The functional design method for public buildings together with gamification of information models enables smart planning by crowdsourcing and simulation and learning of rescue environments

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Abstract. We have developed and piloted a method that can be used to create planning and learning environments that fuse buildings design with game programming. The method also allows e.g. design crowdsourcing and different simulations of building use (like emergency evacuation by rescue teams). The method also brings together the students of game programming and buildings design with building users and construction professionals to work together towards mutual goals. This way all they learn in addition to group work to act in projects with students, building users and professionals of many disciplines. This is increasingly a key skill in the modern work life that relies heavily on projects. In this environment it is important for the actors to learn how to understand and appreciate the specialists of other disciplines and their professional skills. The gamified information model of a building can be used after its completion as a learning and testing space for the construction professionals. In the gamification we utilize our patented Functional Design Method for Buildings that enables to take into account the space needed for human actions in buildings or other targets under design in information model based (BIM) design of buildings. The objects to be dimensioned could e.g. be related to safety, loading and unloading areas or production processes and their requirements for space. An inverse approach is also possible. The method helps all actors of construction business, building users and students to better take into account and understand operational spatial requirements in a building and about safety.

Keywords: BIM, AI, multi-gaming, gamification, crowdsourcing, simulation, learning, learning environment, function dimensioning, universal design, energy efficiency.

1 Introduction

In this paper we present the method and different applications of gamified 3D building designs derived from the methods. We also present our experiences from the pilot studies. We also tell about our views and results we gathered about the usefulness of this kind of information models to learning environments of both game design and buildings design. We will examine them both from R&D and software products points of view. We also present valuable knowhow we have accumulated in pilot studies about the feasibility of the Functional Design Method (FDM) to dimensioning of spaces and about studying dimensioning when related to creating human actions based building specifications.

In addition, we will present the utilization of the Functional Design Method (FDM) “Value Add Data / VAddD“ together with the Gamified BIM Information Model during the different phases and applications of building design. The cases presented relate to the joint R&D and piloting efforts of the S-E Finland University of Applied Sciences (XAMK) and our industrial construction partners. FDM is based on the Finnish patent by our senior lecturer and Licentiate of Science Jukka-Pekka Selin. The patent was derived from an earlier internal innovation report [1], [2], [3].

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. When using Construction CAD these objects can be used in dimensioning different spaces. The goal can be both to fit an action to a space or alternatively ensure that an object can reach all the needed places in a space. If the Information Model in the form of an IFC (Industrial Foundation Classes) file is gamified it becomes possible to use the spatial objects to realise e.g. adaptation capable game colliders around game objects. In that case we can test the fitting of different actions or reaching capabilities of objects to stationary parts of the construction. We can also perform simulations. The buildings and constructions will now fit their purpose better than when using current design methods.

The core idea is to design the spaces and walls in terms of meant actions and not adapt the actions to the spaces available. The FDM provides excellent tools to achieve this goal. In our piloting program we used a real construction project of our industrial partner, a Finnish supermarket [4]. We gamified the complete BIM Information Model and were then able to test the FDM from different perspectives.

In the first pilot we simulated the emergency evacuation from a supermarket with a gamified model by utilize AI (Artificial Intelligence) based navigation of moving avatars in the model of the market. In the simulation we had avatars with individual behavioristic profiles and sets of rules. We made the avatars evacuate themselves using an AI engine and individual parameters along evacuation routes that were rapidly chosen after a fire alarm. This piloting action helped all partners to understand in a concrete way the importance of safety and Barrier Free principles in the buildings design especially when related to fire safety. The attendants could also learn from the research data and apply their new knowledge to practice. The pilot studies also helped the students of data processing to develop skills in simulation applications utilizing Artificial Intelligence (AI). With those applications it was necessary to realize as closely reality matching virtual game environments as possible by combining results from the research. The pilots also enabled to test the feasibility of the FDM to extract the spatial needs of purpose profiled spaces and after this to test the dimensioning of the corresponding game colliders used in the realization of simulations.

In the second pilot we tested the FDM in the dimensioning of spaces to be adequate and enclose all the necessary actions planned to happen in the spaces. The external loading yard of a supermarket was designed for an efficient and safe operation of trucks.

The pilot studies taught the students to dimension spaces according to different norms and regulations. The program also developed the skills of especially construction students and also students from other disciplines in dimensioning loading areas so that all necessary vehicles are able to operate in the space. In this trial we were able to test the feasibility of the FDM to dimensioning studies and professional dimensioning of real sites.

The third pilot was a dimensioning of an industrial plant with manufacturing lines and robots. The positioning of the lines and robots was optimized together with the allocation of minimal manufacturing space. The piloting taught the actors to dimension production facilities so that also knowhow to take into account safety to an adequate degree was achieved. Especially the construction students gained understanding in designing safe production spaces and the required safety zones, as requested by norms and regulations. In this program we similarly tested the feasibility of the FDM to the dimensioning of production lines and safety zones and to the dimensioning studies.

We also present a pilot where the reaching capabilities of moving actors to objects to be moved was tested. We dimensioned the shelves of a supermarket and the corridors between them so that the forklifts can operate in between the shelves and can also reach well and safely the shelves at the top. The piloting actions taught the students to dimension storage facilities. The spaces must be large enough, safe, and it must be possible to reach all objects during operations safely. Related to the pilots we tested also the FDM for the design of reachability.

All piloting actions increased knowledge and understanding of both game programming students and construction students about the human actions base design so that the safety and Barrier Free design principles were realized. The skills related to understanding different norms and regulations steering the designs increased. Different actors also learned to take into account and appreciate the knowhow of representatives of other professional disciplines. The students realized that these kind of design projects will not succeed at all without a combining effort of different expertise. Everybody learned new skills from other actors and the initial idea that one person can handle the whole design field was abandoned in favor of group work. Subsequent paragraphs, however, are indented.

2 Materials and methods

The maximum space requirement in dimensions x, y and z can be derived from video clips of real human actions. In this method the real actions are videoed with at least two video cameras that are situated at right angles. The need of space from the actions in three dimensions is measured and a corresponding geometrical object is created. This 3D object in IFC file format is compatible with different CAD software. The goal is to ensure that the required actions can fit the space under design [1], [2], [3].

