



Final report

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Project : Introducing a Building Information Model (BIM)-based process for building permits in Estonia
Created by : Future Insight Group
Rick Klooster, Judith van Deth, Léon van Berlo, Stephan Meijer



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1. Introduction

On May 6th 2019 the project with contract code SRSS/C2019/024 has officially started. The name of the project is: *Introducing a Building Information Model (BIM)-based process for building permits in Estonia*. During a period of six months the contractor Future Insight BV worked on the five deliverables as agreed upon in the contract. This period of time can be characterized as an exciting and fruitful cooperation between SRSS (client), the Estonian Ministry of Economic Affairs and Communications (beneficiary) and Future Insight. This final report is the wrap up for this project and the contract officially ends with it.

In this final report key elements per deliverable are described such as: approach, resources and outcomes (chapter 3). Together with the lessons learned (chapter 5) and recommendations (chapter 6) this will deliver a great summary that can easily be shared with other EU Member States. Before we start with these details we would like to give the reader a short overview of the context. In this first chapter, we will give you a description of the context of this project for the Estonian government, the goal of this project and a profile of Future Insight BV as consultant. In chapter 2 there is a management summary to get a quick overview of the project and the results.

1.1 Developments in Estonia

Estonia is an innovative nation known for its digital ambitions. Thanks to smart e-solutions created here, it takes only a few hours to start up a company and minutes to declare taxes. The nation is in the top countries in Europe in terms of startups per capita and ranks first in the Entrepreneurship Index by the WEF. Because of the very advanced digital ID which can be used to perform all kinds of governmental actions online, the citizens are used to organizing things online.

The Estonian government aims to increase the construction sector productivity times three by 2030, partly via this digitalization. One way to achieve this is to create a national digital infrastructure for construction. This e-construction platform will create the environment for secure and reliable data exchange: 'lossless exchange of standardized and trustworthy data between all stakeholders throughout the building lifecycle'.

The project: *Introducing a BIM-based process for building permits in Estonia* fits in this bigger ambition. How to reach this ambition is visualized in the image on the next page¹: This project will provide the insights, knowledge and communication tools that enable the Estonian government to consciously proceed with the next step on this roadmap.

¹ E-constructing ENG - presentation from kick-off

e-construction high-level roadmap



An overview of the Estonian e-construction program

1.2 The project

BIM is high on the agenda of the European Union as well as on the agenda of Estonian Ministry of Economic Affairs and Communications (EMEAC). The increase of the use of BIM, will enable the digital transformation of the construction sector and the built environment. Across the world the potential of BIM is recognised. When open digital information is shared and collaboration is encouraged by the use of BIM there are a lot of efficiency and compliance improvements possible in the construction sector and built environment.

Earlier experiments of BIM-based Model Checking (BMC) solutions in Norway, the Netherlands and Singapore have identified that digital service can be expected to be faster and cheaper than manual processing. The results indicate that development of an automatic compliance-checking platform will return ten times the investment required. A faster validation of building permits is highlighted to be one of the major needs to solve when implementing BIM in public services.

In Estonia BIM is an integral part of the e-construction strategy to create more efficient public services and provide open access to public data related to the built environment. The Estonian Public Sector Clients BIM Task Group states that a faster validation of permits, "building permit request" and "building use and occupancy permit", is one of the top priorities to be addressed, as this will help implement BIM in organisations and increase efficiency of public services related to construction. In the end this can be a showcase for the whole sector to increase the use of BIM.



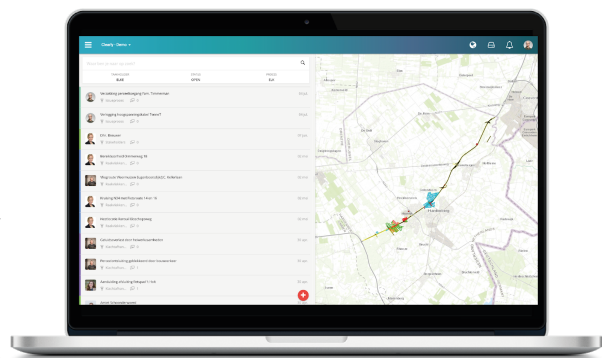
Therefore this project was launched: introduce a BIM-based process for building permits. The general objective of this project is to contribute to institutional, administrative and growth-sustaining structural reforms in Estonia. The specific objective is to support the efforts of the national authorities to define and implement appropriate processes and methodologies by taking into account good practices and lessons learned by other countries in addressing similar situations.

On the longer term the project will increase the use of BIM and construction digitisation in Estonia, which ultimately will lead to the reduction of building lifecycle costs. Also the efficiency and quality of public services related to the building lifecycle will improve. Finally the timeline for obtaining building permits and use of occupancy permits will be improved.

1.3 Future Insight

Future Insight is a successful Dutch scale-up which started in 2014. The founders Bas Hoorn and Rick Klooster were both active in large infrastructural projects and experienced the waste and loss of knowledge and information during these projects.

