Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 156 (2019) 283–291

Procedia Computer Science

www.elsevier.com/locate/procedia

8th International Young Scientist Conference on Computational Science

Emergency exit planning and simulation environment using gamification, artificial intelligence and data analytics

Jukka Selin[a,*], Mika Letonsaari[a], Markku Rossi[a]

[a]South-Eastern Finland University of Applied Sciences, Patteristonkatu 2, 50100 Mikkeli, FINLAND

Abstract

In our research, we explore methods to utilize gamified building data models and data analytics. In this paper, we present a study, where an emergency exit planning and simulation platform is implemented with a commercial center gamified data model. In the study, we compare various emergency exit location options and search the critical areas for customer evacuation. Customized user profiles are used to estimate the movement capabilities of elderly and handicapped people. The feasibility of data analytics methods for analyzing the simulation results is examined. The results show that simulations based on gamification are well-suited tools emergency exit evaluations.

Keywords: BIM; Gamification; Data Analytics; Simulation; AI;

1. Introduction

Building information modeling (BIM) and BIM-based thinking have become more common in buildings design. In our research, we develop processes and techniques for gamification of building information models. This is used to

* Corresponding author. Tel.: +358-50-525-9689 .
E-mail address: jukka.selin@xamk.fi

1877-0509
10.1016/j.procs.2019.08.204

create added value in building design and management. In addition, we develop the utilization of the gamified data models throughout the lifecycle of the building.

Gamification is a quite broad term. In this study, gamification and gamified data model are defined to mean importing building's digital plan (data model) to a game engine (like Unity or Unreal Engine) from a computer-aided design (CAD) software. Game engines provide tools such as a physics engine, character animations, artificial intelligence (AI) for controlling characters, and user interface functions. In this way, a 3D environment like computer games can be implemented from a building plan. A gamified data model may be used in several functionalities, for example, simulations. The functionalities can be implemented using application specific programming techniques. A building data model (or data model) means a building's digital plan that includes building design information, such as the 3D models of the building.

The idea of this project is that the gamified data model serves first the design, planning, and construction of the building. When the building is ready, the gamified data model serves as a two-way maintenance interface for the entire lifecycle of the building. For example, data related to the usage of the building can be accessed with data and analyzing tools through this maintenance interface. The gamified data model of the building provides a digital twin during the lifecycle of the building.

The study presented here is part of this larger research. In this study, we explore the use of the building's gamified data model as a simulation platform for emergency exits. In addition, the aim is to study the analysis of data obtained in the simulation using data analytics.

The aim of this study is to answer the following question: Is it feasible to implement an emergency exit planning and simulation environment using the building's gamified data model and data analytics methods?

The gamified data model enables simulations to be performed with the building. During the simulations, we can automatically collect data from the simulation and analyze the data with data analytics methods. This way e.g. security and accessibility issues can be tested already during the design phase. Possible changes and corrections are much easier to do and cheaper to implement during the design phase than later when the construction of the building is physically finished.

In this simulation-based emergency exit study, we used a real building design from a construction company that participates in our research. The purpose of the simulation was to study the safety of a commercial shopping center during a fire emergency.

In the simulation, we placed computer-controlled human characters (customers) with several different physical profiles to the commercial shopping center. User model profiles include specific types of interest such as elderly people and handicapped people. Computer controlled characters were controlled by the game engine’s artificial intelligence designed to mimic real human behavior.

We tested by simulation how long it would take to evacuate the commercial shopping center in different fire scenarios. To evaluate the model we used the comparative data from studies by the University of Lund and VTT to see how quickly different fire compartments turn life-threatening for humans as the fire progresses [1, 2].

We implemented a data collection mechanism for the simulation. It allows data to be collected e.g. about the behavior of profiled persons during the simulation, as they search for emergency exits. We analyze the data collected with data analytics methods and search the critical places in the design of the emergency exits. In addition, we also compared various alternatives to place the emergency exits.