During the research program the application that is BIM compatible and is meant for Lifecycle Management of Building Data, and the application extension Value Add Data of XAMK R&D, were used for creating 3D objects. The application extension realizes the functionality of the FDM. The Colliders describing the space requirements for different actions to the gamified model were created via the execution of the Value Add Data software [4]. The Information Model used with the supermarket consists of several submodels that have been created by the designers of architecture, structures and different subsystems, with different CAD tools. As an example, the architecture model has been designed with the ArchiCAD software by Graphisoft SE. All submodels of the supermarket have been received for piloting in the IFC format [4], [6]. The submodels have been converted by the tools of the Open Source software family IfcConvert to the OBJ format [7]. The files that were in the OBJ format have been further optimized and shortened with the Open Source software MeshLab [8].

The metadata that are in the IFC files have been transferred by using the XML format. The conversion from IFC into XML has been performed with the IfcConvert. The gamification itself has been performed with the Unity game engine [9].

When simulating the emergency evacuation we used the Navigation extension of the Unity engine. This extension brings possibilities to use AI based navigation schemes [10]. In addition to the Building Information Model we also used other 3D models. To convert these other models and animations related to them to required formats we utilized the 3ds Max software by Autodesk Inc., and also the SketchUp Make software by Trimble Inc. [11], [12].

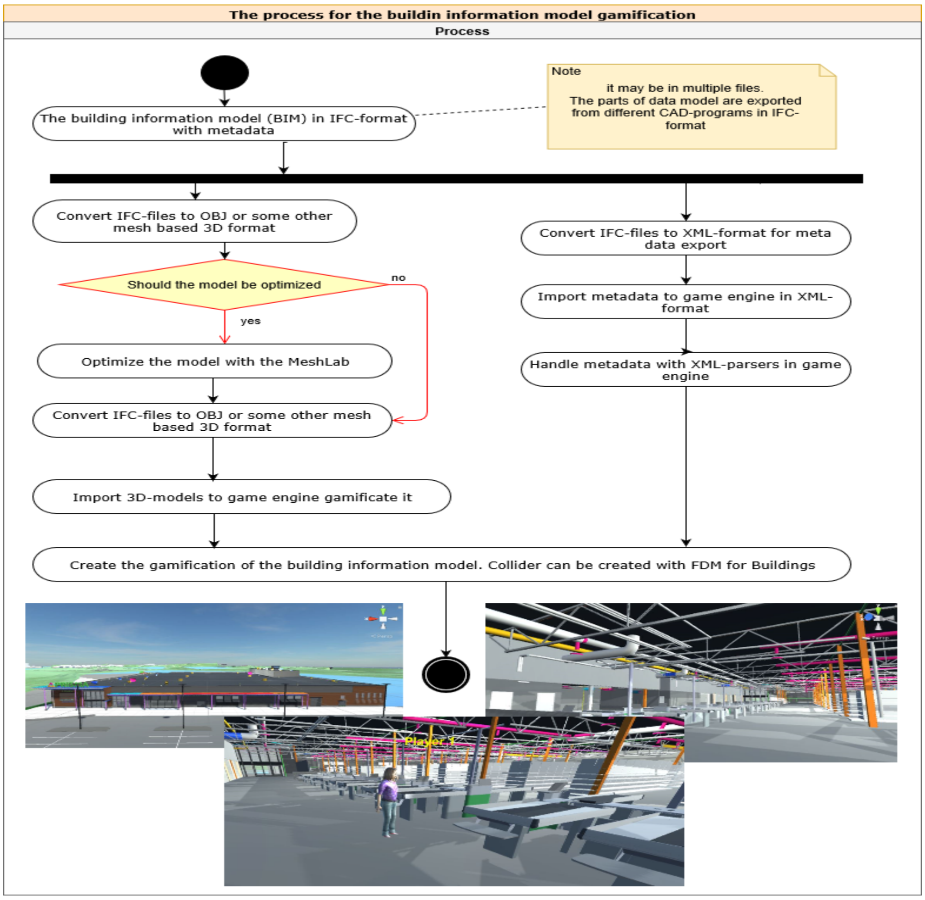

Fig. 1. Our process for gamifying Information Models.

The schematic above describes the process developed by us to gamify Information Models of buildings. The basic principle of the process is that the gamification should be possible independent of the choice of the original CAD design tool. The only requirement is that the CAD tool supports the IFC format and can export both data and metadata into an IFC file according to the BIM recommendations [6]. Into a model gamified this way we can bring spatial objects generated by our FDM. These VAddD spatial objects can also support designs as such or if further converted into Game Colliders.

3 The FDM together with gamification of information models teaches and helps to design safer buildings and structures that fit their purpose better than before

We created pilots to study different possibilities and applications for the FDM. We utilized an Information Model of a real supermarket. Our partner, the construction company U.Lipsanen Oy is currently building the supermarket. We received the Information Model as several IFC submodels, so we were able to test our procedure to gamify models represented according to the recommendation IFC (Fig 2) so that also the metadata can be input to the gamified model [5].The main goal was to be able to use open software. For that reason we ended up to use the IfcConvert software from the IfcOpenShell library to convert IFC files into mesh models supported by game engines. Among the formats of mesh model formats we selected the OBJ format. We had a need to optimize and radically reduce the amount of polygons approximating the surfaces, especially related to pipes. To do this we chose the open MeshLab software that has excellent support for the OBJ format. We also used the IfcConvert to create XML files from IFC and to bring the metadata of the models together with the 3D model into the game engine [7], [8].

With the aid of the gamified Information Model we piloted the usage of FDM to different simulation targets. The first target was the emergency evacuation with an AI navigation control used in a Unity game environment [13]. We placed profiled or individually parametrized avatars randomly inside the supermarket and then commanded the avatars to proceed to the closest emergency exit with the aid of the AI engine.

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

The second simulation target was a loading area outside of the supermarket. There trucks with whole trailers should be able to operate efficiently and safely.

