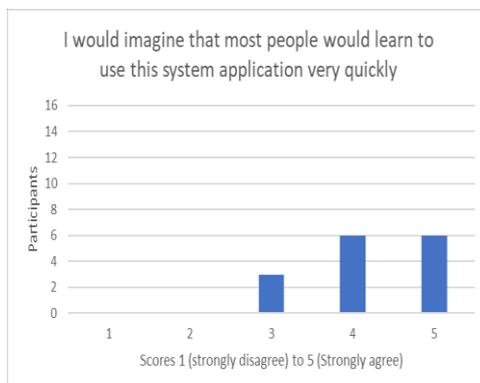
(d) Q4 Response



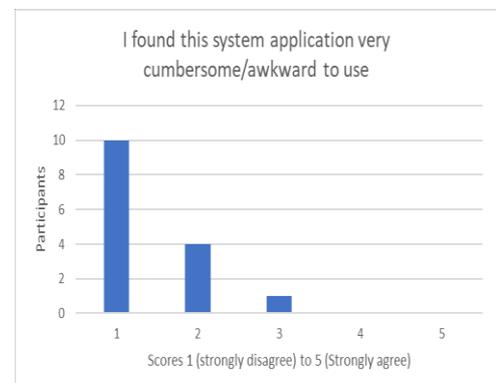
(e) Q5 Response



(f) Q6 Response



(g) Q7 Response



(h) Q8 Response

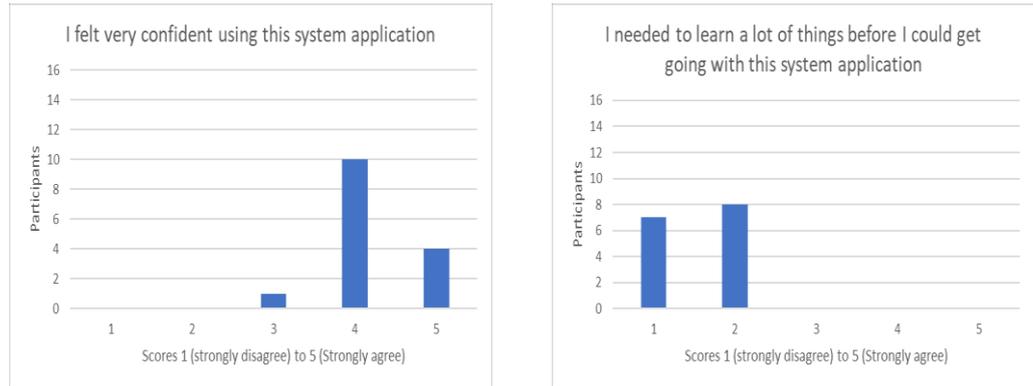


Figure 10. Description of the SUS questionnaire participants response

Further, for a more precise understanding of the SUS response, the Mean, Adjusted Mean and Standard Deviation of all responses to each question are shown in Table 12. It is important to note that question 2, 4, 6, 8, and 10 are negatively scaled question, thereby, generating a negatively scaled response. Thus, in order to have a balance mean for all the SUS questions, the Adjusted Mean arises. The Adjusted Mean is computed with the formula $5 - \text{Mean}$. The highest mean response among the negatively scaled questions is 3.7 (from question 8); hence, this means that some users find the application to be cumbersome/awkward to use.

Table 12. The Mean and Standard Deviation of the SUS Response

SUS	Responses	
	Mean	Adjusted Mean
1. I think that I would like to use this system application frequently	3.93	3.93
2. I found this system application unnecessary complex	1.93	3.07
3. I thought this system application was easy to use.	4.07	4.07
4. I think that I would need assistance to be able to use this system application	2	3
5. I found the various functions in this system application were well integrated.	3.73	3.73
6. I thought there was too many inconsistencies in this system application	1.87	3.13
7. I would imagine that most people would learn to use this system application very quickly	4.2	4.2
8. I found this system application very cumbersome/awkward to use.	1.3	3.7
9. I felt very confident using this system application.	4.2	4.2
10. I needed to learn a lot of things before I could get going with this system application.	1.53	3.47

Moreover, in the semi-structured interview conducted, participants give their honest opinions on the application. It is interesting to realize that the majority of the participants find the application useful. This fact was also realized from the SUS questionnaire responses. On this note, some of the participants suggested interest in other features such as instant messaging. However, for the sake of privacy, some of

the participants have issues with the idea of giving the admin authorization to make some selected documentation posts public to other users. The participants suggest the decision should be up to them alone. In cases where the admin needs to make a post public, permission should be sought. In the next chapter, further discussion on the results of the study is provided.

