



FACULTY OF INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING  
MASTER'S PROGRAMME IN COMPUTER SCIENCE AND ENGINEERING

**VIRTUAL LIBRARY:  
A TECHNICAL IMPLEMENTATION FOR A  
VIRTUAL REALITY LIBRARY INTERFACE**

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## **ABSTRACT**

**Libraries, as traditional information storages, serve an important role in providing free access to civilization's knowledge to the public. In the advent of the information society, conventional means of knowledge seeking slowly become obsolete. As technologies advance, libraries shall discover how available inventions could be utilized in enhancing library services and raising public awareness.**

**The offer to discover Virtual Library project was given to the author by the Center for Ubiquitous Computing in the University of Oulu, with the idea originating from Oulu City Library. The goal of the project was to implement an interactive application that would provide a unique experience for library users and show off capabilities of modern virtual technologies. The requirements for it were elicited and refined in a series of participatory design workshops held in Oulu City Library, and as a result, the content of initial web prototype was utilized in the creation of standalone virtual reality application on Unreal Engine 4. The application works with Oculus Rift headset and Oculus Touch motion controllers and lets the user explore the virtual model of Oulu City Library premises as well as some fictional places, added for diverse experience, and experience several activities.**

**Virtual Library was evaluated in a series of testing sessions held in the Oulu City Library with a total of 12 participants, which were primarily the library's staff members. Overall, the application was positively acclaimed, providing an interesting and unusual library experience, and presenting capabilities of modern virtual reality technologies.**

**Keywords: library, virtual reality, Unreal Engine 4.**

**Minyaev I. (2019) Virtuaalikirjasto: Tekninen kuvaus Virtuaalitodellisuutta hyödyntävälle kirjastopalvelulle. Oulun yliopisto, tietotekniikan tutkinto-ohjelma. Diplomityö, 53 s.**

## **TIIVISTELMÄ**

**Kirjastoilla on perinteisesti tärkeä rooli tiedon välittäjinä ja tallentajina. Kirjastojen tulee myös mahdollistaa pääsy tiedon ääreen. Siirryttäessä lähemmäksi tietoyhteiskuntaa, perinteiset tavat käsitellä ja havainnoida tietoa ovat jäämässä historiaan. Myös kirjastot kehittyvät ja oppivat kuinka uusia teknologioita on mahdollista hyödyntää tiedon välittämisessä yhteisöille.**

**Virtuaalikirjasto -projekti lähti Oulun kaupungin kirjaston pyynnöstä Oulun yliopiston Jokapaikan tietotekniikan tutkimusryhmälle. Projektin päämääränä oli toteuttaa interaktiivinen sovellus, joka tarjoaisi kirjaston asiakkaille elämyksellistä sisältöä samalla havainnollistaen virtuaalitodellisuuden ja siihen liittyvien teknologioiden mahdollisuuksia. Sovelluksen toteutusta hiottiin Oulun kaupunginkirjastossa sarjalla osallistavan suunnittelun mukaisia työpajoja. Virtuaalitodellisuussovellus toteutettiin Unreal Engine 4 -pelimoottorilla. Se toimii Oculus Rift -virtuaalilaseilla ja Oculus Touch -ohjaimilla. Sovelluksessa on mahdollista kulkea vapaasti virtuaalisessa Oulun kaupunginkirjastossa, sekä tilaan liitetyissä mielikuvituksellisemmissa maailmoissa.**

**Virtuaalikirjasto -sovellus evaluoitiin Oulun kaupunginkirjastossa sarjalla käyttäjätestejä. Testikäyttäjiä oli kaikkiaan 12 ja he olivat pääosin kirjaston työntekijöitä. Sovelluksen vastaanotto oli positiivinen. Käyttäjät totesivat sen havainnollistavan käytettävissä olevan tekniikan mahdollisuuksia samalla tarjoten mielenkiintoisen ja epätavallisen kirjastokokemuksen.**

**Avainsanat: kirjasto, virtuaalitodellisuus, Unreal Engine 4.**

# TABLE OF CONTENTS

ABSTRACT .....	1
TIIVISTELMÄ .....	2
TABLE OF CONTENTS .....	3
FOREWORD .....	5
LIST OF ABBREVIATIONS AND SYMBOLS .....	6
1. INTRODUCTION .....	7
1.1 Motivation .....	7
1.2 Scope .....	7
1.3 Research problem and methods .....	9
1.4 Author's contribution .....	9
1.5 Structure of the thesis .....	9
2. VIRTUAL TECHNOLOGIES IN LIBRARY ENVIRONMENT .....	10
2.1 Short history of virtual reality .....	10
2.2 Presence and immersion .....	11
2.3 Benefits of VR .....	12
2.4 VR applications for libraries .....	13
3. DESIGN .....	14
3.1 Objectives .....	15
4. INITIAL PROTOTYPE .....	17
4.1 3D assets .....	17
4.2 Back-end implementation .....	19
4.3 Web client .....	19
4.4 Unity usage .....	22
5. FINAL PROTOTYPE IMPLEMENTATION .....	23
5.1 Unreal Engine 4 framework and application structure .....	23
5.2 Scenes .....	26
5.2.1 Lobby scene .....	27
5.2.2 Village scene .....	28
5.2.3 Study scene .....	29

5.2.4 Future scene .....	30
5.3 Book search .....	31
5.4 Art gallery .....	33
5.5 Featured books .....	34
5.6 Storybook .....	35
5.7 Server side .....	38
5.7.1 Third party libraries .....	39
5.7.1 Searching and routing .....	39
6. EVALUATION .....	40
6.1 Setup .....	40
6.2 Procedure .....	40
6.3 Interviews .....	41
6.4 Quantitative results .....	41
6.5 Feedback from users .....	42
7. DISCUSSION .....	44
7.1 Attainment of objectives .....	44
7.1.1 Create a virtual environment of Oulu City Library and fantasy worlds .....	44
7.1.2 Utilize library's web services .....	45
7.1.3 Show media content and promote reading culture .....	45
7.1.4 Provide multi-user experience .....	46
7.2 Future development .....	47
8. CONCLUSION .....	48
9. REFERENCES .....	49
10. APPENDIX .....	53
10.1 Appendix 1: Questionnaires .....	53

## **FOREWORD**

This master's thesis project was developed for Oulu City Library at the University of Oulu as a part of AIA, AKAI, and COMBAT research projects. The goal of this work was to design and develop an interactive computer model of Oulu City Library. Started as a 3D web application, it later evolved to a standalone virtual reality (VR) application.

I want to thank my supervisor Matti Pouke, for guiding me during this project, helping with technical and organizational matters. I am also grateful to Paula Alavesä for valuable feedback on the thesis's work. Lastly, I appreciate the great helping input from Minna Pakanen and Johanna Ylipulli, postdoctoral researchers at the Center for Ubiquitous Computing at the University of Oulu.

Oulu, May 8, 2019

Ilya Minyaev

## **LIST OF ABBREVIATIONS AND SYMBOLS**

API - Application Programming Interface

AR - Augmented Reality

HMD - Head Mounted Device

JS – JavaScript

UE4 - Unreal Engine 4

UI - User Interface

VE - Virtual Environment

VR - Virtual Reality

# **1. INTRODUCTION**

## **1.1 Motivation**

Oulu City Library is a municipal library, located in Oulu city center. Its history began in 1877 when library establishment with public library and reading hall received its first visitors in Heinätori public school. In the following years, the library moved to a wooden building in Ainola park, which unfortunately was burnt down in the summer of 1929. After the fire, a new building was built in the same place, and it served the library as a home for half a century. During a 100th anniversary, a new construction project was launched, and five years later, in 1982, Oulu City Library moved to its current premises, on Kaarlenväylä 3. [23]

According to the Public Libraries Act, public libraries in Finland shall give open access to culture and education and provide opportunities for “lifelong learning and competence development” [36]. Digital technologies, as an inherent part of the modern information society, could be easily included in this. Oulu City Library management’s initiative was to create an interactive application for its visitors, that could offer interesting non-conventional library experience and show what modern virtual technologies are capable of.

This project promised an interesting study and perspective to gain experience in producing rich and interactive 3D environments. Author’s technical background in 3D modeling and game development served as a good foundation for developing a virtual reality (VR) application for Oulu City Library.

## **1.2 Scope**

This thesis work tries to satisfy the interests of three main parties involved in this project. From one side, Oulu City Library management wants to appeal to the challenging audience, used to smartphones and momentary access to all the information in the world, with unique library-themed experience. From the other – raise the awareness of the library’s general public of what modern virtual technologies are and how they can be utilized in the library’s service. From the point of Ubicomp, author’s research group, the focus was to experiment with virtual VR and explore the benefits of using Unreal Engine 4 for these purposes.

These objectives were achieved by developing a functional prototype of a VR library interface, named Virtual Library. Project requirements were elicited from meetings with library’s management and later refined in a series of participatory design workshops held in Oulu City Library premises by other researchers. The final prototype operates on a powerful computer with Oculus Rift headset and pair of Oculus Touch motion controllers. It allows the user to immerse into a beautiful virtual environment, combining virtual replica of Oulu City Library with some fictional places, coming right from the books, explore them and participate in a number of activities, ranging from purely entertaining to practical usage of library’s web services. Virtual Library was evaluated in a series of exploratory test sessions with the library’s personnel and customers. Based on the received feedback, the accomplishment of the project is discussed, and directions for future development are highlighted.



### **1.3 Research problem and methods**

An extensive list of requirements affected the scale of the Virtual Library project, making it a vast and miscellaneous complex. A variety of virtual environments, assets, internal activities, each with own behavior and interactions with the user, all of this have to coexist in one application. The research problem is to find a way to present both realistic and unrealistic library-related content to users without compromising aesthetics and usability, delivering the solid and coherent user experience.

This thesis aims to solve that problem by designing and developing a prototype of the Virtual Library. Its evaluation had both continuous and momentary practice. During the development process, many showcases and testing sessions were conducted to receive feedback on the current state of the project. These observations have proven to be very beneficial for the development and resulted in tweaks and refinements to design of the different aspects of Virtual Library. The final evaluation included a pilot user study, where both workload assessment tools and open-ended questionnaires were used to appraise participants' user experience.

### **1.4 Author's contribution**

The author accomplished almost the entire technical implementation, from early to final prototypes. The initial prototype has built the foundation for the project, in terms of 3D assets and server code. The functional product uses both own and paid graphical assets from Unreal Engine 4 marketplace. All inner logic and interconnection with the server are developed by the author. In the evaluation phase, the author was responsible for the technical side of the process.

In addition to that, the results of the author's work were used in other publications produced at the Center for Ubiquitous Computing at the University of Oulu [35, 30].

### **1.5 Structure of the thesis**

The next chapter of the thesis gives an overview of existing examples and prototypes of 3D virtual technologies in libraries infrastructure. Chapter 3 describes the design process and its outcomes. Chapter 4 tells about prototyping in the early stages of the development. Chapter 5 gives a technical background and extensive details of the implementation process. Project evaluation and testing results are presented in Chapter 6. Lastly, Chapter 7 concludes the work and opens perspectives for future development.

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## 2. VIRTUAL TECHNOLOGIES IN LIBRARY ENVIRONMENT

VR has become very a trending technology once again and its applications have found their place in many industries now: education, military, entertainment, etc. This chapter gives a short throwback to a history of VR and its main milestones, discusses the benefits of the VR technologies and gives examples of how VR technologies are used in public spaces and, more relevant for the topic of this project, in library environments.

### 2.1 Short history of virtual reality

VR technologies (in a form we know and recognize them now) started to develop in the late 60s - 70s. The first outstanding work was a device called Sensorama, created by cinematographer Morton Heilig in 50s and patented in 1962. A strange arcade-like looking booth, it did not recall modern HMDs but was able to stimulate a wide range of senses. It had a stereoscopic vibrating seat, 3D display, stereo dynamics, smell and wind generators. The inventor created six short films, providing rich and sterling experience. [18]

In 1965 Ivan Sutherland's presented an Ultimate display as a concept. Sutherland speculated on how a virtual reality experience could be achieved, described possible input devices and applications [47]. Later on, in 1968 he and his student Bob Sproull constructed a first HMD, called a Sword of Damocles. It was too heavy to wear; thus, it was hanging down from the ceiling and strapped to a user. The quality of graphics was very primitive due to the early state of technologies, so the project did not get further development [29].