In the third pilot we tested the planning of the placement of industrial robots and other objects in a production facility so that the gamified objects with colliders enabled to optimally plan the functionality and the safety of the space.

In the fourth pilot we tested the FDM for buildings in a situation when we wanted to ensure that a certain object is able to reach target objects with their manipulators. We aimed to place storage shelves to a supermarket so that a forklift could flexibly operate in between the shelves and could also reach the shelves well enough and safely. We now describe more closely the pilots and present the main results and conclusions.

Both Information Technology and Construction Engineering students attended to the piloting actions. According to our observations the pilots were useful as aids of design and visualizing, but also offered an excellent learning environment to the students of both Information Technology and Construction Engineering. During the system and software development phase the prototype system and its components were parts of the learning environment. Later the integrated software applications were parts of the learning environment. During the piloting actions the students of different disciplines learned how to interact and co-operate with graduated professionals, and also among the students. They learned to combine knowhow from different sectors and appreciate skills from other attending educational disciplines.

3.1 In the first pilot we simulate an emergency evacuation from a supermarket by utilizing AI and using the FDM

We dimensioned the spatial needs of different kinds of people who either used aids to enhance mobility, or walked without extra gear. With FDM we generated the 3D spatial objects representing spatial needs for actions. The description of the cases for avatars can be seen in the following table.

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

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 an avatar prototype that has colliders corresponding to the table. In this pilot the characteristics of the colliders were specified on a relatively common level. We felt that this accuracy is adequate from the piloting of simulation method point of view. The avatar profiles could well be much more individual and more different types of avatars representing different customers of the supermarket could be created.

For accurate and realistic simulations corresponding to real situations it is necessary to increase both the number of variables and to increase the number of movement functions that have a partially random outcome. The number of simulation drives should be high when we want to apply statistical methods to the outcomes of the individual simulation drives. The results of the statistical studies would show how well the supermarket supports safety and show hints how to further increase safety by design. Different building designs could be simulated and compared. After iterating with different designs it is possible to reach the functionality requirements.

In our piloting we were mainly interested in the feasibility of the FDM in this kind of dimensioning and simulations. We used in our pilots some randomness in the collisions in between different objects to increase realism.

The piloting was performed by using the Unity game engine and the C# programming language. We added a simulation extension to the gamified Information Model of the supermarket. The simulation extension creates a predefined number of avatars with different characteristic profiles. In the beginning of the simulation the avatars are located at their initial locations around the floor area, derived from random values of parameters. The characteristics for different types of avatars are in the table above (Table I).

In the simulation we used the Navigation tools of Unity, based on AI. With the tool we could create a navigation map situated on the floor level of the supermarket. More generally, the map could include any stationary objects of the gaming world. With the aid of the navigation map an avatar can now be commanded to progress to the needed target area so that the AI tool steers the movement of the avatar. The events during the navigation phase can be controlled by numerous different navigation parameters. Among the features that can be controlled are the maximum physical difficulty level of obstacles that can be over- or sidewise passed, and the intensity of effort in movement [10].

We realized the simulation in a way that the customer avatars with spatial needs according to their profiles are moving and directed by the AI towards emergency exits. The situation can be monitored by virtual cameras situated in the gamified Information Model. Each of the avatars are also carrying their own cameras that can be switched on when necessary.

The development of the situation can now be monitored from all angles. With the simulation application developed You can quickly control e.g. the number of customers, randomness of events and navigation parameters. It is also possible to change and define quickly the target-objects that are the destinations of the avatars.

The avatar game objects that represent supermarket customers and are used in the simulation can in principle look like whatever the artist decides, but we increased the realism of the simulation by creating 3D avatars that look like typical shoppers. We also made them move according to kinetic data from an earlier human motion capturing session with cameras. Their movement looks therefor quite natural.

The realism of the simulation can be enhanced by adding different effects. Here we wanted to simulate a fire in a supermarket and we added a smoke effect to the gamified model. The progress of the fire follows a well known Fire Intensity Curve that is a generalized model about how the fires progress (Fire Intensity against elapsed time) [14]. The following picture (Fig 3) visualizes a generalized Fire Intensity curve that represents the intensity of the fire in majority of cases. In addition, the picture visualizes the phases of the evacuation and parameters used in the case of a supermarket.

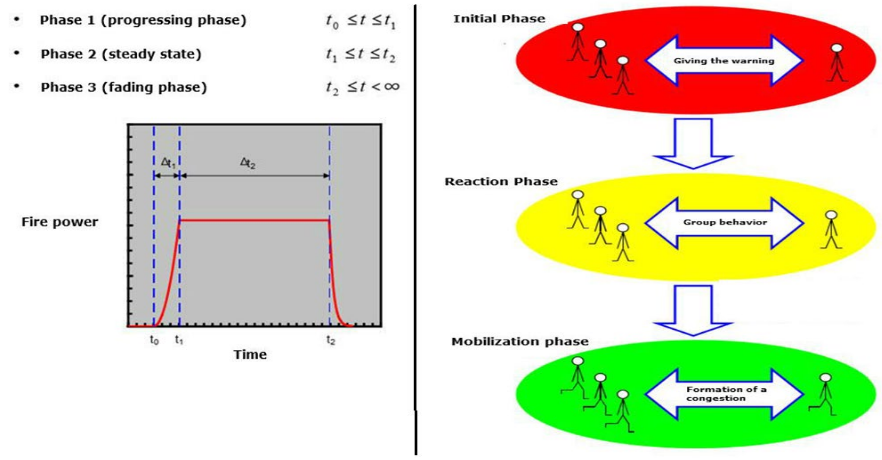

Fig. 2. On the left side a generalized Fire Intensity curve that represents the intensity of the fire in majority of cases. On the right side the phases of an emergency evacuation [14].

The fire develops inside a building usually so that the environment becomes intolerable for humans. The cause can be different poisonous and irritating gases and the heat. Because of the fatal environment one should remove humans from the building as quickly as possible [14].