5. DISCUSSION

5.1. Contribution

This work contributes to research in the field of digital fabrication. Supporting analysis systems in prototyping is vital in Fab Lab because it helps self-reflection and knowledge sharing during the prototyping process. As a result of this, this thesis uses a design science methodology in the light of research to provide a solution to lack of proper documentation of design stages in Fab Lab. These solutions include the implementation of a mobile-enabled client-server architecture and a web-based administrative dashboard for supporting managing and analysis of annotated visual data of prototype designs in Fab Lab

Improving documentation systems for users in Fab Lab has been a critical research study in recent times. Dalsgaard et al. [15] mentioned that many people have criticized the current lack of a well-structured approach to documentation severally. Although the systems implemented in this thesis support the concept of reflection-in-action and reflection-on-action, it is essential to mention that our systems do not improve the result of prototype design. In other words, these systems capture data during the design process stage for users to be able to reflect on them at any stage of the design process.

The next section provides insight on the idea of documentation derived during the course of this thesis.

5.2. Documentation and Reflection

Several attempts in developing a system for proper documentation of the design process in Fab Lab have limitations to a specific location or accessibility. For instance, Barhoush et al.'s Protoboosth system [27]. Using a Protoboosth system for keeping track of prototype stages can only be done in Fab Lab due to it being a situated physical system. Although, according to Barhoush et al.'s pre-study, students prefer the automated form of documenting prototyping progress [27]. However, scaling the physical system up can be quite challenging, as the system cannot be available for every student/user at the same time. In the case of the mobile application developed in this thesis, users get to capture data for their prototypes at any given time or place. On the other hand, the admin can select which of the documentation post that is suitable for the public (i.e., in the form of blog posts) so that having junks or irrelevant posts visible to the public can be avoided.

Besides, annotations for every document post is essential for reflection. However, this is also what Barhoush et al. Protoboosth system lack [27]. This limitation has been addressed in our system. Hence, users can easily annotate every post he/she makes. Furthermore, the systems designed in this thesis is similar to Sánchez Milara et al. system. It can be seen that they tackle the issue of poor documentation in the paper. However, the application software in his design has restrictions of use whenever a user cannot access the internet. This is so because the mobile application directly communicates with the web server. It is believed that users should be able to use the documentation tool at any given time or place. For this reason, a local storage system is implemented for saving documentation posts and a background service

called WorkManager, which automatically updates the web server whenever the users have gained access to the internet.

Overall, after evaluating the current state of the mobile application and the web application, it can be observed that users find the application to be easy to use and that a good percentage of all our participants may find the systems useful for them in the future. However, besides being able to use the applications as a design-in-progress reflecting tool, most users are concerned about the social aspect. In this concern, users want to be able to interact with other users and maybe ask questions in case they need help. Such feedback is considered as one of the future works in order to improve usability and user experience. More future works are also mentioned in the following section.

5.3. Future Work

The mobile application is only available for Android users. For this reason, in the future work, it is required to provide a cross-platform application. This means that the application will be available for users with different operating systems such as, iOS, Windows, etc.

In addition, the systems does not enable users to socialize and give feedbacks to different posts. This limitation was derived from the feedbacks retrieved from the semi-structured interview held with the participants. Therefore, it has been taking into consideration, and the future goal is to develop a system that has a chat application included and a feedback mechanism for every public post, most notably for users participating as a team in project work. Another direction of future work is to provide comment boxes or feedback mechanism on every documentation post specifically for a project supervisor.

Finally, as a future work, a proper field study on these applications should be carried out, whereby, participants will be allowed to install the app and test run the application for about 30 days or for a duration of a course. It is believed that this would provide a clearer insight into more usability and enjoyable user experience on the systems for supporting analysis.

6. CONCLUSION

The purpose of this thesis is to contribute to research in the field of digital fabrication, specifically in Fab Lab. One of the main challenges of the users of Fab Lab is having proper support for analyzing and reflecting on prototyping stages. In other words, Fab Lab users struggle with having proper documentation for supporting their analysis of prototyping phases. Hence, the development of different organized system designs that serve as tools for storing information, ideas and knowledge from the various stages of developing prototypes in the Fab Lab. These systems are interconnected platforms that provide solutions to the challenges of proper documentation during design prototyping.

In this concern, the developed systems in this thesis consist of Web API, a Web Administrator Application and a Mobile Application. Following the reviews on the related works discussed in this thesis, these systems are implemented, and a study to evaluate the user experience and usability are conducted on the Web Administrator Application and the Mobile Application. It is observed from the results of the study that these systems have the potential to be useful for Fab Lab users.