In the second chapter of this article, we present the materials and methods used in the study. We also introduce the programs we use. In the third chapter, we present our research. We study the planning and simulation of the emergency exit of the commercial center using gamification and data analytics. In the fourth chapter, we review the main results of the study. Conclusions and discussion about the study are presented in the last chapter.

2. Materials, methods, and programs

Gamification is defined as the use of game design elements in a nongame context. In this case, the context is the building design and construction. Gamification is also often used for example in teaching or marketing to arouse interest. [3] In this study, the method of gamification means that tasks involved in building design and planning are done utilizing game engine functions that are normally used in games.

Machine learning technology is a method for making predictions from existing history data using analysis models taught by different algorithms. Algorithms are used to identify and learn interdependencies between data. Using the information obtained in this way, from the data to be analyzed we get different assumptions and predictions. Analyzing new data is based on the information learned from previously analyzed data. The result of the analysis will improve as the amount of data analyzed (history data) increases. [4]

The data model of the building we used in this study is the information model of a real shopping center built by our R&D partner Construction Company U. Lipsanen. [6] We obtained the data model for research use.

The data model used with the shopping center consists of several sub-models created by the architects, and engineers designing different structures and functional subsystems using CAD tools. As an example, the architecture model is designed with the ArchiCAD software.

All sub-models of the commercial shopping center have been received in the IFC file format. [6, 7] The sub-models have been converted to the OBJ file format using IfcConvert open source software tools [8]. Files that are in the OBJ format have been further optimized using open source software MeshLab [9].

Using the gamified data model we studied the emergency evacuation with an AI navigation control provided by the Unity game engine [10, 11]. Profiled and individually parametrized game characters were placed randomly inside the shopping center. The game characters were then commanded to proceed to the closest emergency exit with the aid of the AI engine.

Around each game character, we placed game colliders that described the space needed for the game character when mobile, according to the game character profile. Such a game character can use different aids to overcome limited mobility when moving. A game character using a mobility aid like a rollator usually needs more space than an average person. Each of the game characters also possessed an individual moving speed. [12]

The Functional Design Method (FDM) was used to determine the spatial needs of profiled customers (game characters). The Functional Design Method is based on the Finnish patent by our senior lecturer and Licentiate of Science Jukka Selin. The patent was derived from an earlier internal innovation report. [13, 14]

The core idea in the FDM is to capture the space requirements of real action in three dimensions and then create a new 3D spatial object. The new 3D objects represent the maximum spatial space requirements of actions. With FDM we generate the 3D spatial objects representing spatial needs for actions. The description of the cases for game characters can be seen in Table 1. [12, 15, 16]

Table 1. Maximum space requirements for the dimensioning of the colliders created by the FDM [11].

The dimensioned Action	Space Requirement (m)
A walking person	0.50 x 1.90 x 0.70 (x, y, z)
A running person	0.65 x 1.90 x 0.90 (x, y, z)
The assistant walks with the wheelchair user on behind the wheelchair	1.30 x 1.90 x 1.00 (x, y, z)
The wheelchair user without the assistant	1.00 x 1.50 x 1.00 (x, y, z)
The user with rollator	0.90 x 1.90 x 0.75 (x, y, z)
The user with crutches	0.90 x 1.90 x 1.00 (x, y, z)

From each of the cases, we generated a game character prototype that has colliders corresponding to the table. In this study, the characteristics of the colliders were specified on a relatively common level. We estimated that this accuracy is adequate from the simulation method point of view. The profiles could well be much more detailed and more types of profiles representing customers with different attributes could be created if required.

The simulation is programmed so that each profiled game character writes all their events during simulation to the log file. We analyze the data thus obtained using data analytics. We strive to find the problem areas of the emergency exit and to optimize the location of emergency exits.

The collected data is analyzed using the Microsoft Azure Machine Learning Studio. As an example, simple predictive analysis models are used. Data analysis is not dependent on the analysis tool so it is possible to perform the same analysis using other preferred analysis tools.