At the University of Lund the research aimed to find out how long it takes before the environment close to the fire becomes intolerable for humans. Also the VTT Technical Research Centre of Finland Ltd has performed research on the topic. In both research programs the critical factor was found to be the smoke occupying the whole volume of the building. The scattering of the research results is however relatively high [14], [15].

Based on the before mentioned research results we set the critical elapsed time after the start of the fire to 25 minutes with a standard deviation of 8 minutes. We put 500 customers into the supermarket corresponding to the daily rush hour. Our simulation can however adapt easily to a wide range of parameters for each case.

The evacuation of humans from the buildings can be divided into three main phases. The phases are called the preliminary phase, the reaction phase and the mobilization phase. The total time elapsing in the evacuation follows the formula t = t(initial) +t(reaction) + t(mobilization). The durations of these times are naturally very individual, so we need to include random variables related to the behaviour of people to our calculations [16]. The following picture visualizes the phases of the evacuation and parameters used in the case of a supermarket.

We realized the simulation application of an emergency evacuation by utilizing scientific studies mentioned above. We set the parameters of the dangerous situation (here a fire) so that the situation can be divided into the above mentioned phases. It was possible to freely change the durations of the phases. We also designed the customer (avatar) profiles so that there is randomness in the profiles and the process follows the phases of an evacuation [14].

The following picture shows a view from the simulation application on the display during the run of a process performed by the Unity game engine.

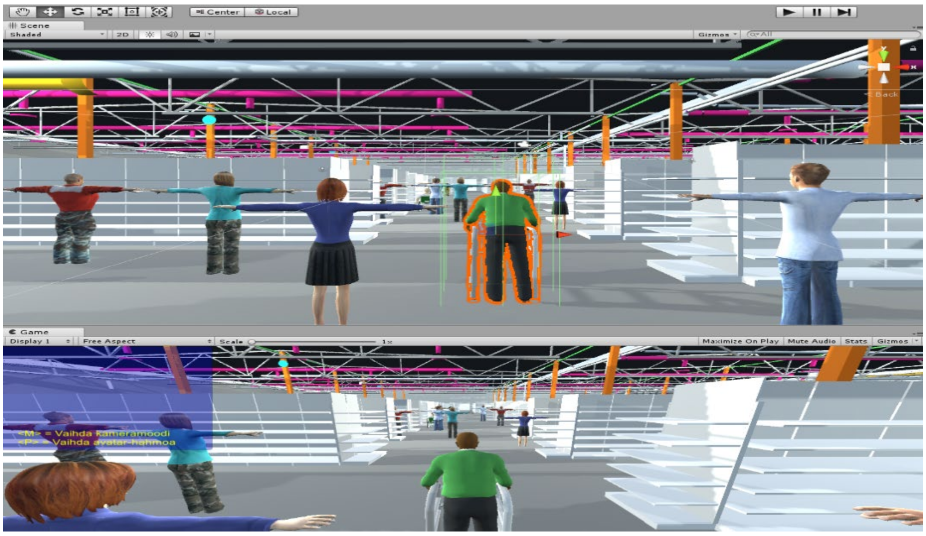

Fig. 3. A simulation application realized with the Unity game engine. A game collider corresponding to the spatial need of an avatar is visible on the picture.

The event that causes the need for evacuation can be parametrized and the seriousness and location can be varied. We can test a situation where a fire restricts access to a certain area and can even prevent to use certain emergency exit.

After the simulation starts the game objects corresponding to profiled supermarket customers begin to move towards the selected emergency exits. The following picture visualizes a situation where the fire simulation is active and the profiled customers are trying to move towards the emergency exits. Their spatial needs and profile settings affect their moving speed and route when they navigate past shelves and other structures, while interacting with the other customers. We can observe how the customers occasionally prevent each other to use the most direct routes.

Fig. 4. The simulation is active and smoke begins to enter the interior of the supermarket. The profiled customers (game objects) are rushing in chaos towards the defined emergency exits under the control of the AI engine (the reaction phase and the mobilization phase).

The structure of the simulation application is such that it saves the movements of the profiled customers to a log file. The applications also recorded for every customer the moment when he moved from a phase to the next. We also recorded to the log the collisions with the other avatars and the moment of time when the customer was able to exit the building. Then the avatar reached the emergency exit that was the target location of the navigation.

The simulation was built so that the profiled customers possessed randomness according to the range found out in the studies [14], [15] and [16] during the initial and reaction phases. The simulation run specific log file generated gave a lot of valuable data about the functioning of the building in an emergency. With the aid of the logs it is e.g. possible to study the success level of different safety increasing measures. The log includes data for e.g. finding out when 90% of the customers have left the building or how much a new exit reduces the time of evacuation and also what the best place for a new exit is.

In the exemplary simulation presented here all of the 500 customers could exit the building in 15 minutes. Over 90% of the customers had exited already in less than 10 minutes from the beginning of the fire. The last ones to exit were the individuals who have long reaction times and who are using aids for reduced mobility. When we made the distance between the shelf units narrower the evacuation times increased significantly especially with high numbers of people. Correspondingly, extra exits shortened the evacuation times, as expected. According to this simulation the supermarket was found to be safe enough in fire situations with the designed types of corridors and exits.

We also tested during the simulations a situation where the cameras are videoing from the point of view of the customers. We gave each customer an own camera enabling us to switch to the view from any of these cameras. It was especially interesting to note how an aged customer using mobility supporting aids and moving slowly suffers from collisions with other customers moving move swiftly. The following picture visualizes the emergency evacuation event from the point of view of e.g. an older customer moving slowly and using a rollator. This fact could also be found from the generated log files. The following picture visualizes the emergency evacuation event from the point of view of e.g. an elderly.

Fig. 5. Simulation showing the point of view of a slowly moving elderly using a rollator.

Finally, we simulated a situation where the viewer is a TPC-type object (Third Person Controller) who tries to exit the building. Also in this case we have a set role and spatial needs that were dimensioned by using the FDM. We conclude that this could be an excellent way to practice doing the emergency evacuation. By using the multiplayer functions of Unity we could simulate situations where several players are practicing emergency evacuation or generally any co-operation with other players.