Next leap and interest of the public happened in the late 80s - 90s. In 1987 Jaron Lanier, a founder of the visual programming lab (VPL), developed a hand gesture interface device called DataGlove [61]. The device was a glove with sensors which let the user manipulate geometrical objects in computer application. A shortly after, in 1988, VPL made and started to sell a head-mounted display EyePhone. It had colorful displays and attached to user with rubber diving mask and fabric straps [37]. Over time, VPL developed new versions of EyePhone and was a first commercial company selling VR devices.

In 1993 SEGA presented an HMD for Sega Genesis gaming console at the Consumer Electronics Show, but due to technical difficulties, the device ended up just as a prototype, though four games were already developed for it. In 1995 Nintendo released a Nintendo Virtual Boy, a first-ever portable VR gaming console which turned out to be a commercial failure. The reasons for that are considered as lack of color support and uncomfortable usage of the whole set [60].

In the following years, the public interest for VR tails off, no big announcements or consumer devices, though experiments with it continued in scientific, military and medical fields. For example, in 1999 Georgia Tech and Emory University researchers used VR to perform exposure therapy for PTSD Vietnam veterans. A virtual environment simulating war zone events was experienced in an HDM with head position tracking. [38]

In 2010, the prototype of Oculus Rift HMD was created by Palmer Luckey. In 2012 it was successfully funded on Kickstarter, refreshing public interest in VR and giving hopes for low-

cost consumer devices. One important feature of it was a wide viewing angle, which substantially enhances user experience. Later on, in 2014 Facebook bought Oculus company, and competitors from industry started popping up. These events were the start of a new VR “era”, which we are living through now. [24]

## 2.2 Presence and immersion

Oxford dictionary defines Virtual Reality as “computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors” [57]. And while it is true, this definition focuses solely on the technical side, highlighting the significant role of computer, headset and motion controllers, while omitting user’s own experience with the system. As J. Steuer stated, the concept of presence is the core factor in defining virtual reality in terms of user experience [45].

There are two essential terms usually used in describing user experience in VR (and which would be used frequently in this work) - immersion and presence.

Immersion is more applicable to technological level and measures to which degree VR maintains an illusion of reality to the experiencing it user. Immersion is accomplished to a varying extent through many ways: shutting out the physical reality, engaging more senses (for example adding wind simulation or smell generators), increasing range of view and quality of the displays, etc. In addition to these properties, matching between the user’s physical activity and their consequences in the virtual world is required. For instance, when the user moves his hand holding a motion controller, he shall see his virtual embodiment doing the same action as well. One more important factor in creating immersive environments is the plot. The virtual world should have its narrative and internal rules on how virtual objects interact with each other and, ideally, also a user. Imagine a forest scene, whereas the sun moves, the shadows of trees change according to it, sunflowers rotate towards the light, and when user’s avatar steps on grass, the insects jump away from him. Each of the mentioned factors could be realized to a different scale, affecting the overall sense of immersion a user can experience with the system. [43]

While immersion is quantifiable and could be objectively assessed, the presence is more of a psychological definition. It is understood as a feeling of being in a particular virtual space rather than in the physical location of the body [43]. Many studies held in this area prove that a higher degree of immersion delivers a higher level of presence, though with some factors influencing it more than the others. HMD’s properties, such as tracking, the field of view, refreshing rate, etc. do affect the feeling of presence, while the level of visual realism is not so important so that there is no difference between being in a virtual environment with simple cartoonish or with photo-realistic graphics. The spatial sound and haptic feedback greatly influence the feeling of presence, though the later one is technically difficult to achieve to a full degree, even with the current state of technologies. Deep association with the user’s virtual body play a significant role in the creation of truly immersive VR experiences. User’s avatar movement should correspond to the movement of the user’s body parts, without dissonance

between the sensory input that the brain receives and what it observes in the HMD. The high level of such linking may potentially lead to user perceiving his virtual body as his own. [39]

It is essential to study the effects of different factors influencing the VR experience, as this knowledge could help design and develop better systems, saving time and resources, while focusing on important matters.

### **2.3 Benefits of VR**

Essential advantages of adequately designed VR application, such as immersive experience and embodied browsing, allow this technology to find numerous usages in many areas of the society. The most interested in VR areas are manufacturing, medical care and education.

In comparison to conventional means of content consumption, such as reading an article from a computer display or listening to an audiobook, VR introduces a more personal and natural approach. We live in a 3D environment, and even though our eyes since the real world via 2D projections, our brain is programmed to reconstruct the surrounding 3D world from these images by using different depth information. VR HMDs simulate depth with stereoscopy, wide field of view and head tracking, thus giving the brain more information and increasing spatial understanding of the subject [7]. In addition to that, the mobility of modern HMDs and motion controllers allow very natural interaction with virtual objects. Whenever the user wants to look something closer, he could lean towards the object of interest and inspect it in detail. Additionally, if the interaction behavior and physics are implemented for this application, user can “take” specific object in their virtual hands, watch it closer, rotate it, throw it away, do all sorts of allowed manipulations. [11]

The ability to feel being present in a quality virtual environment gets very convenient when the corresponding real experience is either too expensive to organize or even not possible at all. In this case, a virtual simulation of the required phenomena could provide nearly the same feelings and results. This feature has proven to be very useful in the medical and military fields. Medical care can utilize it to treat phobias and other traumas in virtual rehabilitation [9]. Military uses include sophisticated training simulators, which decrease the cost of the real training, reduce soldiers’ exposure to battlefield hazards, and allow to test a wide selection of conditions which are now always present in reality [25].

The openness of modern VR hardware and software could also be accounted for as a significant benefit. Accessibility of technology is expressed in the price of the VR units, and ease of usage and development of VR applications. The two leading manufacturers of VR equipment (HMDs, motion controllers, tracking stations) HTC and Oculus are pricing their units in a comparable range of 500 - 600 dollars, which could be considered quite obtainable for the consumer market. Modern models do not require much free space and any special skills to set them up and use. This allows utilizing VR in areas where access to real experience is limited (for example taking virtual rehabilitation in the remote locations where the real medical experts could not easily travel). Moreover, popular game engines support modern VR devices from the box, which lets anyone with programming experience to pick up and develop their own VR applications.

Combining these features with unlimited possibilities of virtual environments production gives us a powerful tool for use in education, prototyping research, and other areas. A particular VR application, set in specific time and space, with certain physics laws and types of interaction with the user, could be created for any given purpose. Most of the time, such a virtual environment would be cheaper in production and usage than its “real” equivalent.

## **2.4 VR applications for libraries**

During the search for dedicated VR applications for libraries, it quickly became apparent that there are very few examples that can suit this category. The prevailing majority of general search results only reported about the possibility to try out sample applications in libraries premises. The search among scientific papers and articles was not successful as well, with only mentions about mobile and augmented reality (AR) focused projects.

In 2016 the University of Oklahoma set up two VR ready machines in the Bizzell Memorial Library located in the university’s campus area. Students, staff, and just the general public could upload 3D content in Oklahoma Virtual Academy Laboratory (OVAL) through the library’s website and then manipulate it in VR applications on mentioned machines. The project was successful - several university courses tried OVAL and a few even utilized it into the coursework in the form of assignments and other activities. By the end of the year, the number of workstations was increased up to 8 spread around the whole university campus. [11]

In 2015 - 2016 the Bibliotheque et Archives Nationales du Quebec in Monreal (BAnQ), Canada was having a unique project, called “La bibliotheque, la nuit” (The Library at Night). An original idea from BAnQ - virtual exhibition of prominent world libraries was developed by Ex Machina production company and its director Robert Lepage. Participants were able to observe ten beautiful libraries around the world in 360 view using Gear VR headsets. The application was not interactive; it was rather a very atmospheric experience, liked by the public. [26, 34]

As was already mentioned, majority of the search results report about libraries lending out VR hardware to try (for example: NCSU Libraries [52], Georgetown University Library [55], Elia Area Public Library [53], Virtual Reality Lab at Western Michigan University libraries [56], Virtual Library at Tikkurila library [27]) or organizing dedicated to VR events with presentations and trials of applications (for example: VR day in Oxfordshire County Library [46], VR events at Evergreen Branch Library [54]). It is also worth pointing on increasing support from leading VR companies, which give out hardware to libraries to increase public awareness of new technologies [22, 33]. The spread of such announcement indicates that many libraries already have technical conditions suitable for deployment of VR applications. The next step is to design and develop these.

### 3. DESIGN

The development process of the Virtual Library project was not strictly linear. It instead consisted of two long cycles. In the first one, a web prototype was created, which fulfilled the role of proof of concept. The second cycle concentrated on the development of VR application using already made assets and server-side code.

The development process of the Virtual Library can be accounted for as Agile. This paradigm aims to maintain a continuous delivery of working software while rapidly reacting to changing requirements and focusing on close cooperation between customer and developers. Agile principles were brought to light in 2001 with the publishing of so-called “Agile manifesto”, compiled by representatives of many different software development models. They are represented in the form of 4 expressions, where the first part shall prevail over second, such as [3]:

1. Individuals and interactions over processes and tools;
2. Working software over comprehensive documentation;
3. Customer collaboration over contract negotiation;
4. Responding to change over following a plan.

Agile appeared as an answer to conventional incremental waterfall models. In the following years, it quickly drew popularity and changed the software engineering field, producing new software methods, guidelines, tools, researches, etc. [13]

However, Agile can be viewed only as an archetype, and thus real software development techniques use its principles as a basement. Process for this project had the most similarities with the Feature Driven Development (FDD) model. This model works in short-term iterations, in which a set of definitive, easy to describe features are designed and built. [4] The full process for this model consists of 5 stages, shown in Figure 1:

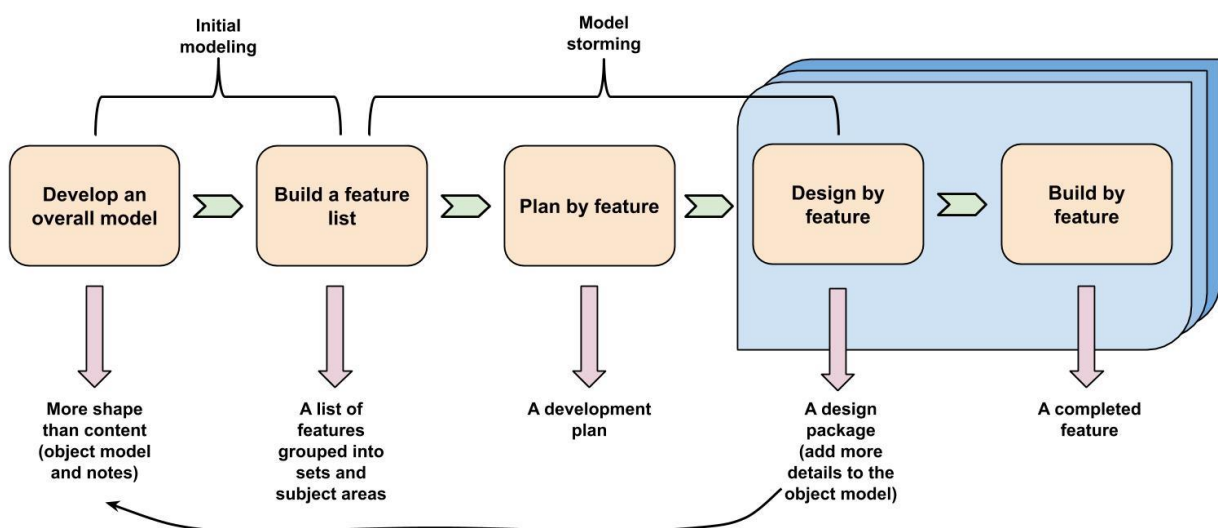


Figure 1. The FDD lifecycle.