3. Research

In this study, we tried to find answers to our research question: Is it feasible to implement an emergency exit planning and simulation environment using the building's gamified data model and data analytics methods?

An emergency exit simulation application is used as the basis for this study. The emergency exit simulation application has been implemented with a gamified data model of a commercial center built by our construction partner.

The simulation application of the emergency exit of the commercial shopping center is presented in Fig. 1. In the figure, the game characters (customers) profiled with different profiles try to find defined emergency exits under the control of the Unity Navigation System. The figure also shows the space required for the person using the rollator (Collider) [11, 12].

Fig. 1. A simulation application realized with the Unity game engine. A game collider corresponding to the spatial need of a game character is visible in the figure.

The profiles, quantity, and location of the game characters can be freely changed. In addition, the location and extent of the event that caused the emergency can be altered in the simulations. For example, it is possible to test a situation where a fire restricts movement in a particular area and can even prevent the use of a certain emergency exit completely.

In this study, we placed from 1 to 180 gaming characters with artificial intelligence to the gamified data model of the shopping center. We added a program code to game characters, which allows the character to write all their events during the simulation to the log file. We carried out in total 36 simulation runs with different amount of game characters. In each simulation, we randomly placed the game characters differently in the commercial center. The data for each simulation run was written to the log file.

The floor of a gamified data model is divided into 5m x 5m squares. The game code associated with the game characters automatically calculates on what square the collision has occurred. The application writes the id (boxid) of the square to the log file instead of the coordinates. If necessary, the size of the squares can be reduced to provide a more accurate result or the exact location can be obtained using the raw coordinates. In this case, the grid size was selected for the task-dependent visualization purposes. With this grid size, the result is accurate enough to find the problems of emergency exits.

The events written by the game engine to the log file are presented in Table 2. For different use cases and applications, it is possible to include more detailed information on required simulation events.

Table 2. The events that were written by the game characters to the log file.

A game character event	Data to the log file
A game character collides with another character or other object	The name of the game object
	The name of the other object
	Time from the beginning of the simulation (s)
	In which box did the collision occur (id)
The game character leaves the building through the emergency exits	The name of the game object
	The name of the other object (not relevant)
	Time from the beginning of the simulation (s)
	In which box did the collision occur (id) (not relevant in this case)

In this study, we had two separate emergency exits. The game characters were programmed to move always to the nearest emergency exit. The result of each simulation was written to its own log file in CSV format. As a result of the simulations, we got 36 separate log files.

The data collected at simulations were analyzed with the data analytics and data visualization to find the problem areas of the commercial shopping center emergency exits. The critical parts of the building were determined by analyzing the number of collisions between computer characters and building model objects.

An excerpt of a CSV log file generated by the simulation application is presented in Fig. 2.

<table>
<tr><th></th><th>A</th><th>B</th><th>C</th><th>D</th></tr>
<tr><td>1</td><td>name</td><td>target</td><td>time</td><td>boxid</td></tr>
<tr><td>2</td><td>rollaattoriprof2 (3)</td><td>0ia0pygcbFcRGpBJPlbqdF</td><td>00.360</td><td>R229|170</td></tr>
<tr><td>3</td><td>rollaattoriprof2 (3)</td><td>0ia0pygcbFcRGpBJPlbqdF</td><td>00.660</td><td>R229|170</td></tr>
<tr><td>4</td><td>pyoratuolipref1 (3)</td><td>3QJVxVOgz1vAvJ71BDJfG_</td><td>01.140</td><td>R229|169</td></tr>
<tr><td>5</td><td>rollaattoriprof2 (3)</td><td>0ia0pygcbFcRGpBJPlbqdF</td><td>02.360</td><td>R229|170</td></tr>
<tr><td>6</td><td>exit2</td><td>rollaattoriprof2 (1)</td><td>16.860</td><td>R225|176</td></tr>
<tr><td>7</td><td>rollaattoripref1 (1)</td><td>hahmo62 (1)</td><td>35.420</td><td>R230|172</td></tr>
<tr><td>8</td><td>hahmo62 (1)</td><td>rollaattoripref1 (1)</td><td>35.420</td><td>R230|172</td></tr>
<tr><td>9</td><td>hahmo1</td><td>2dVDDYcvPDVfW9kClBAzt2</td><td>41.640</td><td>R226|168</td></tr>
<tr><td>10</td><td>hahmo6</td><td>rollaattoriprof2 (2)</td><td>45.200</td><td>R228|173</td></tr>
<tr><td>11</td><td>rollaattoriprof2 (2)</td><td>hahmo6</td><td>45.200</td><td>R228|173</td></tr>
<tr><td>12</td><td>hahmo6</td><td>rollaattoriprof2 (2)</td><td>45.300</td><td>R228|173</td></tr>
<tr><td>13</td><td>rollaattoriprof2 (2)</td><td>hahmo6</td><td>45.300</td><td>R228|173</td></tr>
</table>