The following picture visualizes a situation where each of the players of the simulation is moving a profiled avatar that has settable parameters. The players can do different roles like rescue or leading the evacuation operation. In the picture the player has entered the supermarket and encounters there customers who are rushing out. This way we could practice beforehand the actions during emergencies from the point of view of different actor roles.

Fig. 6. A TPC player (Player1) has entered the supermarket after having received an alarm, performs resque and assistance work and encounters customers who are rushing in panic.

The approach of this pilot appeared to be very interesting and relevant. The FDM brought clear added value to the piloting, because the different individual spatial needs could be taken into account in the simulation. According to our industrial partner the principle to combine the simulation of emergency evacuation with the usage of the FDM is a very good idea. We are planning to further develop these methods in our current research project.

The insertion of multiplayer functionality and co-operation of a community into this kind of simulation was especially rewarding. When the Information Model is gamified and we crowdsource the emergency evacuation simulation we could get valuable knowledge and ideas from a large group of people to enhance the accessibility and safety of a supermarket. We plan to develop these methods and tools further in the future.

The simulation of emergency exits increased the knowhow and awareness about safety related matters of buildings both for attending students and the graduated professionals. The realization of the pilot program called for studies of previously published research and applying these results to the environment under development.

This process increased the skills of the personnel in designing safety and especially in this case the knowhow about fire safety when designing buildings. The piloting program also gave excellent new skills in utilizing AI in this kind of applications. The attendants learned to find and include research results as well as different design rules, norms and requirements from standards to the specifications of the software code they produced.

3.2 Dimensioning of a loading area of a supermarket in such a way a truck with full trailer is able to move there safely and with sufficient space

In the second pilot we utilized the Functional Design Method to dimension the loading area so that a truck with a full trailer fits in safely and with space to spare. We used the building object data cards (RT-cards) of Rakennustieto Oy to create the needed 3D spatial objects. This assistive information card library helps to design buildings and infrastructure according to the Finnish regulations. The building object data cards used were from the sublibrary Dimensioning of roads [13]. We would have also been able to dimension the truck with the trailer by measuring the maximum space requirements to x,y and z-directions from video captures.

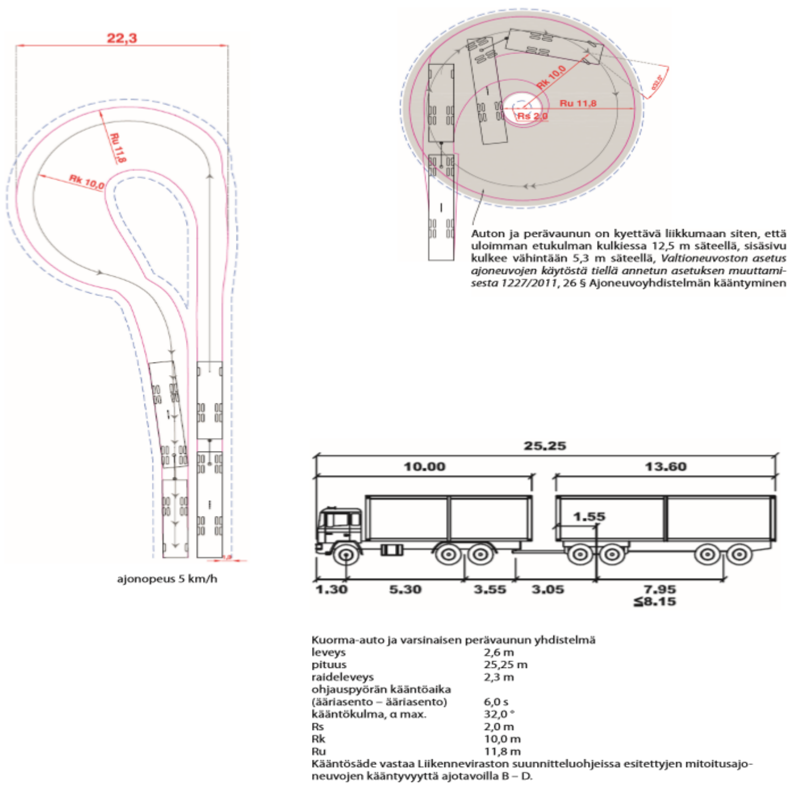

Fig. 7. Dimensions the truck with the trailer [13].

The next picture (Fig. 8) shows how a loading area can be dimensioned with FDM and gamification.

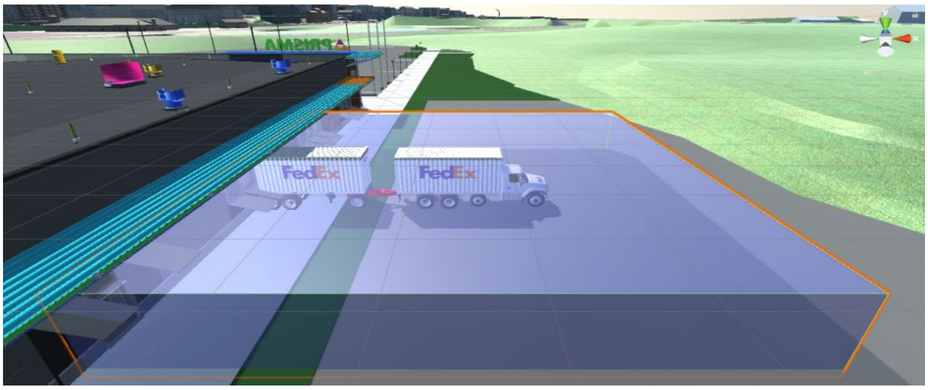

Fig. 8. Testing of the spatial fitting of a truck with a full trailer at a loading area of a supermarket with the aid of a transparent 3D spatial object.

The piloting was successful according to our expectations. We think the FDM brought clear added value to the planning of the loading area and to the comparison of design alternatives. When using our new methods it is possible to have the spaces serve better than before the real functions and procedures performed in the space under design. In this case the target was smooth and safe unloading operations. Our partners agreed that the added value compared to the traditional methods was significant.