That is where Future Insight was born with the mission to reduce this waste in projects. By combining areas of work, optimizing working processes and applying high-tech technology Future Insight brings surprising and practical solutions for their clients. They keep an eye on the human factor. It's their experience that in most cases the real challenge is to properly connect to the (future) users and include them in the development process, making sure to build a



Future Insight's Clearly platform

solution that will fit their needs. Because of the belief that this approach is key to success, the staff of Future Insight consists of a highly versatile group of people with very different backgrounds. This way they can always put together a tailor-made project team which is perfectly equipped for the specific challenge.

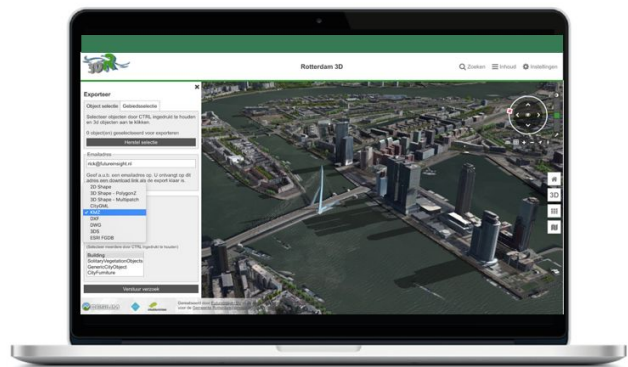
Future Insight develops software on three main products: 'Clearly', 'Clearly.VISi' and '3D Digital Twin'. Two of them are briefly introduced here, since they have the strongest connection to this project.



Clearly: Based on knowledge of the needs within the building sector, Future Insight has developed the Clearly Platform. This is an online collaboration platform where everyone who works on a spatial project can work together and share project information. It consists of a 2D/3D map where spatial information and designs about the project can be shared but most importantly it has an integrated easy to use workflow management module (WFM). The WFM is connected to the 2D/3D map and an integrated Document Management System, linking all project information in a really easy way. Clearly is used more and more by projects in the Netherlands, giving them insight and control over their activities.

3D Digital Twin: Another service Future Insight delivers is the open 3D Digital Twin. Within a digital twin we combine 3D city models with, for example, sensor information and BIM designs. This makes a digital twin a broad tool for authorities to use in the different phases of a project, from planning to completion. By offering it as an easy accessible online service through www.Nederlandin3D.nl it is even easier for organizations to start. Future Insight is one of the most experienced partners regarding this topic. They have a tight collaboration with users and partners across Europe.

Their most important principle regarding 3D Digital Twin is always using open standards and technologies as the basis for solutions. This way insurance can be given that the solutions are flexible and scalable and can easily be reproduced by other customers or countries. At the same time this gives the opportunity to connect with the newest open technologies which are available worldwide. The open design principles have also been adopted by the European H2020 Espresso project, which resulted in an open Smart City framework. A guideline from the EU about how the setup your Smart City infrastructure in a sustainable way.



3D Rotterdam



2. Management summary

In this project the goal was to setup a BIM based model checking Proof of Concept for the Estonian government. To make sure the best technical approach for such a solution was taken, earlier experiences from comparable initiatives from other countries were researched and taken into account. Besides a working Proof of Concept, a user experience design of how such a solution could look like in the Building Registry had to be delivered as well. Both these deliverables aim to visualize the vision of the e-construction platform and to show that it is actually feasible.

In Estonia BIM is an integral part of the e-construction strategy to create more efficient public services and to provide open access to public data related to the built environment. This project is a first step in this strategy and will help implement BIM in organisations and increase efficiency of public services related to construction. On the longer term the project will increase the use of BIM and construction digitisation in Estonia, which ultimately will lead to the reduction of building lifecycle costs. Also the efficiency and quality of public services related to the building lifecycle will improve.

The first step in the project was to research five comparable initiatives from other countries, and to investigate the state of BIM in Estonia. The most important lesson that was learned was that a distinction has to be made between Rule based and Algorithm based model checking. Rule based is the more traditional way of checking which was used by most projects, but is very error prone and dependent on the quality of BIM models supplied. The Algorithm based checking approach is newer and is a reaction to issues arisen from the Rule based approach. It is less depending on high quality BIM models and depends on more complex algorithms. Therefore the advice was given to develop as much as possible on top of the algorithm based checking approach. This improves the productivity of the industry and the quality of the checking result.

For the research of the state of BIM in Estonia an online survey and interviews with key stakeholders were executed. The results show that the BIM maturity in Estonia is quite high and there is a good base for an automated model checking solution. At the same time feedback was given that such an initiative could count on a warm welcome. The only fear stakeholders addressed was that a possible list of additional requirements would be set up which they should meet. This is known as a typical consequence using a Rule based checking approach. The Algorithm based approach aligns perfectly with industry needs to lower the bespoke requirements to the BIM dataset.



The Proof of Concept was built in a full web based environment using open source components, making it really scalable and easily accessible. Through this web interface IFC models can be uploaded after which they are automatically stored in a database and visualised. Nine example checks are automatically run and the results are shown in the interface. Mostly Algorithm based checks have been setup for the Proof of Concept, but some Rule based checks were configured as well, in order to show the difference and illustrate the consequences. In the final checking solution for each new check, a consideration must be made as to how this can be set up as reliably, simply and flexibly as possible.