Fig. 2. A beginning of the log file created during simulations.

Using the data analytics tools, we created an application that gets the data from the log file to the input data and searches out the problem locations for the emergency evacuation. We located the areas of the commercial shopping center where more collisions occurred than usual in simulations. If there are lots of collisions within a short time in a certain area, it is clearly problematic for evacuations.

The application implemented in the graphical programming environment of the Azure Machine Learning tool is illustrated in Fig. 3. The application analyzes the collected data and performs analysis. Data can be used to retrieve various data using SQL.

In the first analysis, the number of collisions of each square is retrieved. The search result is sorted to descending order based on the number of collisions. The top of the list shows the most problematic areas of the emergency exit. In addition, the analysis searches from the data material for the maximum time it takes to clear the shopping center (Time_to_empty). The analysis also calculates the average (Exit_avg_time) of the exit times of all the game characters in the game.

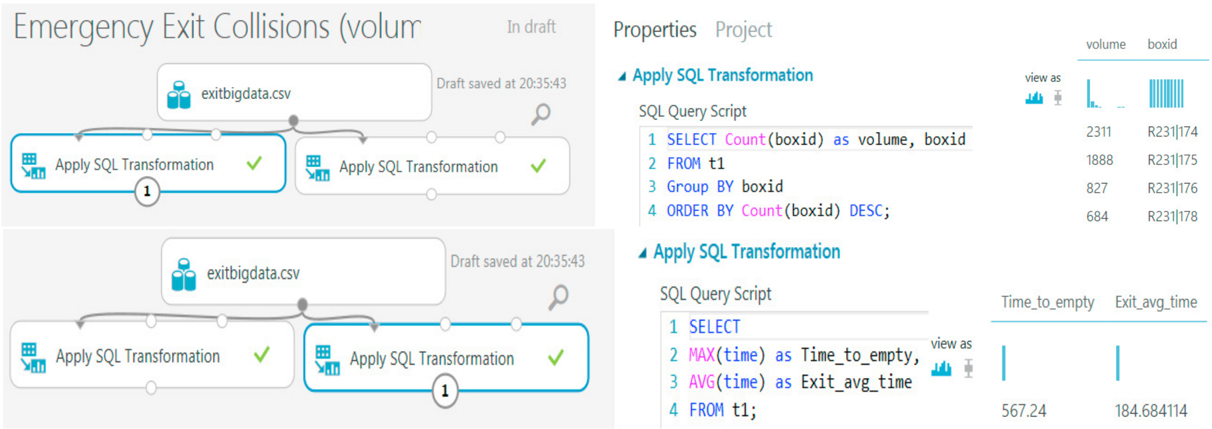

Fig. 3. The number of collisions by grid square and exit characteristics analyzed from the log data.

A result file with the number of game characters, the maximum exit time, and the total number of collisions for every 36 simulations was created by the analysis. This data file is used in the second analysis presented in Fig. 4. A linear regression model is used to predict emergency exit times with a different amount of customers. 30% of the data is used for the teaching model and the quality of the model is analyzed.