The benefits of our methods are wide scope of applications, flexibility and high quality of visualization. A spatial object can be generated out of the actions and movements of any object if the used cameras can capture the whole object, and converted by FDM into a 3D spatial object compatible with IFC files. The method is not limited to whether the moving object is a person or several persons, robots or e.g. a truck with a trailer as in the pilot two. The piloting successfully demonstrates the excellent visualization capabilities. It is possible to increase details by creating a 3D model of a truck that has the Physical Capabilities parameters of the game engine in it. We could then simulate the movement of a realistic truck on the loading area of a supermarket. This piloting program increased the knowledge and understanding of the attendants in dimensioning and in the norms and standards related to dimensioning. We also gained very good practical evidence about the good applicability of the FDM to this kind of tasks. Based on these results it is possible to build e.g. to the Logistics sector game based simulations for virtually practicing steering, driving and loading in reality conforming virtual operation environments of e.g. commercial malls.

3.3 Dimensioning of manufacturing spaces for industrial robots with the maximum spatial need data

The purpose of the third pilot was to test the feasibility of the FDM to dimensioning of manufacturing spaces so that the spatial needs of all the industrial gear are taken into account in the design. We think that this kind of thinking enables to place the functionality on the first priority when designing facilities. Instead of first designing the walls and then trying to fit the actions inside we can now design the spaces according to the needed actions and after that design the walls to safely encompass the needed actions. This increases the fit of the spaces to their purpose, enhances safety and minimizes the material costs.

We think the FDM suits very well to the task of dimensioning the need of space of manufacturing equipment, like robots. The maximum space required by the equipment can be defined and then the gear can be placed to the floor with the safety margins but at the same time minimizing the need of space.

It is possible to make the use of space more efficient and increase safety. In this simulation it is possible to enter the time as the fourth dimension. Then the colliders of objects could touch each other as long as the collisions appear at different moments. There would not be safety issues in this case if the machines are time controlled. The tools and methods also make it possible to use realistic looking models of the manufacturing gear with animations bringing in the spatial needs aspect. In addition to spatial needs we could then simulate also the functionality of the machine and then the whole production.

In this pilot we used the supermarket space model as a factory space model and placed some industrial robots with their spatial movement needs into the hall. We were now able to test the feasibility of the FDM with this kind of spaces. In this pilot we performed the placement of objects and the dimensioning of spaces directly in the Unity game engine. Similarly, the spatial requirements in the IFC format from the FDM process could be the source of 3D data in any of the various CAD design tools, and one could do the dimensioning and the design of spaces there.

The following picture visualizes the situation where a couple of industrial robots has been placed into a hall so that their maximum-reaching game colliders derived from FDM results are not intersecting each other, but all manufacturing gear has space to operate and move simultaneously. The 3D spatial objects shown include the actual visual models and the movement animations making the picture quite real looking. From the view of the spatial design alone this higher level of detail is not necessary.

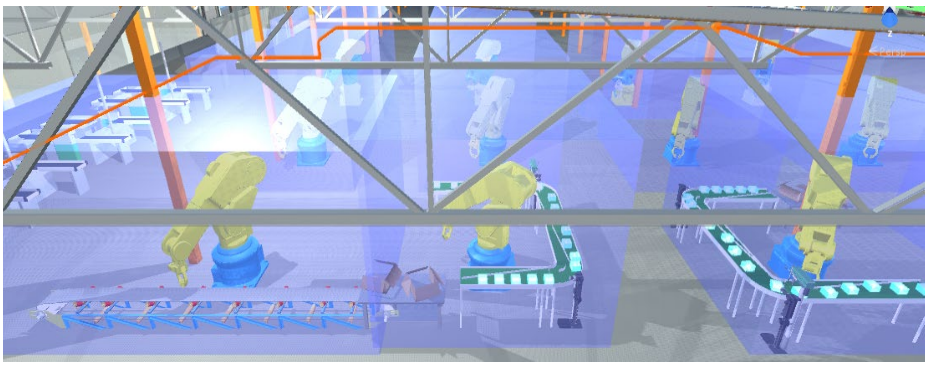

Fig. 9. The production equipment with colliders according to the spatial need objects placed to the gamified Information Model of the manufacturing hall.

Our way to apply the FDM to the dimensioning of manufacturing facilities appeared to be rather feasible. The method and 3D spatial objects bring according to our opinion added value to the design and dimensioning of this kind of spaces. The method suits very well together with gamifation and game engines because the colliders from 3D spatial objects already bring by their definition the possibility to test the fit of the object to the surrounding spaces.

The idea presented in the piloting could be further developed e.g. by introducing workers to the production space in the game engine. The workers could have FPC- (First Person Controller) or TPC – (Third Person Controller)-type characteristics as used in game engines. In this case the player of the game could act as an active production worker in the manufacturing space and we could see the functionality from the efficiency and safety perspectives. The following picture shows a situation where the game application is executing the game and the player in moving among the manufacturing gear. We can now examine the feasibility of the placement plan and e.g. safety.

Fig. 10. The piloting of a game application is under execution and the production gear with game colliders aligning with the real spatial needs is performing its production process.

Further, it would be possible to simulate production by the multiplayer capability and crowdsourcing so that several simultaneous players with different roles are performing their duties together with the production equipment. If the players are actual workers and end users of the spaces we think we could get valuable data about the real user friendliness and real safety of the facility.

We became convinced ourselves that the FDM actually is an excellent tool when designing the spatial needs of machinery in a space and probably also when designing the spaces for human actions. We can address both dimensioning and the simulation of movement of objects. Our partners find the results especially interesting when the original goal of our joint development program was to develop design of buildings with Information Models so that the basis of the design would be the actions taking place in the building under design. We want to design with the customer's actions as the starting point, not the walls or the pre-estimated cubic volume. We will definitely be continuing this kind of research with construction companies.

This piloting research program turned out to be both interesting and skills enhancing. The most of the attendants found the safety issues and dimensioning problems of production lines relatively new to themselves. Alone the studying of the building norms and regulations was very instructive. The simulations gave a very good view about the functionality of production machinery and about why the safe distances and safety zones are needed. The students also came to understand why there are strict design rules for production facilities. Robots operating with humans can move quite unexpectedly and introduce dangerous safety risks.