The diagram derived from <http://agilemodeling.com/essays/fdd.htm>

The first two stages could be considered preparatory; they build a fundamental understanding of the scope of the project and plan the initial list of objectives. The next three stages are flowing in the cycle, maintaining the agile process and allowing to adjust development according to ever-changing conditions. In this project, an overall model and features list were revisited after a first participatory design workshop, where the updated course for the Virtual Library was defined.

### 3.1 Objectives

Initial requirements for Virtual Library project were formed in cooperation of Oulu City Library management and department's researches. Those were general and served as a motivation of Virtual Library purpose, as follows:

1. Familiarize ordinal citizens and library stuff with VR and 3D virtual environments;
2. Introduce new ways of interacting with library services;
3. Create an attractive environment to engage "challenging" customers.

These starting goals were enough to get the development going with the production of 3D virtual environment and prototype application that utilized library web services (searching through the catalog). The early prototype would be described in detail in the next chapter.

Later these requirements were refined in participatory design workshops held in Oulu City Library premises. The participatory design core idea is that "people destined to use the system play a critical role in designing it" [41]. Moreover, this approach focuses on ways to include actual users of the system into the design process. This cooperation can improve the knowledge upon which the systems are built and enable users to develop realistic expectations towards the final product [19].

Purpose of the first workshop was to define new visions and ideas for hypothetical "Hybrid Library", a concept product that unites virtual reality with library services. The half-day workshop introduced participants to VR/AR technologies and let them try some virtual reality applications and virtual library web prototype (which is described in next chapter), followed by a number of design activities, such as discussions, mind maps, and collage crafting. This workshop proved to be very beneficial and resulted in adopting many ideas, such as the strong shift to creating a rich VR experience, fantasy levels on top of "real" library premises floors, collaborative activities, etc. The second and smaller workshop was held six months later and was focused on getting feedback and refining of Virtual Library beta version. [59, 25]

To summarize, several formal targets for Virtual Library were set as a result of the first workshop. These were formulated as follows:

1. Adapt model of Oulu City Library for VR and implement corresponding standalone application (which includes optimizing scene effects and assets to maintain stable performance, implementing control mechanism, updating UI elements and interaction with it, etc.);
2. Design and construct additional environments different from "real" lobby scene (this led to the creation of three "fantasy" scenes which would be described in detail in later chapters);

3. Design and implement a configurable way to present media content in the application;
4. Design and implement activities promoting library usage.

These objectives served as top-level features in the feature list and were later divided into sets containing smaller features to ease task definition for development. Trello, a free web service for task management [50], was used to organize the workflow and keep track of development progress.



## 4. INITIAL PROTOTYPE

Initially, Virtual Library was seen as a web application, where customers will be able to navigate in a virtual model, having access to familiar services, as well as new ones, which are not possible to achieve in reality.

### 4.1 3D assets

The biggest challenge for this project was to create an appealing environment, which would encourage users to explore it. And thus, the first task was to create a sufficient amount of 3D assets to fill the spaces of the library's model. Due to having previous experience with Blender, it was chosen as a primary tool for content creation.

Blender is an open source tool for the creation of 3D content, including mesh models, skeletons, animations, rendering, etc. [5]. In the context of this task, the creation of models and applying materials to them were main activities with Blender. A mesh model, or also called polygon mesh, is a set of vertices, edges, and faces that defines a 3D object in computer graphics. A process of creating a one consists of manipulating these three components using various methods, from very basic like moving, rotating and scaling them in 3D space, to more complex and specialized, like extrusion, edge sliding, smoothing, beveling, etc. Objects in computer graphics are almost always covered in textures, so after the model is done comes a stage of applying materials onto it, which maps faces of the object to a specific material. Later in development, these materials would be given a color, image or any other properties to paint it properly.

To help with modeling of the interior objects of the premises a series of photo shooting were conducted (Figure 2). Because of limited time and human resources, attention was only given to most prominent interior objects, such as stairs, different types of shelves, furniture and some eye-catching items.



Figure 2. The second floor of the library © Author, CC BY 4.0.

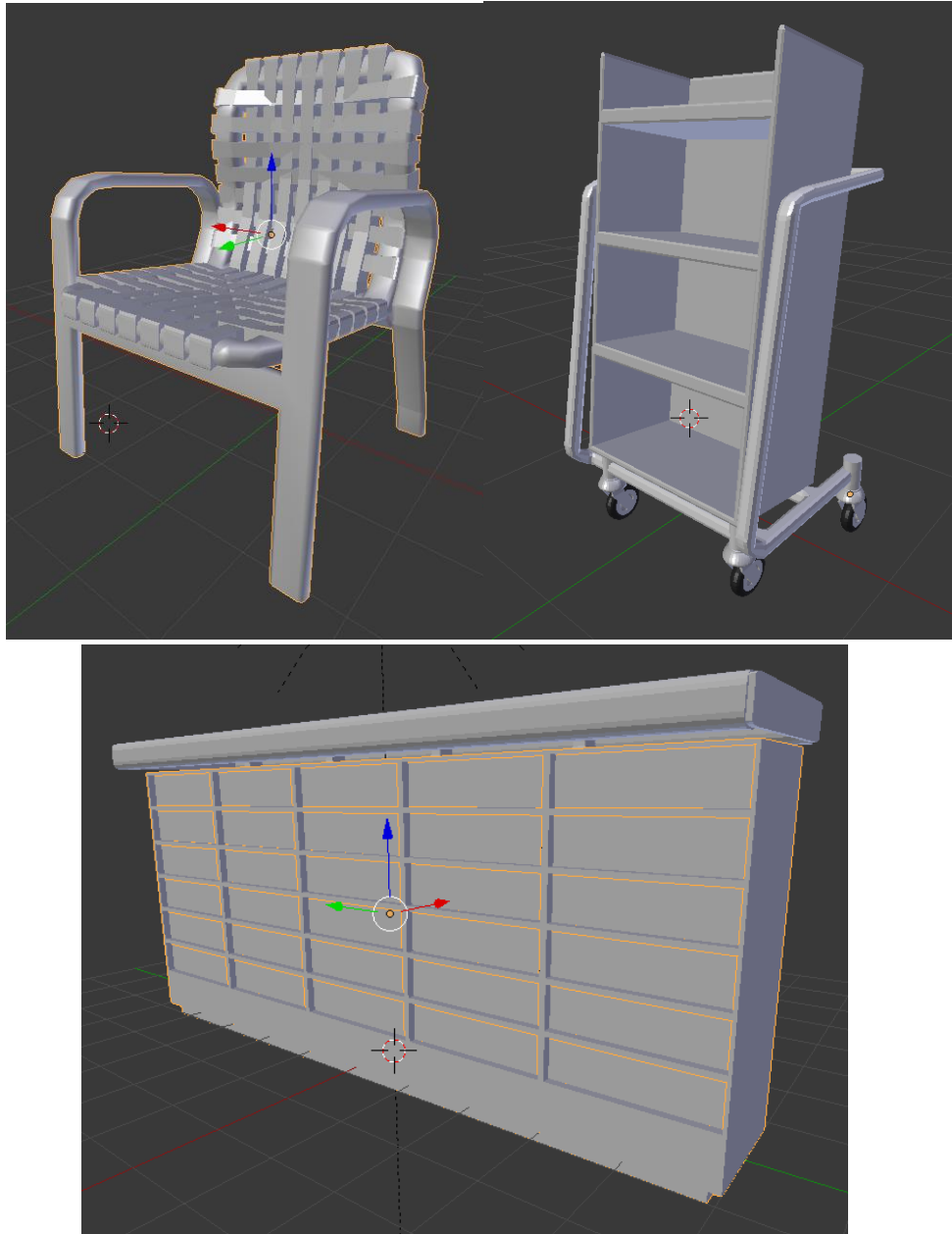


Figure 3. Modeled shelves and chair.

At first, the fundament, second-floor plate, and stairs were modeled in order to start the implementation of application as fast as possible. Walls were taken as primitive objects, scaled appropriately. That way I could already construct the building, the outer “shell” with inner base structures, for using in web application. This approach goes very well with the chosen FDD model such as it delivers a working prototype very early. After those necessary objects were placed to a web application environment and tested (their visualization and scale), rest of the objects were created in the process when needed (Figure 3, examples of modeled objects based of photograph on Figure 2).

Throughout the thesis, many screenshots will present models used in the application. Most of them were created during the prototyping stage and reused later as the project got more mature. In total, around 50 models of different scale and level of detail were created.

## 4.2 Back-end implementation

The need for server arose when first difficulties with interacting with the library's web services were found. Access to the library's catalog was one of the promising features of Virtual Library, but Oulu City Library web services did not provide any public API for it. Their online service (at <https://koha.outikirjastot.fi/>) responds only with HTML files ready to be rendered in the browser. The solution to this problem was to manually send a request to web catalog (as the website does when the user clicks on the search button), intercept the returned page with search results, parse it and form it in a convenient form for the client to display. This way a server would play a role of "virtual" API of the library: the client would send requests to the server, which in turn will perform a search on web catalog and return results to the client as if they were returned by catalog API.

In addition to the search function, the server took responsibility on building a route to a specific shelf. The map of the library was represented in the form of a node graph, where each shelf is a node, and the weight of links is the distance between shelves. This node graph was used by server application to calculate the shortest path to a specific shelf, based on client's coordinates. For pathfinding, Dijkstra's algorithm has been used because of its simplicity, as the task itself was not very complicated and did not contain a high number of nodes.

And such, application server on a prototype stage provided the following services:

1. /search - Perform a search by title and returns a list of books
2. /book - Gathers details about the book (such as publisher, ISBN, locations, etc.)
3. /path - Calculates a path to specified shelf

Server application was written on Node.JS and Express (a popular open-source web application framework). Node.JS is JavaScript environment based on Google's V8 engine and is dedicated for use on the server side. Node.JS uses asynchronous I/O event model which fits perfectly with JavaScript callbacks. [49]

## 4.3 Web client

The technical implementation of client heavily depended on 3D rendering capabilities of modern web browsers.

Internet content has gone a long way in its representation to a user: from a simple plain HTML page to a complex, highly interactive web applications, developed with user experience in mind. Moreover, the web is ever evolving, expanding its scope and technologies, that previously were not meant for it. One of such technologies is 3D graphics. First attempts to render 3D objects in a web browser could be tracked since 1994, when a Virtual Reality Modeling Language was developed, which allowed describing a 3D scene. The big step in this direction was done in 2011 when the first version of the WebGL standard was released. WebGL was brought to the light by Khronos group, in collaboration with leading companies (such as Mozilla, Apple, Google, Opera, and others) and is describe by them as "...a cross-platform, royalty-free web standard for a low-level 3D graphics API based on OpenGL ES 2.0, exposed through the HTML5 Canvas element as Document Object Model interfaces". WebGL

JavaScript API (and subsequent JavaScript third-party wrapper libraries) allow developers to access OpenGL directives in the browser, providing an easy and effective way to utilize 3D graphics in web development. [14]

ThreeJS [48] was a core library used in the web client of Virtual Library. It is an open source JavaScript 3D library, that supports a set of different renderers and gives simple and at the same time rich API for drawing 3D content. For the most straightforward application on ThreeJS a developer only needs to initialize scene, camera and a renderer with reference to <canvas> or <div> element of the HTML page, where the content will be displayed.