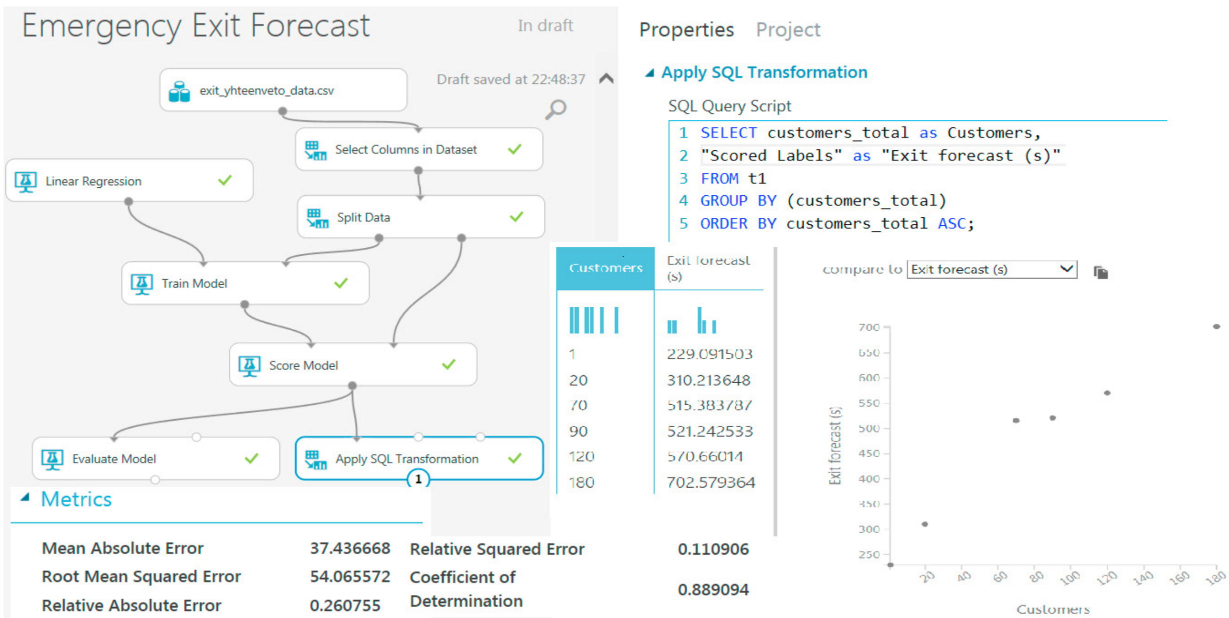

Fig. 4. Emergency exit forecast, a predictive model.

4. Results

The data analysis is presented in Fig. 5. It shows that the most critical point for an emergency exit is the exit lines adjacent to the cash desks, whose capacity is not good enough for emergency exits. It would be very important that, in the event of an emergency, customers could go past the cash registers unhindered. In these locations, there were especially such collisions in the simulations in which the person (customer) using the assistive device was the other stumbling party.

Another critical point is found in between the shelves. For this reason, the space between the shelves must be extended.

0	0	4	35	0	14	0	0
0	0	18	28	0	0	0	0
0	0	6	15	0	0	0	0
2	0	46	37	0	0	0	0
0	0	84	0	0	0	0	0
0	58	18	0	3	1	0	0
0	27	39	20	38	1	322	0
0	457	254	174	8	37	39	0
0	342	5	74	28	0	0	0
0	383	0	0	152	73	0	2
0	242	0	0	0	0	0	0
0	94	0	0	0	0	0	0