3.4 Dimensioning of storage shelves so that the forklift reaches them well and safely

In our fourth pilot we studied the feasibility of and applied the FDM to an inverse application compared to avoiding collisions between different objects. So we wanted to ensure that a forklift moving in between shelves can reach all the shelves safely. A good design is essential to the working safety because the forklift can become unstable when lifting heavy cargos high and the forklift can even topple over. We utilized the FDM in the design of the elevations of the shelves, the placement of the shelf units and the width of the corridors so that the forklift can well move in between the shelves and also load and unload objects on the shelves.

In this pilot we used the FDM to design around the forklift an 3D object describing the maximum need of space of the forklift when it operates. In addition we designed a second 3D object. Within the space of the second object a forklift is able to safely lift and unload cargo onto a shelf. The collider related to fitting to the corridors existed simultaneously with the latter collider.

The following picture has been captured from the Unity game engine from a situation where the shelves were placed in such a way that the forklift has sufficient space to move and can also safely reach all the shelves.

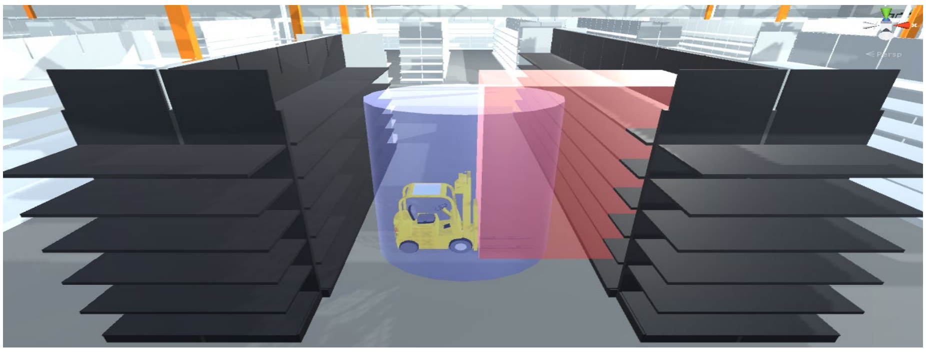

Fig. 11. The forklift has colliders generated by the FDM and they are used to dimension both shelf units and the corridor space in between the shelf units. Blue represents the moving space and red the volume of safe reaching.

We think that the FDM fits excellently also to this kind of reverse dimensioning when the goal is to have an object reach other objects in the Information Model.

Based on the former pilot we could even generate several forklifts that operate simultaneously and would be steered by the AI engine of the game. We realized a quite similar case earlier when we simulated the emergency evacuation. We would be able to observe how well the co-operation of forklifts succeeds. The simulation could be further developed into a training environment for the forklift operators for learning how to act the right way and safely. It is possible to generate a camera view to the storage space from the driver's seat pointing normally forward. It is possible also to utilize VR (Virtual Reality).

On the following picture the player and the forklift occupy the same environment. We could then test and simulate e.g. the smoothness of operations in the storage and safety. Further, when activating multiplayer functionalities we can practice and test operations so that each player has an own role. In such a way we can crowdsource parts of the design work to actual end users and receive valuable knowledge and development proposals.

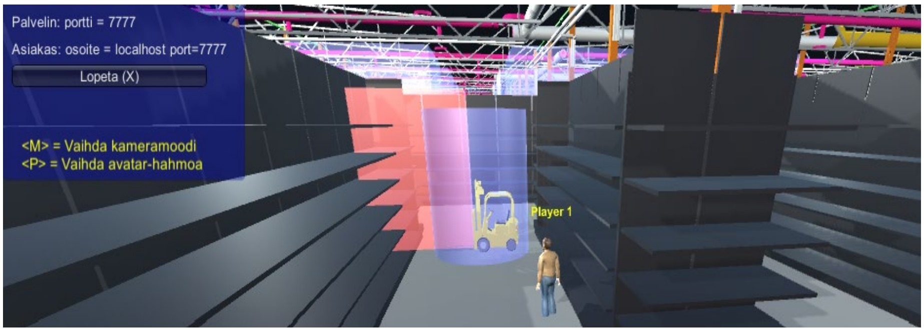

Fig. 12. A forklift with added game colliders and the added reachability region operates in a warehouse and the player of the piloting application exists in the same space.

The results from the pilots awakened interest and new lines of thought also among our partners. By combining results from methods piloted here to the same gamified Information Model we created a comprehensive gamified Information Model that is also a simulation environment capable of testing and simulating the functionality and operations of e.g. a supermarket during different levels of spatial stress and emergencies. In this piloting subproject we were able to test the FDM to two process directions, to dimensioning both adequate spaces and reach. The actors also gained excellent knowledge about designing and dimensioning safe storage facilities. We actually concluded that a further development step should be a learning environment where students of Logistics could became familiar with operating forklifts safely in different reality conforming virtual environments and operations.

4 Results and discussion

The pilots presented strengthened our view that the Functional Design Method VAddD developed earlier is a useful and practical tool for designing buildings and that it is flexible to cover different purposes and application environments. The method suits also to different design challenges of infrastructure and built environment in addition to building design. It helps to perform the designs based on end users' activities in the buildings. The method is also independent on what CAD ecosystem was used to design the first 3D model. The pilots presented belong to our research program for the construction and building industry.

We conducted a small scale interview among our R&D partners related to the research results. We interviewed the industrial contact persons who are either managers or designers from the construction industry. One of the designers interviewed was specialized on game engines and gamification and has an IT background at our partner company.

As a summary from the results of the interviews the usage of BIM, the gamification of Information Models and the Lifecycle Management of the Information Model were seen very welcome and needed development paths for the construction industry. The interviewed also said that the FDM is a very good idea for taking the human actions into account in all kinds of design challenges better than before. All new methods belonging to this category of methods were seen as welcome development. The topics of the piloting actions performed originated partly from our partners so their orientation towards the pilots was positive and enthusiastic from the beginning. They especially thought that the simulation of the emergency evacuation scene was successful and stated that the FDM brings clear added value and new feasibility because You can now profile the users of the building and create individual characteristics and spatial needs to the avatars used. This way the simulation can be made very realistic and the results really bring new data about the building design and its functionality.