One might notice that it would be tedious to manually load objects and put them together one by one at runtime, so the first step in application flow is loading a prebuilt scene. ThreeJS supports a wide range of formats through different loaders. Due to the open-source nature of this library, some of them are made by the community, and not always work as expected. Though many trials it was found that JSON format worked the best (it was free of geometry corruptions, missing textures and wrong scale). And so, the following workflow was used (Figure 4):

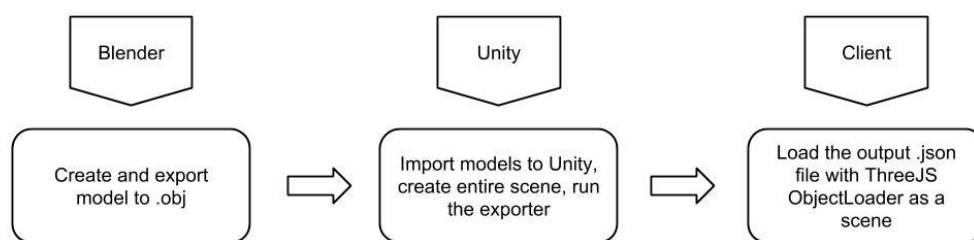


Figure 4. Working process on prototype stage.

Unity does not have built-in support for ThreeJS, so for the second step an own plugin has been developed. This exporter [15], written in supported by Unity C#, parses the current scene and produces a .json file in a format suitable for ThreeJS, as well as placing all textures nearby in a separate folder. Unity (as a tool for scene construction) was chosen over Blender due to its convenience and ease of extensibility by scripts.

Examples of how a web Virtual Library looks are shown in Figure 5. Most screen space is dedicated to world view, with a thin line of a functional panel on the top. User has two perspectives of control from a global view and a first-person view. In the global view, the camera is placed on distance from a fixed point (the center of the model by default) and user control it by rotating and zooming in/out. In the first-person view, the camera is placed in the avatar's head, and the user controls its rotation and avatar movement in a fashion similar to modern first-person shooter computer games.

On a stage of the prototype, library features were only implemented in the form of overlay windows, which user should have triggered by interacting with menus in the top bar. The most significant and most attractive implemented feature was searching. Searching is done by the book's title and after it is complete, shows results in an unfolded panel beneath the search input field. In there, the user can display the path to selected bookshelf from the current position of the user's avatar (in the form of a translucent spline).

Another exciting feature was an experimental multiuser mode, where several users can exist in the same instance of the library at the same time. However, it was not fully developed, only to the extent of replicating users' avatars movement to each other.

ThreeJS was handy and easy to learn and develop, but the chosen web platform was lacking performance to display a big number of models effectively. Even with configured low graphics quality, the FPS was not stable. It is worth mentioning that exporting of animations was not possible with given workflow, so it crossed out plans on having humanoid avatars and "lively" characters to interact with. These drawbacks and other reasons caused reconsideration of the project's basis, and in turn, lead to shifting to Unreal Engine 4 and virtual reality application.

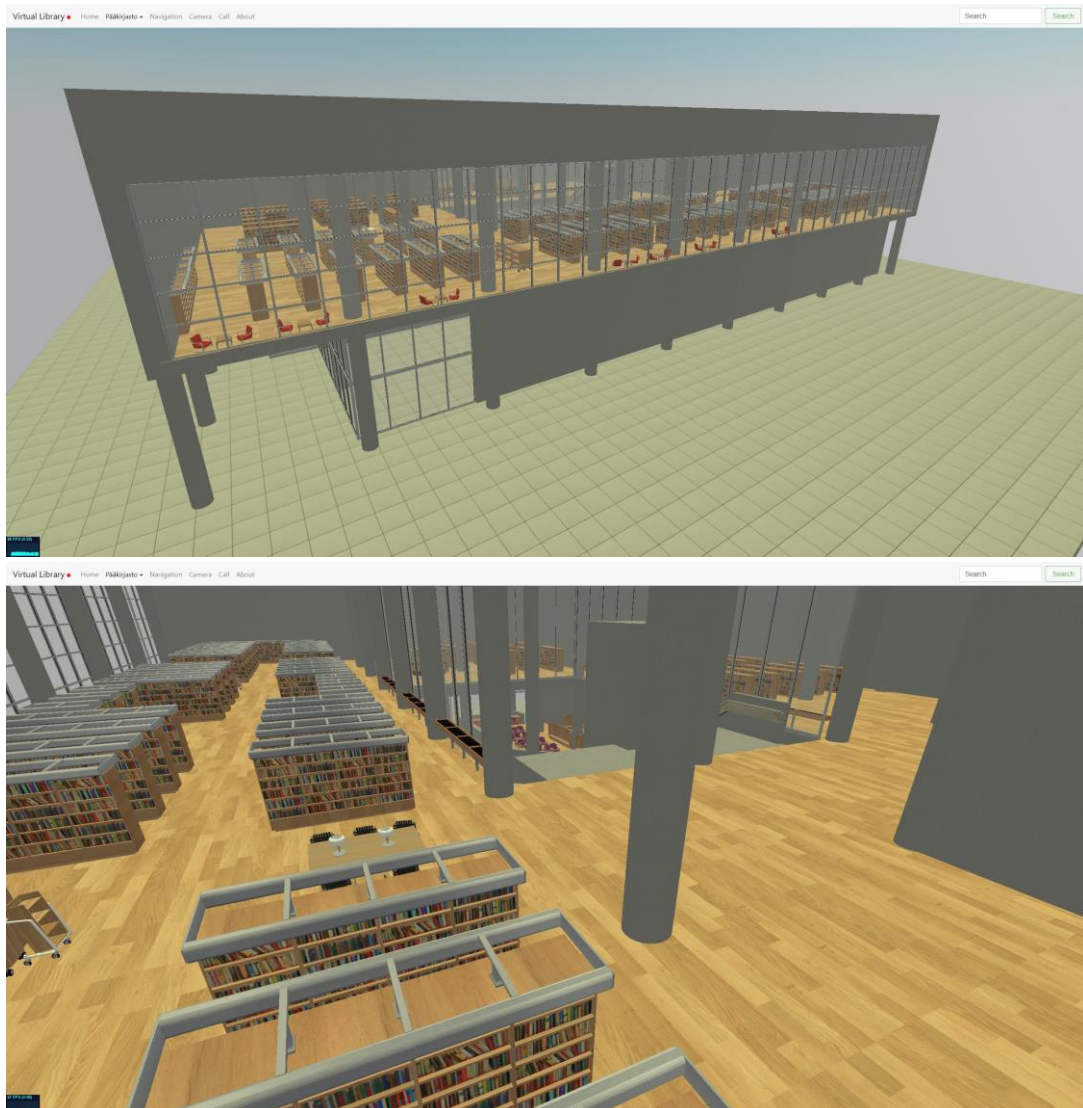


Figure 5. Web application of Virtual Library.



#### 4.4 Unity usage

As mentioned previously, Unity was used as an intermediate stage between modeling and importing to the web application. All static models were assembled to the library in Unity and this structure exported to supported by ThreeJS format.

Unity library scene is pictured in the screenshots in Figure 6. The great advantage in looks is much noticeable due to the proper lighting system. After the decision of abandoning web platform, there was a short time of uncertainty when author upgraded a Unity scene with functionality to move around the model and search for books, thus implementing features of Virtual Library in a standalone desktop application.

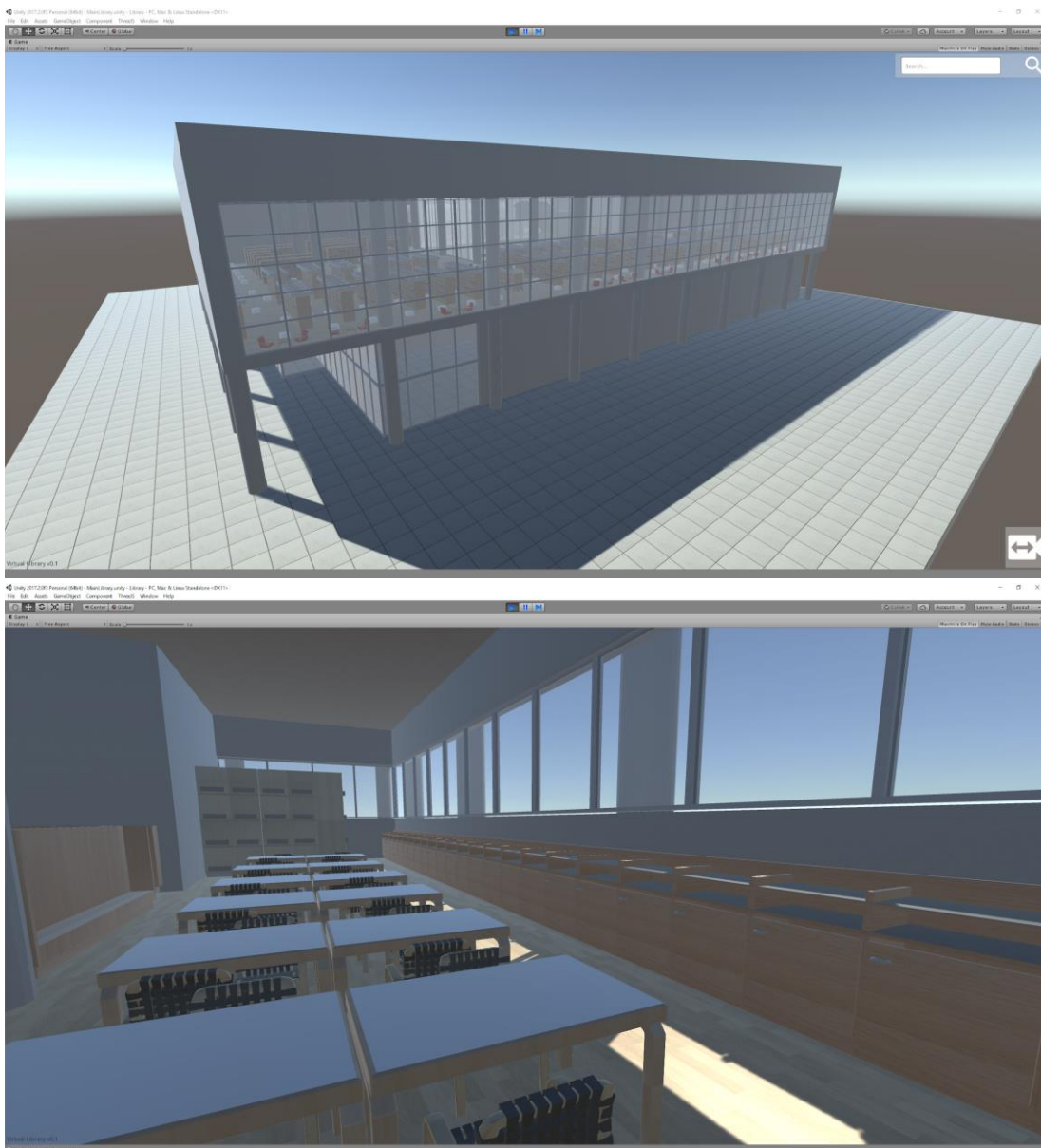


Figure 6. Virtual Library in Unity.

## 5. FINAL PROTOTYPE IMPLEMENTATION

The web application trial showed that this platform was not very well suited for the needs of the project. As limitations of the web were gone, the project became open for new directions and ideas. At this time our department got interested in studying Virtual Reality area, and consequently, it was suggested to be a core pillar around which Virtual Library could be rebuilt. And thus, taking the original idea of interactive 3D library application, it was decided to utilize Virtual Reality technologies for creating a new immersive experience for library users. Considering this, the choice of next toolkit fell on Unreal Engine 4.

Unreal Engine is a modern game engine made by Epic Games. Its 4th version was shown to the public in 2012 at E3 (Electronic Entertainment Expo - a yearly event for the game industry) and became free for all users on 2nd of March in 2015. It provides a wide range of tools for game developers to create large beautiful virtual worlds, which in a couple with a wide variety of different platforms to deploy to, makes it a great solution to build interactive applications on.

One of the major features in Unreal Engine 4 are blueprints. In blueprints, the programmer uses blocks of operations and links their inputs and outputs correspondingly. The system is flexible and straightforward, also allowing to write components in conventional C++ and use them in blueprints. That gives the opportunity to add complex behavior to their games and applications to a wide range of users with different level of programming skills.