Based on the study sessions that involved the participants, it was realized that many of the Fab Lab students are interested in the modern ways of documentation. Some of them even suggest a more social system. In this concern, they want to be able to choose some of their documentation notes to be available to the public, and they want additional features that allow other users to be able to comment their opinions on them. On this note, it is worth mentioning that this study demonstrated that leveraging the easy-to-use mobile phone technologies, such as cameras, can be highly beneficial for documentation, whereby users can take pictures and annotate them for self-reflection while designing a prototype.

Finally, this study outlines the development process of the systems for supporting analysis of prototyping in Fab Lab. The results of the usability testing of the applications will lead to continuation on improving some of the features mentioned in the discussion section. In addition, the future work on this thesis consists of data collection and providing analytics through the aid of machine learning, deep learning, data analysis, etc., for improving and supporting educational atmosphere for students in Fab Lab.

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8. APPENDICES

Appendix 1. Questionnaire

Appendix 2. Interview Questions

Appendix 1.

System Supporting Analysis of Prototyping in Fab Lab Education

User Interface Design Evaluation Guide

Participant ID: _____
Date: _____

Consent form

Purpose of study

The participant is asked to evaluate a mobile application and web administrator application developed for supporting analysis of prototyping in Fab Lab. The purpose of this study is to find out the usability and the user experience of the applications in concern. Hereby, obtaining the usefulness of both applications to the participant. Furthermore, knowing the features each participant finds useful and what features participants think could be added or improved. The outcome of the study would provide useful data for the improvement of the usability, user experience and features of the applications in concern.

Collected Data

The data required from the participants are based on the following concepts;

- User experience of the web administrator application and the android mobile application
- Other useful implementations and features needed to be changed or improved, and opinions on experience with similar applications,
- Age, gender, and latest level of education, occupation, and
- Response to System Usability Scale (SUS) questionnaire

Procedures

The user study is estimated to take approximately 20 - 30 minutes.

The procedures and tasks are verbally demonstrated to the participants.

Conditions

The entire study is conducted in only English, for this reason, ever participants is expected to be able to communicate independently in English. In addition, the participants must be familiar with Fab lab. There is no technical skills or experience required to take part in this study. Also note that, all the questions are not mandatory. Participants can choose to ignore any of the given interview questions.

Benefits

This study contributes to the research study in Fab Lab for improving student experience in prototyping. However, there is no personal benefit for the participants.

Confidentiality

This consent form will be highly confidential and will not be disclosed any third parties. However, it is important to bring to your notice that by participating, your data will be use by the University of Oulu for further research and contributions to the field of digital fabrication. Hereby, you give your consent that the data and information gathered during the study may be used by the University of Oulu.

By signing this document, I affirmed that I have read and understood the terms outlined above. I formally agree to give the required date for this study.

_____ (date and signature)

Participant ID: _____

Date: ____/____/____

SYSTEM USABILITY SCALE

Instructions: For each of the following statements, mark one box that best describes your reactions to the website today.

1. I think that I would like to use this system application frequently

Strongly disagree				Strongly agree
1	2	3	4	5

2. I found this system application unnecessarily complex.

Strongly disagree				Strongly agree
1	2	3	4	5

3. I thought this system application was easy to use.

Strongly disagree				Strongly agree
1	2	3	4	5

4. I think that I would need assistance to be able to use this system application

Strongly disagree				Strongly agree
1	2	3	4	5

5. I found the various functions in this system application was well integrated.

Strongly disagree				Strongly agree
1	2	3	4	5

6. I thought there was too many inconsistencies in this system application

Strongly disagree				Strongly agree
1	2	3	4	5

7. I would imagine that most people would learn to use this system application very quickly

Strongly disagree				Strongly agree
1	2	3	4	5

8. I found this system application very cumbersome/awkward to use.

Strongly disagree				Strongly agree
1	2	3	4	5

9. I felt very confident using this system application.

Strongly disagree				Strongly agree
1	2	3	4	5

10. I needed to learn a lot of things before I could get going with this system application³.

Strongly disagree				Strongly agree
1	2	3	4	5

Appendix 2.

INTERVIEW QUESTIONS

How often do you work on projects in Fab Lab?

How often do you take documentations?

What is your opinion about an admin providing some of users' documentation post to the public?

Apart from Fab Lab, where else would you want to use the application?

Do you find any features in this application irrelevant?

Do you find any features in this application difficult?

How else would you want this application to be built?

What other features would like to have access to in this application?

Have you ever used a similar application in the past?

Do you prefer to use book and pen or mobile devices?

Level of education

Occupation

Gender: _____

Age: _____