The partners of our R&D program think that the FDM for buildings and the pilots utilizing the methods are interesting, bring added value to the design processes and so are definitely worth further studies. Exactly to this direction should the design of buildings according to their opinion be developed in the future.

The piloting program and the interviews related to it show that the Functional Learning Methods combined with multidisciplinary teams provide an excellent learning environment. We observed increased abilities in communications and co-operation during the program. The familiarity and respect of other fields of study increased when the students realized the necessity of the involvement of all professionals. The expertise in the student's own field increased when studying the norms and regulations preceded the problem to find solutions to real life concrete applications. These benefits emerged as results from both our lab observations and post program interviews. The program offered a very good learning environment via the Functional Learning Method to the attendants. The developed software applications themselves also acted as new kind of learning environments. During the program we also created a parametrized multiplayer game development platform using game engines. When utilizing our platform it is now possible to realize corresponding piloting programs relatively swiftly. Because of the platform we can construct virtual reality games to enable the simultaneous operation of several avatars or users in the virtual building. This makes it possible to study and simulate e.g. the co-operation of several avatar workers and the production machinery in a factory or the co-operation of the rescue personnel in a commercial mall.

As the different exemplary cases of the piloting of the FDM show, the 3D spatial objects representing the maximum needed space for actions can be created in several different ways. We can use videos from played actions or corresponding still pictures. It is possible to create them also e.g. based on readily available dimension data of objects, like demonstrated above. The dimensions to the three directions can be recovered either manually or by e.g. applying pattern recognition algorithms. The FDM adapts to all of these methods. It is possible to create nearly an infinite number of 3D spatial objects to describe different actions that should fit the building under design. By using different functional limits in the gamification one can allow certain objects to touch or intersect each other up to a needed level or deny intersections. The designer can allow the needed objects to use the same space when possible. When we add the time as the fourth dimension the same objects can occupy the same space if this is not happening simultaneously. The number of different cases and design challenges that can benefit from these methods is numerous.

5 Conclusions

The pilots presented strengthened our view that the Functional Design Method VAddD developed earlier is a useful and practical tool for designing buildings and that it is flexible to cover different purposes and application environments. The method suits also to different design challenges of infrastructure and built environment in addition to building design. It helps to perform the designs based on end users' activities in the buildings. The method is also independent on what CAD ecosystem was used to design the first 3D model. The pilots presented belong to our research program for the construction and building industry. The partners of our R&D program think that the FDM for buildings and the pilots utilizing the methods are interesting, bring added value to the design processes and so are definitely worth further studies. Exactly to this direction should the design of buildings according to their opinion be developed in the future.

The piloting program and the interviews related to it show that the Functional Learning Methods combined with multidisciplinary teams provide an excellent learning environment for students and professionals. When these presented and piloted analysis cases are combined with further analysis of other actions in the building we have a large number of analysis results from a complete toolset of analysis fulfilling the needs in structural design, simulation, building automation design, training and even lifetime measurement and control during the whole lifecycle. Our vision is to adapt and expand the methods to develop virtual user interfaces or digital twins to buildings for the whole lifetime, beginning from the design phase.

The method we developed can be used both for building design and infrastructure design (like city design). Design can also be crowdsourced and this way the users of the building can fit their process to the spatial design from the early stages of the project.

References

1. An action space defining object for computer aided design. Finnish Patent 125913 , 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.
2. An action space defining object for Computer Aided Design. PCT patent application WO 2014/154942 A1. Applicant Mikkeli University of Applied Sciences Ltd (Selin Jukka).
3. Rossi Markku J., 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.
4. Rakennusliike U.Lipsanen, A Building Information Model of Commercial Center. Saved in the IFC format. Construction Company U.Lipsanen Oy, Pieksämäki, Finland, 2018.
5. Selin Jukka., Rossi Markku J., Simulation of universal design by a functional design method and by Gamification of Building Information Modeling. Computer Science and Information Systems (FedCSIS), 2016 Federated Conference, Gdansk, Poland, 2016. ISBN 178-8-3608-1090-3 and 978-1-5090-0046-3, IEEE.
6. 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.
7. The Open Source BIM Collective. The official website of the IfcOpenShell-project. Accessed on April 15, 2018. http://ifcopenshell.org/.
8. The National Research Council (Cnr). The official website of the MeshLab software. Accessed on April 20, 2018. http://www.meshlab.net/.
9. Unity Inc. The official website of the Unity game engine. Accessed on April 18, 2018. https://www.unity3d.com/.
10. Unity Inc. The official website of Navigation System in Unity. Accessed on April 19, 2018. https://www.unity3d.com/Manual/nav-NavigationSystem.html.
11. Autodesk Inc. The official website of the Autodesk 3DS MAX software. Accessed on April 16, 2018. http://www.autodesk.com/products/3ds-max/overview.
12. Trimble Inc. The official website of the SketchUp software. Accessed on April 16, 2018. https://www.sketchup.com.
13. Rakennustieto Oy. RT-kortisto. RTS 16:12. Ajoväylät, hitaasti liikennöitävät. https://www.rakennustieto.fi/material/attachments/5fIPeDhrH/HMiOkjixB/Ajovaylat_hitaasti_liikennoivat_16_02.pdf. Accessed on April 22, 2018.
14. Paloposki Tuomas, Myllymäki Jukka, Weckman Henry. Teknologian tutkimuskeskus VTT Oy. Julkaisu. http://www.vtt.fi/pdf/tiedotteet/2002/T2181.pdf (ISBN:951–38–6114–7).
15. 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.
16. Weckman, H. Rakennuksista poistumisen laskennallinen arviointi. Espoo: Valtion teknillinen tutkimuskeskus, 1997. 50 s. + liitt. 11 s. (VTT Tiedotteita – Meddelanden – Research Notes 1846.) ISBN 951–38–5133–8 ISSN 1235–060.