Two main directions for development arose right away when moving from web to standalone desktop platform: recreating Oulu City Library scene on Unreal Engine 4 and developing Virtual Reality mode for it (as well as adapting existing activities to it).

### 5.1 Unreal Engine 4 framework and application structure

In this section, the core structure of default Unreal Engine 4 application will be explained, together with showing how Virtual Library works in this context. Because Unreal Engine 4 is primarily targeted for game development, some game-related vocabulary will be used.

The structural unit of any Unreal Engine 4 application is level. Levels hold all elements required for a player to act in specific virtual space, such as scene, effects, objects, their behaviors, and interaction with the player, etc. All these assets can be of course reused on different levels.

Every level has the hierarchy of entities that define its behavior. These entities are presented in the diagram in Figure 7. The most fundamental ones are [17]:

1. GameMode
2. PlayerController
3. Pawn

GameMode is a foundation stone of any level, also serving a role of the container of other gameplay entities, and so it cannot be changed at runtime. Most importantly it defines the rules of how level shall proceed (how player enter this level and spawn) and transitions to other levels. The GameMode might need to store some information about its level (for example number of joined players and when they joined, for how long the current level is being played,

current score, etc.) and GameState serves this purpose. GameState is synchronized between all players of this level so that they could have up to date information.

PlayerController takes control over a player's in-game representation and contains the business logic of its interaction with level objects. There is also an AIController, which serves the same purpose but intended to manage nonplayable characters. PlayerController can have a PlayerState entity which stores necessary information (for example, player's name, status, hold items, etc.) in a similar fashion to GameState.

Pawn is a virtual representation that can be controlled by a player or computer. If the PlayerController (or AIController) could be considered as "mind", the Pawn then can be viewed as "body". The pawn usually holds the actual physical model and control mappings.

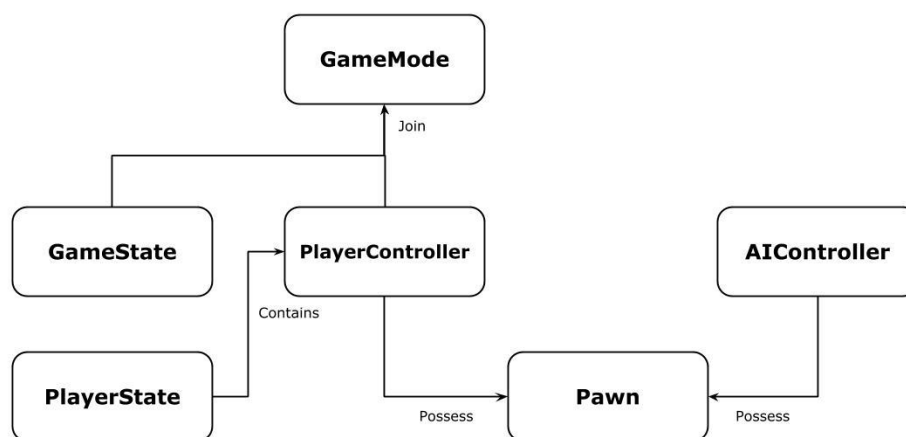


Figure 7. Unreal Engine 4 gameplay framework scheme.

Virtual Library was developed using previously mentioned Unreal Engine 4 blueprints. This approach was chosen to achieve a high speed of development and satisfy the author's interest in experimenting with this technology. An alternative approach would have been to use C++ language to program all custom entities, but that had proven to be cumbersome and not very smooth (Author faced many compilation and packaging problems when was trying to create a custom network plugin).

Virtual Library consists of 4 levels (which will be described in detail in the next chapters): Lobby, Forest, Cave, and Future. Each one of these can be run in two GameModes, which are classified by means of controls used:

1. LibraryMode, dedicated for usage with conventional controls, such as mouse and keyboard, and computer display as visual output;
2. VRMode, for virtual reality HMD and motion controls.

LibraryMode was mainly used for the development of parts that are common for both modes, such as scene construction, interactions with server-side, character animations, etc. It has the same functionality as VRMode and can be used in the absence of VR hardware.



VRMode and LibraryMode use VRPawn and LibraryPawn respectively, which map controls to player's avatar movements and configure other interactions with in-game objects.

LibraryPawn maps an avatar's movement to keyboard presses and camera rotation to mouse movements. The primary sequence of interaction is as follows. Each frame LibraryPawn emits a limited distance ray from the center of camera view; if it touches an interactable object and the user presses a specific key on the keyboard, an object-specific interaction event will be triggered (which can change this object state or spawn other objects, menus, etc.). It worth to mention that LibraryPawn is, in fact, a Character subclass because it also contains the user's avatar humanoid model, whose movement animations are controlled by another linked blueprint.



Figure 8. Oculus Touch controllers.

Image from <https://www.vrheads.com/how-get-most-out-oculus-touch-batteries>

VRPawn contains additional components for HMD and motion controls to map their changes to player's movement while being in VR. The primary hardware used was Oculus Rift with Oculus Touch motion controllers (Figure 8). User has no visible in-game avatar model. Instead, there are models of Touch controllers copying the position of physical ones. These virtual controllers also highlight specific button or another input item if the user touches them on the corresponding physical controller (this is done through provided by Unreal Engine specific Oculus blueprint functionality).

VRPawn utilizes so-called "teleportation" method for player's movement, which is intuitive and straightforward, while also easing nausea and bad user experience in VR [8, 16]. Whenever a user presses on one of the buttons on the motion controller, it will render a parabolic arc of distinguished color from the virtual controller, which pinpoints the destination of teleportation (and the user have to release button to perform the movement). User can also perform short distance leans by physical movement in reality, and thus in-game presence copies horizontal and vertical shifts of the HMD.

Interaction with objects works through usage of motion controllers as well. If user points (laser pointer will emit from the virtual controller) or moves anywhere closer to interactive object, the press of trigger button (the ones under pointing fingers) will invoke interaction event.

The rest of the objects in the scenes can be classified as actors, ranging from simple ones, like furniture models and lightning, which have no special behavior, to custom blueprints, for example, lift panels and picture frames, which are complex objects, consisting of multiple sub-components and programmed interaction with the player.

## 5.2 Scenes

The virtual environment (VE) is perhaps the most crucial part of the VR experience, directly influencing the feeling of presence. Though, as one might expect, it does not require a high level of realism. Presence is the degree of user belief that he or she is in different from actual physical space. It depends on a wide range of VE features, such as scene dynamic, sound effects, physical model, interaction with objects, etc. [40, 32]. In the process of environments construction, these factors were prioritized over the racing for high-quality model production.

Virtual Library features four virtual worlds to explore. The starting scene in the lobby of Oulu City Library replicates the real world to some extent, while other environments are fictional, picturing the scenes user might have seen in movies or read about in books. They all have a different style and atmosphere trying to be appealing and reach a wider audience.

The movement between worlds is made by using an elevator in the lobby of Virtual Library. Users interact with an elevator control panel, showing a small dialog menu with destinations buttons (Figure 9). While being in other scenes, they can always return to the lobby using a controller menu on their left controller.

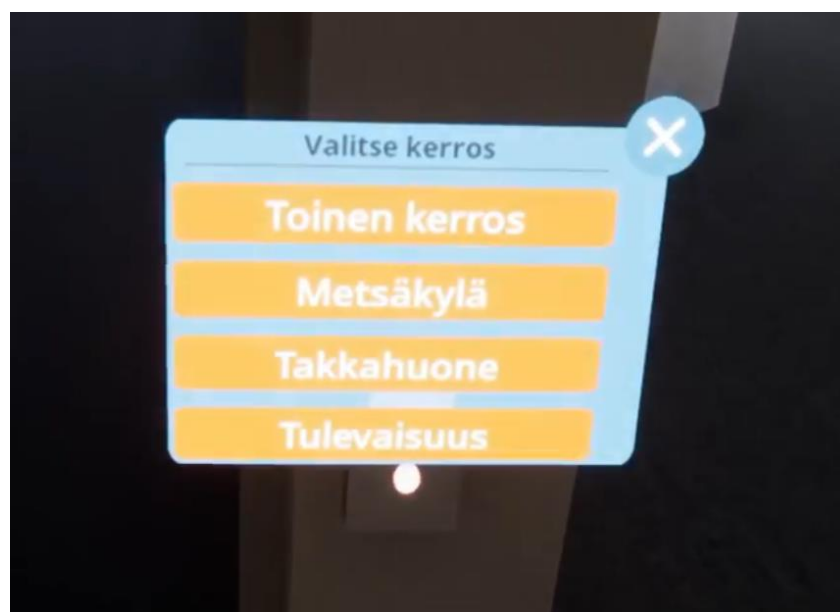


Figure 9. Elevator menu.

### 5.2.1 Lobby scene

The user would start in Oulu City Library lobby (Figure 10), right after the entrance. Users are met with a short tutorial which introduces movement and interaction using motion controls, after which they are free to explore Virtual Library. This scene copies the geometry of the first two floors of Oulu City Library and tries to keep the interior look similar to original premises so that regular users could easily navigate in a familiar place. All assets used in this scene are created by the author. Two major features are intended to be used in the lobby: book search and art gallery (these will be described in later chapters).



Figure 10. Virtual Library's lobby and second floor.



### 5.2.2 Village scene

The first fantasy scene is Village (Figure 11), the vast forest area with a small village and a lake in the center. It has an activity called “featured books”, which will be described later. A significant part of assets for this scene was found from Unreal Engine marketplace vendor [2]. Its style is different from other scenes and can be described as minimalistic and cartoonish. The reason for that lies in reduced performance of rendering a scene of such size and complexity, so less polygonal objects and lighter effects are used.



Figure 11. Village scene.



### 5.2.3 Study scene

The second scene did not have any precise name for it for a long time but was called internally as a Study (Figure 12). It is represented as a closed apartment with a corridor and a big hall, filled with old furniture. The entire scene is supposed to give a feeling of visiting a flat of old historian or librarian. This place is filled with some physics-enabled objects, which the user can grab and take a closer look, and the main activity here is a story book, which will be described later.



Figure 12. Study scene.

### 5.2.4 Future scene

Third, and the last scene is a Future world (Figure 13). A user can walk around a small street between a block of flats in a not so distant future. A few external packages were used in constructing this scene as well [12, 42]. The atmosphere was inspired by iconic works in cyberpunk genre (for example Blade Runner by Philip K. Dick and relevant movies), and so it takes place in the dark rainy evening in a suburban area in not so distant future. The activity here is the same as in Village - featured books but related to sci-fi theme.



Figure 13. Future scene.



### 5.3 Book search

As in the prototype version, the user can search through the library catalog via the book search function in the lobby scene. Search is performed by book titles and results in getting a list of books, which in turn can be used to request navigation to a shelf containing a specific one book.

In the application, the user can open the search interface pressing on the book with a magnifying glass on it in the lobby service desk or by clicking on the corresponding button on the left controller menu. This action will, first of all, freeze user in current position, preventing it from accidentally teleporting away, and then open a search panel widget in front of the user. Search widget consists of a keyboard panel and input field (Figure 14). User types by pointing to corresponding keys with a motion controller and pressing an interaction button.