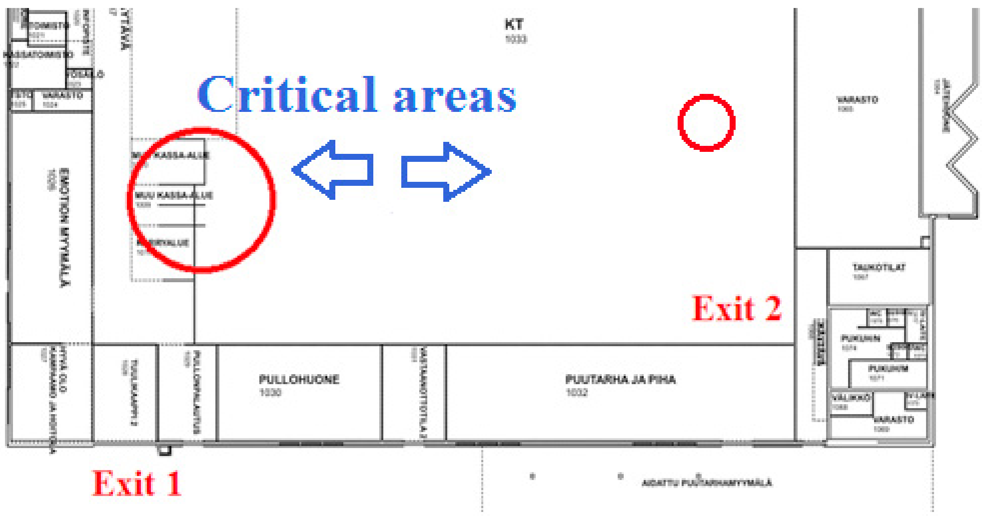

Fig. 5. The heat map of critical areas found by the data analysis.

With the prediction model (Fig. 4), it was shown that shopping center emergency exits are good enough for emergency exits, even if the number of customers exceeds the maximum number allowed.

Previous research has shown that in a fire, the critical time in a building is about 20 minutes. After that, the fire gases in the fire rise to a life-threatening level. [1, 2] In these simulations the maximum time for evacuation was 703 seconds which is about 12 minutes. For the safety of the shopping center, it is very good that in all simulations the commercial center was emptied in time with clear marginal to the limit on 20 minutes.

5. Conclusions

In this research, we looked for the problem locations for a commercial shopping center emergency exits using simulations on gamified building models. In simulations, computer-controlled characters were controlled by the Unity game engine's artificial intelligence that is designed to mimic the behavior of real humans.

The artificial intelligence algorithm is based on the A* (A star) pathfinding algorithm. [11] The algorithm expects agents to be fully aware of the map of the building and the location of exits. It can be argued that this is not always the case in real life situation. But usually exits are marked well in modern buildings and we can expect the A* algorithm to correspond well to the behavior of a person who follows exit signs. Also, exits are often located near the entrance of the building and it can be expected that customers are aware of their location in relation to the entrance of the building.

The more simulations we would have completed, the larger the data material we would have collected. Through this, the reliability of analyzes made would also increase. The data analytics tools also allow one to create machine learning applications. As the data material grows, the quality of analyzes made would also improve. In addition to the data material collected in the simulations, reference data collected from other similar buildings obtained either by simulation or from actual situations could be included in analytics. There are a lot of different possibilities.

We used data analytics tools through their own interface. We could also create Web Services (Web APIs) based for example on REST/JSON interface technologies. In this case, the client applications could communicate with the data services directly through the interfaces.

Results from the gamified simulations are credible and generally believable even though no formal validation was performed. For the visual validation, it must be noticed that we expect computer characters to behave unnaturally. The default behavior for games is that character "runs 90 miles per hour, comes to a halt immediately and turns on a dime" [17]. So extra caution must be applied to quantify physical characteristics of game characters.

The data analytics tools also allow applications where the application is taught to analyze data. In that case, the accuracy and reliability of the analysis will improve over time as the application learns to better interpret the data material.

In our opinion, the research and our results show that simulations and data analytics are well suited for emergency exit analysis of this kind. The answer to our research question is that it is possible and feasible to implement an emergency exit planning and simulation environment using the building's gamified data model and data analytics methods.

The attained results confirm our vision that the idea we have developed to utilize the gamified data model as a platform for various simulations is good and usable. Analyzing the resulting data material with data analytics methods helps to identify potential problem points during the design phase, where the modifications are still fast to perform and inexpensive. This kind of simulations and associated data analysis will help designers to achieve better design solutions. The results confirm our view about the usefulness of data analytics methods also for the whole lifecycle of buildings.