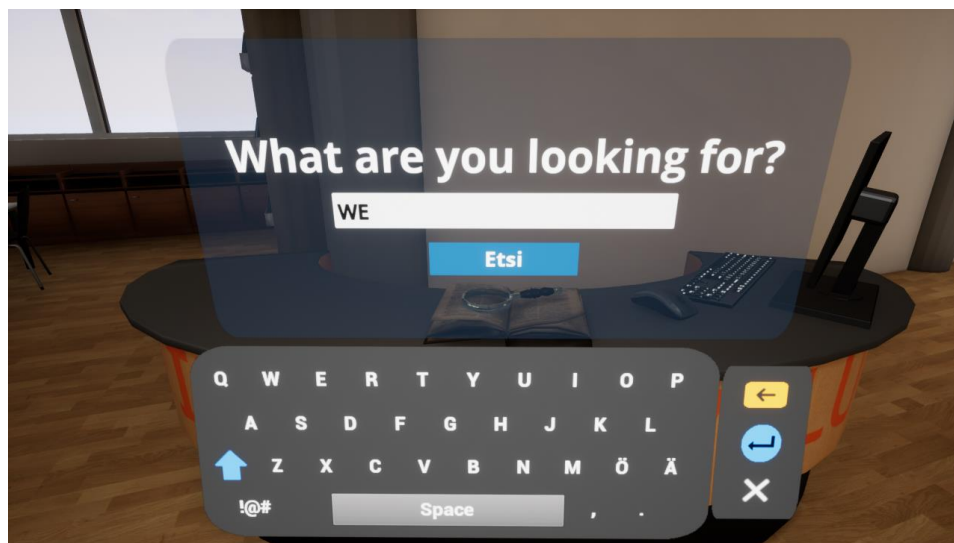
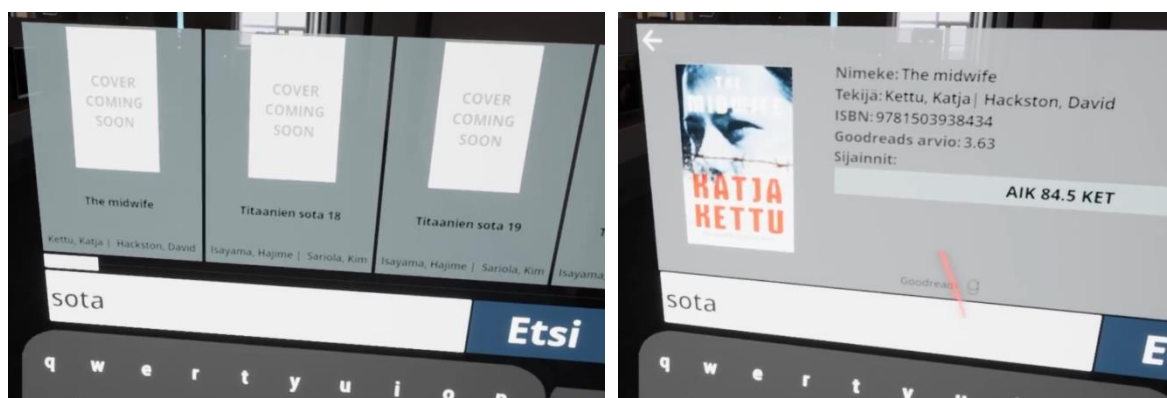


Figure 14. Search input interface.

Initially, the search results window was implemented in a different form. A rectangular area with the horizontal list was showing tiles of search results containing some descriptive information, such as book cover (if available), title, and author names (Figure 15a).



(a) Search results list

(b) Search book item

Figure 15. An old variant of search results interface.

A user has to manually move the slider to advance through the list. Pressing on the particular book tile would open a window with detailed information about the book and list of shelves, clicking on which would launch navigation (Figure 15b). After some trials and second participatory design workshop sessions, this approach was proven to be too difficult for an unprepared user, so it was discarded, and new simpler and more intuitive interface was designed and implemented.

In the final version, results are displayed on a rotating circle “shelf” in forms of book covers, labeled with title and author (Figure 16). The user rotates the circle naturally by dragging it with motion controllers while holding the interaction button.



Figure 16. Search results.

Pressing on the panel with book information will launch routing to the shelf containing this book. Routing is represented by an illuminated line path from closest to the user position to the shelf (Figure 17). Although it does nothing aside from that, user can learn where he/she can find this book in reality.

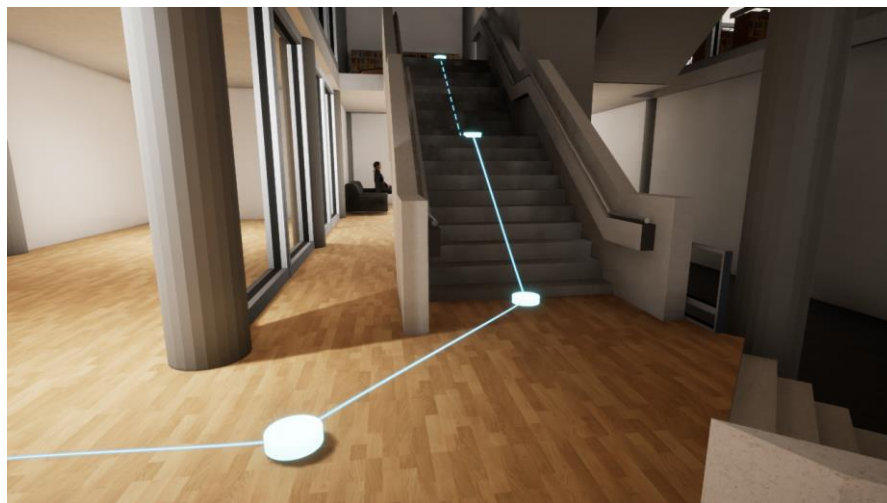


Figure 17. Navigation path.



## 5.4 Art gallery

On the first floor of the library's lobby, there is a glass case embedded in the terrace. It serves as a small exhibition place, welcoming visitors right from the entrance. It was decided to copy this usage to the Virtual Library, but without the limitations of physical volume.

All eight picture frames in the virtual world could be filled with configurable content. Each picture frame is a custom actor with multiple overlay widgets. On the startup of the application these actors request server to fetch data assigned to them. The user interacts with each frame, by either hovering over or pressing on it with motion controller pointer. If the user holds his controller pointing at the picture, new UI will appear, consisting of picture's title, direction and like buttons. Direction arrows are optional and would only appear if this frame is configured to have additional pictures. By pressing on these buttons, the user can list through all available pictures for this frame. Like button is shaped in the form of heart and by pressing on it user increments like counter for a currently displayed picture. Those counters were only implemented for local storage, but the idea behind it was to synchronize them with backend in order for library workers to be able to analyze them later and see what content is more popular.

Management of pictures is happening on the server admin application. In the section dedicated to lobby frames (Figure 18) admin can upload, delete images, edit their information, and assign to specific frames. Each frame has a unique identification number, which can be found from the scene. When assigning an image to a frame, the administrator would put its identification number to an appropriate field. If multiple images are assigned to one frame, they would be navigated with mentioned arrow buttons.

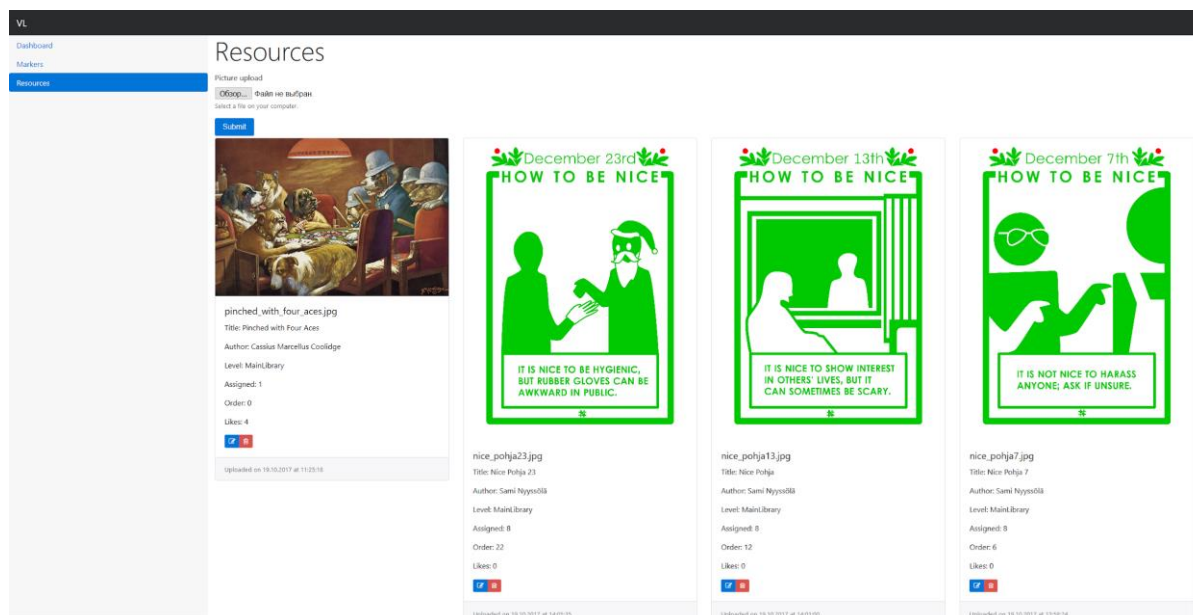


Figure 18. Frames management page.

This art gallery system is not dedicated for frames in the lobby, the custom blueprint can be added to any object, and with a little setup can be utilized to show library news, advertisements, personalized information, and other media content.

## 5.5 Featured books

Feature books is a promoting activity that sets its goal to encourage reading and showcase books that challenging customers might get interested in. It works as part of the exploration of scenes, meaning that users can stumble upon highlighted items during their traveling through fantasy levels.

In the forest and future scenes, there are many distinguished objects with different indications which can help recognize them. These indicators could be either bright visual appearance (meaning that it pops out of the surrounding environment), sound cues, particle effects emitting from it, or any combination thereof. These indications are used actively in the forest scene, and not so much in the future because later one is less obstructed.

The user interacts with such featured books objects in a similar fashion to an art gallery. Just pointing to such an object with motion controller will highlight it so that the user can ensure that this is indeed a curio item (Figure 19). When the user presses on this item, it will spawn a world widget above it, showing book cover and a short description (Figure 20). In addition, these featured books have an audio track of book summary which would start playing when the user activates this item. When the user closes the world widget, by pressing on the cross button in the corner, audio stops and item become interactable again.

Featured books are related to the theme of the scene where they are (like village and future correspond to fantasy and sci-fi novels), but not always clear to an item they are assigned to, due to limited resources and no time to create quality objects for every proposed by library book.

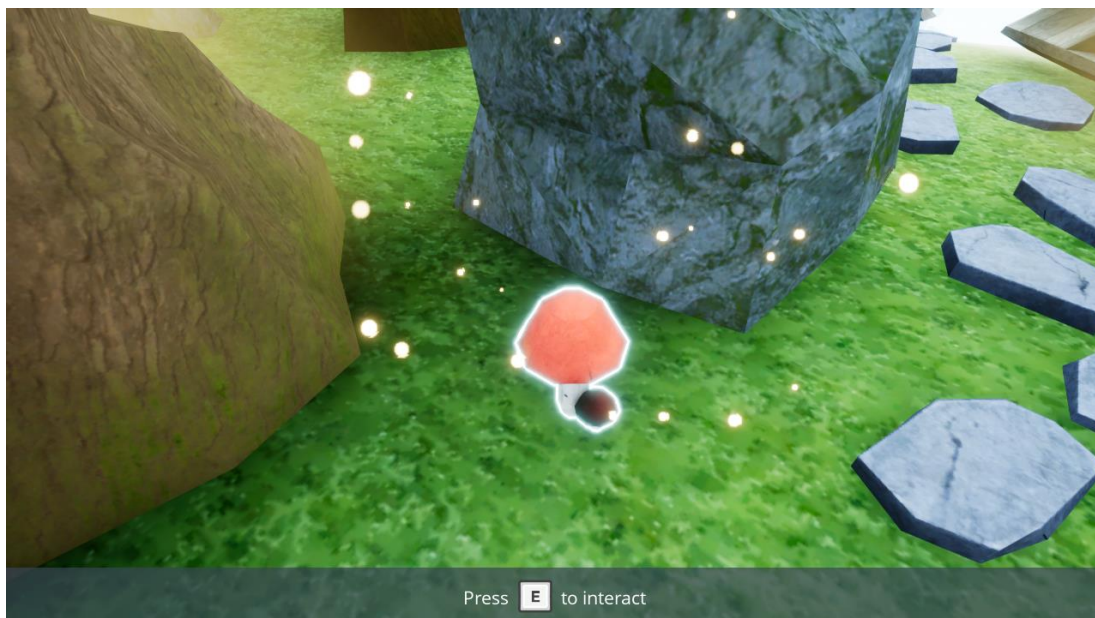


Figure 19. Highlighted object.



Figure 20. Featured book information, after being interacted with.

The management of the featured books was implemented inside the application, and so it cannot be changed once an application is compiled or configured from the server (which could be a perspective for further development). Each item that bears a featured book business logic contains blueprint that manages interaction with the user, loading of widgets with book information and playing sound cues. Booklist and references to audio tracks are stored in an internal data table. On a startup of the scene objects lookup for the featured books record assigned to them by row index and preload content to their widgets.

## 5.6 Storybook

One of the ideas collected during participatory design workshops was to make some collaborative activity, that would accomplish the purpose of libraries as public meeting places. Taking into account the project's resource limitations (for instance, there was no way of deploying and testing simultaneous multi-user configuration), this activity must have been designed to work with one HMD. And so, a storybook was developed - a collaborative storytelling implicit multi-user experience.

Collaborative storytelling engages two or more people in writing a short story together. In the Virtual Library's scenario users only watch and reflect on the other users' story progress, so the action does not happen simultaneously for involved parties. This may be considered a drawback of the experience, but even the current implementation can showcase the potential of this activity. The underlying mechanism is inspired by magnetic tiles for refrigerator poetry [28]. A fridge with such set of tiles in some public space (for example kitchen in the office) is a "real" equivalent for Virtual Library's story book. People would willingly and with interest move a few words together, and with time these constructions could spill out in a story.



A storybook is represented by an opened book laying on the dining table in the middle of the hall (Figure 21a) in the study scene. It is not very distinguished, so if the user missed it and is located too far from it, it starts to emit particles to get attention. When the user clicks on it with the motion controller, it disables the user's movement and elevates to a position in front of him displaying the widget interface on the open pages (Figure 21b). From there user has three options:

1. Create a new story
2. Explore stories written by other users
3. Continue those stories from the last page
4. Close book



(a) Storybook object in the environment



(b) Activated story book with main menu

Figure 21. Storybook object.

The activity itself consists of composing a story out of a limited set of words. Both continuing and creating stories uses the same principle, where two areas form a working space - opened book with empty pages and a tray with word blocks. User drag and drops word blocks between storage and book area to compose a short narrative (Figure 22). All manipulations with word blocks are proceeding in a natural manner, just as a user would physically take blocks in one place and put them in the other. When word block is hit by the laser pointer emitting from the user's right controller, it gets highlighted signaling that it could be picked. After this user needs to hold a button on the controller to "grab" a word block, which would lift it and stick it on a fixed distance from the controller. While the user holds the button word block would replicate the movement of the right controller, allowing it is rotating (for example to see it better) and positioning. When the user releases a button, the word block would either be added to the story or placed back to the storage, depending on which area it was upon. If taken word block were elevated on top of another block in the story (which is indicated by also highlighting the bottom word block), it would replace it and replaced block will get back to the storage tray. Otherwise, it is added to the end of the story. And lastly, the user always can take the block out of the story and put it to some other place or drop it back to the storage. In any of these actions, word blocks in both areas will always shift left, right, or on a new line in order to cover the space most effectively. For example, if a user removes a word from the middle of the line, all following words will shift back to consume freed space.



Figure 22. Story creation interface.

Once per story user can click on the refresh button which would restock the words in the tray, removing all of them there and creating the same number of new ones. When the user is ready with the story, he could submit it, by clicking on the submit button, then automatically returning to the main menu.

Once submitted, one page of the story becomes accessible by other users in a shared pool of stories. User can view it from a menu, where they will be organized in lists and labeled by a number of pages in each story. User can select to view story pages and most importantly,

continue it from the last page (Figure 23). This way user creates a new page in a story the same way he would make a new one. This way stories could be created in collaboration with many people.



Figure 23. Browsing other stories.

Storybook activity heavily depends on the server side. When a user initiates story, as a part of the new creation or continuing the already existing story, the server is requested with a set of words. Those words are randomly selected from 1000 most commonly used Finnish words [1]. The set went through a small moderation in which words were given a probability depending on how frequently it is used in real life. The estimation of probabilities was not strict - only based on the author's personal experience with Finnish language and multiple trials of random generation, just good enough to produce a decent collection of words for story creation. Committed and updated stories are uploaded to a server and can be later managed by the administration through a server web application.

## 5.7 Server side

Server-side code from an early prototype was updated to be used with Virtual Library to support (mainly information storage) a number of internal activities, such as search, art exhibition, and story book management. In addition to existing server code built with Node.JS on Express framework, a web application was written to simplify management of an increased number of provided services.

Virtual Library application communicates with external APIs with the help of free UE4 extension, called VaRest [51]. This plugin allows to easily send GET and POST requests, as well as process the response from blueprints.

### ***5.7.1 Third party libraries***

A number of third-party packages were used in backend to simplify the development. This is a common practice for JavaScript development, due to well organized and maintained a global library of packages which could be easily installed by running one command in the console.

The most significant one is cheerio [10] - an unofficial server implementation of core jQuery functions. It is used in search requests to parse the incoming from Oulu City Library web catalog page with results and find necessary information by class and id selectors.

The other one is vue.js [58], a user interface framework, used in conjunction with bootstrap [6] for building all visual part of the server web application. Bootstrap provides handy ready CSS classes for the responsive and functional user interface.

The scale of this project did not justify the usage of big enterprise database solutions for storing information on the server, like MySQL or PostgreSQL. Instead, a lightweight package was utilized. Nedb [31], an embedded persistent or in-memory database for Node.js, uses similar to MongoDB syntax and saves data openly to JSON files.

The rest of the packages used in the server code could be considered as “syntax sugar”, as they only simplify already existing functionality provided by Node.js.

### ***5.7.1 Searching and routing***

This part of functionality has not changed much from the prototype code. When the user requests the information about a particular book, the server makes this request to library online service by book id and parses the response web page. In addition, it also requests information about this book from popular online social network and database - Goodreads, in order to include in response book recommendations (these were used in the first variant of the search interface).

Each library book has a shelf code, called call number. Positions of shelves in the model and reality are the same. Thus it is possible to map those shelf codes to make a navigation system. The shelf map is generated in Unreal Engine to a JSON document. This document consists of names of the waypoints, their links to other waypoints with corresponding distances, and shelf codes that they could lead to. The file is stored at the server and used to find the quickest way to requested waypoint from another waypoint. The Dijkstra’s algorithm is used for pathfinding, because of its simplicity. The map is only formed for adult’s section of the library on the second floor, which limits pathfinding to only call numbers “AIK”.

## 6. EVALUATION

Evaluation of Virtual Library was organized in a set of sessions held in the premises of Oulu City Library. The goal was to test the application with real library users and gather their feedback on the main features. The process was done with the substantial help of department's postdoctoral researchers. The results opened a big room for enhancement and further development of implemented ideas.

### 6.1 Setup

As mentioned before, the evaluation has taken place in the conference rooms of Oulu City Library, kindly provided by the library's management. Each session was held in a small comfortable conference room, containing a big TV. The free space in the middle of the room was assigned as a play area, when conductors were staying on the coaches by the sides, observing user's perspective on the TV. The video of the process and screen capture was made to help in future analysis.

Twelve people participated in the study, predominantly middle-aged women. Most of them are library personnel. Some has already been on participatory design workshop and had some expectations of features of the application.

### 6.2 Procedure

One session lasts approximately 1.5 - 2 hours, including post-interview, and thus we could only take 2, maximum of 3 sessions a day. The entire evaluation took as about two weeks with breaks in between.

The procedure starts from traveling to the library with computer and VR hardware to set it up and do a quick test run to ensure that everything runs as expected. When the user arrived, Finnish speaking researchers would first explain the overall goal of the project and give an initial survey with basic information and agreements to fill. An introduction then held to familiarize the participant with motion controllers and help to put on the VR headset. Finally, the evaluation session begins with launching Virtual Library application, and a responsible person must check that camera and screen capture are enabled and working.

As application start users were advised to accomplish tutorial in the library lobby to get accustomed with movement and interaction. After this, they were free to explore the Virtual Library, though we as observers sometimes reminded about the missed activity or points of interest. Users were not limited by the time they could spend with the application, but on average it took them 20-30 minutes until they got tired of heavy VR headset or tried everything the Virtual Library.

After the application trial user would have an extensive interview about his/her experience with Virtual Library. The introductory conversation and interviews were held in Finnish by accompanied researchers.



### 6.3 Interviews

After the playtest participants were interviewed using various assessment tools. One of them was a NASA-TLX system to evaluate general Virtual Library experience.

NASA Task Load Index measures the workload of performing a specific activity. The workload here is meant as “the cost of accomplishing mission requirements for the human operator”. This estimation uses six independent dimensions: mental, physical and temporal demands, frustration, effort, and performance. This set is a result of comprehensive studying of what affects the subjective experience of workload for different people performing tasks of heavily ranging complexity. NASA-TLX was published in 1988 in “Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research” by Hart & Staveland, and since then earned popularity among researches all over the world. [20, 21]

Other cooperating researches prepared custom questionnaires (presented in Appendix 1) focused on their area of interest in studying public VR applications. Some of the results from these are gathered in the next section.

### 6.4 Quantitative results

The results from NASA-TLX assessment tools are converted to a digital score ranging from 0 to 100. In the following Table 1 these results are presented for four distinguished Virtual Library activities: collaborative storytelling, art exhibition, search in the library catalog and featured books recommendations. Each of these activities was measured in 5 metrics: mental and physical demands, performance (temporal demand), effort, frustration, and the calculated cumulative mean.

Table 1. Mean NASA-TLX scores of interaction

Activity	Mental	Phys.	Perf.	Effort	Frustration	Mean
<b>Storytelling</b>	52	22	46	49	30	40
<b>Art exhibition</b>	20	10	21	17	18	17
<b>Database search</b>	56	14	38	35	31	35
<b>Recommendations</b>	29	21	30	28	24	26

Storybook and art exhibition activities got the highest and lowest result, respectively. These results could be explained by the difference in complexity of these activities. Art exhibition only requires the user to utilize three buttons at most, and those are simple clicks on visual elements. On the other side, collaborative storytelling activity involves multiple menus and non-trivial usage of motion controllers, such as simultaneous button holding and precise movement. Another difficulty could arise from the story creation mechanism. The implemented

approach does not account for Finnish grammar rules, and this may cause confusion. Searching functionality has a similar score to story book activity, which could be explained by long waiting times and limited search and pathfinding capabilities (one-half of second-floor shelves is mapped for navigation and search only goes by book title).

In overall, the results could be considered good, which is proven by significant positive feedback from users.

## 6.5 Feedback from users

An extensive set of qualitative data was gathered from interviews with participants and notes made during observation of users exploring Virtual Library and their live commentary. This section will describe commonly found complaints, given comments and other remarks.

A big part of comments was regarding controlling. Even though there were only two buttons used in all interactions (main and grab buttons, used for clicking on objects and dragging them respectively), it was still proven difficult for some users to use correct control in a specific situation. Some complaints were raised about teleportation. A few participants marked that it is difficult, others felt little vertigo when accidentally teleporting on top of other objects.

As part of personal observation, it was noticed that most participants haven't moved much in the reality, were standing in the center of the play area with their hands hold tight to the body, which could result in poor experience in virtual reality, decreasing feeling of presence and causing difficulties with motion control [44]. This behavior could be explained by user's lack of experience with virtual reality applications.

Art exhibition place was taken very positively, though some participants suggested that it should have more information about the shown pictures.

It was rightfully pinpointed that book search works slowly and did not complete some search requests. There were not any specific remarks on typing except that one user noticed that "it would be nicer to write using fingers". Overall participants have coped with it very well.

In overall participants agreed that featured books examples were fitting the environment they were in (forest for fantasy and future city for sci-fi) but raised doubts about connections between featured books and items bound to them ("...senseless associations between books and objects"). Participants also would like to have more interactivity with those items.