Acknowledgment

This work was supported by the European Union Regional Development Fund and the Leverage from the EU 2014-2020 programme.

References

[1] Magnusson, S.-E., Frantzich, H. & Harada, K. Fire safety design based on calculations –Uncertainty analysis and safety verification. Lund, SE: Lund University, 1995. 120 s.(Report 3078.) ISSN 1102–8246k.

[2] Weckman, H. Rakennuksista poistumisen laskennallinen arviointi. Espoo: Valtionteknillinen tutkimuskeskus, 1997. 50 s. + liitt. 11 s. (VTT Tiedotteita – Meddelanden –Research Notes 1846.) ISBN 951–38–5133–8 ISSN 1235–060.

[3] Seaborn Katie., Felsh I. Deborah., Gamification in theory and action: A survey. International Journal of Human-Computer Studies Volume 74, 2015, Pages 14-31. ISSN: 1071-5819, https://doi.org/10.1016/j.ijhcs.2014.09.006, Elsevier Ltd.

[4] Barnes, Jeff (2015) "Microsoft Azure Essentials: Azure Machine Learning" Microsoft Press, Redmond, Washington 98052-6399. ISBN: 978-0-7356-9817-8.

[5] The official website of the Azure Machine Learning service. https://azure.microsoft.com/en-us/services/machine-learning-service/. Accessed: 2019-4-22.

[6] The Construction Company U.Lipsanen Oy, A Building Information Model of Commercial Center in IFC format, Pieksämäki, Finland, 2018.

[7] BuildingSMART International. The official website of the IFC-format (ISO 16739:2013). Accessed on April 18, 2018. http://www.buildingsmart-tech.org/specifications/ifc-releaces. Accessed: 2019-4-24.

[8] The official website of the IfcOpenShell-project. http://ifcopenshell.org/. Accessed: 2019-4-24.

[9] The National Research Council (Cnr). The official website of the MeshLab software. http://www.meshlab.net/. Accessed: 2019-4-24.

[10] Unity Inc. The official website of the Unity game engine. https://www.unity3d.com/. Accessed: 2019-4-24.

[11] Unity Inc. The official website of Navigation System in Unity. https://www.unity3d.com/Manual/nav-NavigationSystem.html. Accessed: 2019-4-24.

[12] Selin Jukka., Rossi Markku J., The functional design method for buildings (FDM) with gamification of information models and AI help to design safer buildings. FedCSIS, 2018 Federated Conference, Poznan, Poland, 2018. ISBN 978-83-949419-5-6, 978-83-949419-6-3 and 978-83-949419-7-0, ISSN 2300-5963, IEEE.

[13] An action space defining object for computer aided design. Finnish Patent 125913b, granted on April 15, 2016. Fourteen claims. Current owner : Xamk. Inventor: Selin, Jukka-Pekka. Is the origin of the PCT patent application WO 2014/154942 A1.

[14] An action space defining object for Computer Aided Design. PCT patent application WO 2014/154942 A1. Applicant Mikkeli University of Applied Sciences Ltd (Jukka-Pekka Selin).

[15] Rossi, Markku J. and Bhargav, Dave, Digitalization and quality enhancement initiatives in sw assisted design processes in building and construction industries. 9th International Conference on Computer Engineering and Applications, Dubai, 2015. ISBN 978-1-61804-276-7.

[16] Selin Jukka., Rossi Markku J., Simulation of universal design by a functional design method and by Gamification of Building Information Modeling. FedCSIS, 2016 Federated Conference, Gdansk, Poland, 2016. ISBN 178-8-3608-1090-3 and 978-1-5090-0046-3. ISSN 2300-5963, IEEE.

[17] Unity Inc. Manual: Character Controller. https://docs.unity3d.com/Manual/class-CharacterController.html. Accessed: 2019-7-4.