Collaborative writing was taken as a beautiful idea, but many users commented that writing the story itself is not very convenient and doesn't give much freedom in improvisation ("...but it's depressing that I can't actually write"). It was suggested that adding a story page should be allowed in any place of the story, not only starting from the last page.

Many comments were about general looks and virtual environment. Participants liked the graphics quality ("visually very nice", "really good graphics, better than I expected", "water looks better than in reality") and noted that different details make this virtual space more lively ("human characters make the spaces less threatening", "small things are nice for presence"). Participants appreciated physical objects in the cave scene, though some had difficulties with actually grabbing them ("it is really nice to grab objects, it increases the sense of being there"). Though participants like visual and audio details of scenes, sometimes it left them disappointed

because not everything was interactable (everyone tried to open the doors in the village scene, “it would be nice to play the piano”, regarding street cafes in the future scene - “menu lists should be interactive”, “there are so much tiny little details (like fancy lights in the future), but nothing happens if I try to interact with them”).

## 7. DISCUSSION

In comparison to medical, educational and industrial uses of VR, which have the public focus and better resource support, general purpose VR applications for public establishments are scarcely present and lacking expertise. Standard VR practices and guidelines are applied to such applications, but they do not answer the questions of how their services shall be implemented to provide a better user experience. With no doubt, as technology progresses and gets more accessible, the VR would gain a steady foothold in our infrastructure, but for now, it is an evolving domain for explorers.

The Virtual Library prototype, designed and developed in the context of this thesis, tried to answer the needs of Oulu City Library for a modern and fresh user experience, which would not only provide a new and unusual way of accessing library services but also raise public's awareness of the state of the art VR technologies.

### 7.1 Attainment of objectives

The implementation of the project idea aimed to accomplish a list of objectives gathered in the result of meetings with the library's management and participatory design workshops — this section reports on the outcomes of these objectives' fulfillment.

#### 7.1.1 *Create a virtual environment of Oulu City Library and fantasy worlds*

Virtual Library models the Oulu City Library building to make the user feel familiar with the surrounding. The first two floors of the premises are reassembled in the virtual space, duplicating prominent architectural features and interior design items. It would have been a loss to not utilize VR potential in creating diverse virtual worlds. And so, an elevator takes the user to fictional scenes, inspired by books, sustaining the purpose of application as “portal to fantasy worlds”.

The core piece of any VR application is a virtual environment in which the user is going to be immersed. The essential factors, defining pleasant user experience, are visual aesthetics, audio effects, world dynamics and means of interaction.

Study and future scenes have similar realistic style graphics, focusing on maintaining the atmosphere of these worlds. Library scene has simpler visuals because it was constructed using custom assets, initially made for an early prototype. However, even then, the sophisticated lighting system of UE4 makes it quite pleasant for the view. Lastly, the forest scene maintains the image of the cartoon world, bringing variety to the whole selection of worlds to explore. All the audio sources are spatial, meaning that sound emits from the original object, maintain the realistic audio behavior. There was an attempt to keep some degree of dynamics in the virtual environment so that scenes do not look static and lifeless. As a result, the user can find a hand full of animated or interactable objects in all scenes (for example, talking people in the library, animals in the forest, repair robot and interactable doors in the future, cat and various draggable

items in the study). Motion controllers are heavily used for both movement and interaction with the UI and objects. The control scheme, consisting of two main buttons, may be considered simple, allowing anyone to dive into the VR after going through the introductory tutorial.

Based on achieved implementation and generally positive user's feedback it is fair to say that Virtual Library delivers a good immersive VR experience.

### ***7.1.2 Utilize library's web services***

Digital services (such as browsing through the content catalog, checking availability, reserving or prolonging the period of book loan, etc.) are an inherent part of modern public libraries. Virtual Library attempted to give the user some of this functionality inside the VR world.

In the lobby, scene user can activate search function, which allows to seek out books in the Oulu City Library catalog by title. As a result, books are presented on an "infinite" circular platform, which user naturally controls by dragging it. Clicking on specific book launches navigation process and, if the containing shelf is found, draws a glowing path line to it.

Searching functionality has a couple of issues. The one that mostly affects user experience is the long waiting times. During the development process, the library's web services were going through modernization, so the implemented prototype uses an old system. In addition to that library does not provide public API, making the backend application use a rather clunky workaround. These factors result in user waiting for one-two minutes before search UI can respond with book information. Another issue is the limitation of the currently used navigation map. Adult's section on the second floor was the only charted area (and as it turns out, also outdated), so during the evaluation, not every search result was able to demonstrate how pathfinding works.

To summarize, the Virtual Library prototype has tested the utilization of library web services in the catalog search feature. The functionality works as intended and shows the perspectives of introducing useful library functions into VR application. However, the activity itself requires an update from two sides: the behavior and UI in Virtual Library, and, most importantly, the performance and convenience improvement of library's web services.

### ***7.1.3 Show media content and promote reading culture***

VR could be a handy tool for presenting content that is hard or even physically impossible to show otherwise in reality. Additionally, it can provide some exciting interactions with it.

The initial wish, given by the library's management, was to provide the ability to show library related advertisements and other visual information in the form of banners anywhere in the application. In the prototype, this objective is implemented on a smaller scale in the form of a virtual art exhibition. The terrace in the lobby of Oulu City Library is a traditional place for small exhibitions. The drawback of it is that it cannot be easily changed. Virtual Library's art exhibition, located in the same place, attempts to answer this problem. Picture frames, located in the same place as a real exhibition site, can display content, easily manageable from

administrator web application. On a startup, Virtual Library loads images assigned to the frames and information related to them, such as author, title and number of likes. The frame can host multiple pictures, and the user can easily switch between them. The interaction with the frame interface is effortless and requires only pointing to interface elements and pressing on one button on the motion controller. This activity showed the best score in the evaluation, as it is very straightforward and engaging. Additionally, the implemented mechanism can be easily used utilized in showing configurable content all around the virtual environment, as specified in the initial requirement.

Promoting the reading culture is one of the public library's responsibilities according to the Public Library Act. The virtual Library project was also given a task to take on this objective in the virtual world. The implemented activity takes form in containing little information (author, title, short text and audio description) in the items, related to the content of a particular book. When the user interacts with these objects, the information pops up in the form of a world widget. The list of featured books was prepared by the library's management and contained titles to be presented in the forest and futures scenes. The list was quite ambiguous, and not all of the items made it to the prototype, because of difficulties in the creation of related objects for them. The implemented activity offers a solution for a set requirement, but from the author's point of view, it requires some further work to make this activity more engaging and exciting.

#### ***7.1.4 Provide multi-user experience***

Libraries largely serve as public meeting places, offering premises for learning, working, recreational and other activities. Similar functionality was suggested to be included in the Virtual Library, in one way or another.

The way multi-user experience could be achieved depends on the deployment of the application. The general approach is seen in multiplayer VR games, where players, having own VR stations and instances of the application, compete or cooperate to achieve game goals. In the process of development, only one VR equipment was accessible, and no information on the library's plans of how the application would be spread. In these circumstances, multiplicity could have been achieved with other users accessing the same environment from other platforms, for example, web or desktop application. However, in this case, a much larger work would be required to design user capabilities and interactions from different origins, and this was out of the project's time frames. In the end, the collaborative storytelling activity was implemented, making possible stories sharing among Virtual Library users.

In the study, scene user can interact with the book on the dining table to open up an activity interface. The story creation mechanism is inspired by magnetic word tiles for fridge and consists of placing word blocks in order to write a page of text, that would be uploaded to a server and later shared with other users for continuation. It is safe to say that this activity is the most complex in the whole application, both in terms of behavior logic and involved interaction with the user. According to the evaluation observations and interviews, the activity was taken as an interesting idea with very natural controls, but the current implementation of word blocks limits the story creation process.

## 7.2 Future development

The evaluation phase opened a big room for fixes and improvements, which would be grouped and discussed here.

First of all, one big issue exists with the current way of accessing the library's web services. The implemented workaround using back-end server as an intermediate node to mimic web API is slow and limiting. The solution to this issue goes from two sides. From one, the library's team should finish their web services, which have been in development during the Virtual Library progress. From another one the Virtual Library itself should implement interfaces to the provided by library's proper API to implement useful and interesting features, such as better search (for example with sophisticated filtering), authentication as library user (for example to order books or prolong the ones being held), giving scores and writing reviews for books, etc.

Secondly, pathfinding shall also be corrected and enhanced. During the evaluation, one of the library's staff participant pointed out, while searching for a specific book and requesting navigation to it, that it is not located in the shelf that system showed up. This mistake could be explained by the fact that library's code map was built in the early stage of the development process and could contain errors, as well as just the position of shelves or their content could have changed. Which leads to one more perspective improvement - making the routing maps dynamic (for example letting administrators update or tweak them in back-end web application). The current navigation map only covers first two floors of the Oulu City Library, but with the addition of the rest of the building and likely adding more route nodes, the overall complexity of the map would be significantly increased. In order to meet keep processing times small it could make sense to switch from currently used Dijkstra's algorithm to something more practical.

Featured books activity requires further work in better correlating objects with suggested books. Making this activity more engaging (for example adding more interactivity with objects or implementing some simple puzzles or quests) would make it more interesting than just walking and stumbling upon these items.

Collaborative storytelling needs a massive update on word blocks logic to provide more flexible and inspiring story creation process (just the simple ability to change the case of words would significantly improve the experience).

One of the experimental features that were tried during the development was real multi-user mode, in which two or more users could use activities and see each other on all scenes of the Virtual Library simultaneously (the same way as online multiplayer games work). This feature has proven to be challenging to maintain, so it was not prioritized and had been left in the backlog. Future developers could experiment with it and maybe find some interesting usage or create new activities based on it.

And lastly, the overall improvement of graphics and polishing of all scenes could always be made to provide better user experience and immersion.

## 8. CONCLUSION

Virtual Library had a rough development path, started as an interactive web-model of the Oulu City library and gradually, enforced by new ideas and ever updating requirements, evolved to a versatile VR application, moreover - one of few pioneers in such field as VR applications for library institutions.

Virtual Library tried to create a complex experience themed around library entity presenting what modern VR technologies are capable of in terms of graphics, interactions, and immersion. It accomplishes this goal through different environments with different activities focused on content, interactivity with surroundings and imagination. On top of purely entertaining features, connection to library's catalog allowed to implement a somewhat limited, but search function with routing inside the application, that can help to locate a book in the real library. Evaluation process resulted in both positive response and a lot of valuable, constructive feedback that forwards to improving some aspects of the application before it actually can be installed in the library for public use.

VR technology is a new frontier for library's non-conventional services, and Virtual Library tried to set foot on this land proving that it is worth studying further. How well would VR be adopted in future libraries? Only time will show.



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## 10. APPENDIX

### 10.1 Appendix 1: Questionnaires

Johanna Ylipulli questions:

1. How people experience the VR library that is partially built according to their ideas?
2. How they experience the fact that VR library combines a mirror world and a fantasy world?
3. How they experience using VR library at library premises?
4. How they experience the services and functionalities of the VR library? Do they have added value for them? Which parts do they like and which ones they don't? Why?
5. How would they develop the VR library and its services and functionalities?
6. How well the library and VR connect - should the library offer a possibility to use VR?
7. How have they experienced the whole design process?

Minna Pakanen questions:

1. How would you describe your overall experience with the virtual library?
2. What was the most fun in it and why?
3. What was the least favorable in it and why?
4. Was the interaction with interactive object easy or difficult and why?
5. How did you find interactive objects in the scene and how did you know they were interactive?
6. Was the visual indication of the interactive button sufficient (elevator)?
7. Was the visual indication of the interactive objects sufficient (basement)?
8. Was the audio indication of the interactive objects sufficient (forest)?
9. How do you perceive the search of the book and route instructions to the actual location of the book in the library? (Was it easy or difficult to type, browse books, find the route to the actual location of the book?)
10. How do you perceive the interaction with story creation application? (Was it easy to create a story, edit a story, browse stories...?)