Finally the user experience designs were made to show how such a BIM based model checking solution could be integrated within the Estonian Building Registry using mockups. This way it is easy to explain to both the permit applicant (eg. architects, project developers) and permit issuers how such a solution could ease their job. During the stakeholder meetings which were organized during the project, we learned that this worked very well. Stakeholders understood the opportunities of the solution very well and were very enthusiastic.



3. General overview

As said in the introduction of this final report this project can be characterized as an exciting and fruitful cooperation between SRSS, the Estonian Ministry of Economic Affairs and Communications and Future Insight BV. The challenge for this project was ambitious and over time we could specify the deliverables to be of even greater value. According to the contract an Inception report, a Technical report, a UX design and a Proof of Concept should be delivered. All these tasks were executed in close collaboration with the beneficiary resulting in very ambitious outcomes. This could only be done because of the enthusiastic partnership within the project team. This brought, within the given time frame, great results.

3.1 Inception report (deliverable 1)

Approach

March 2019 Future Insight was approached and asked by SRSS to submit a proposal on the 'Tender Introducing a Building Information Model (BIM)-based process for building permits in Estonia'. The proposal was submitted on March 25th and on April 18th assigned to Future Insight. On May 3rd all contracts were signed and accepted, this date marks the official start of this project.

The kick off of this project took place on May 17th. This kick off was an important moment for all project members involved (SRSS, Estonia and Future Insight). It gave everyone involved in the project the opportunity to go into depth on the wishes and demands for this project. Of course, the outlines of this project had already been mentioned in the Tender documents, but they were drafted a few months earlier. In the meantime the Estonian Government had made progress on the bigger program and could specify better what their needs for this project were.

With this new knowledge and fresh insights, Future Insight was able to draft a custom made inception report. Before finalizing this inception report, the draft was shared on the shared folder. This way both the project team of Estonia and the SRSS team were directly involved in the details for finalizing the inception report.

Resources

The resources that were used for drafting the inception report are as follows:

- SRSS tender specifications c2019;024
- Offer SRSS/C2019/024 of Future Insight
- Presentation of the Estonian Ministry of Economic affairs and communications
- Minutes of the kick off meeting



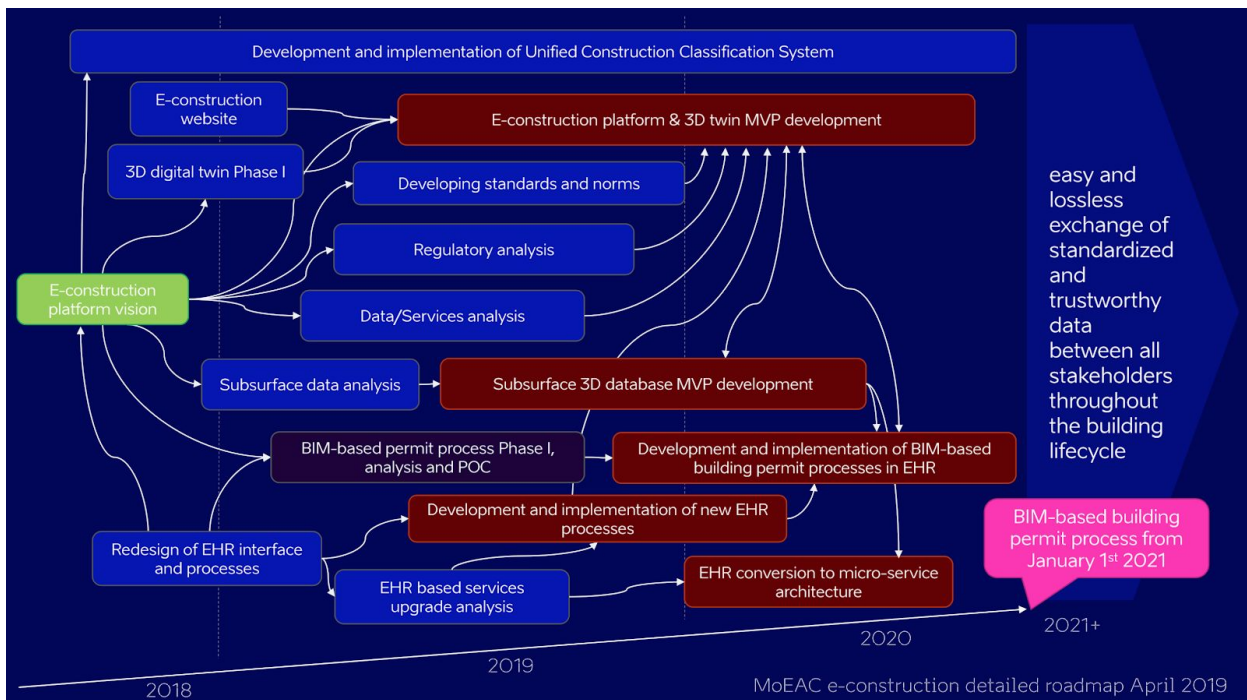
Outcomes

The inception report gives a summary of the updated approach and agreed way of working during this project.

3.2 Technical report (deliverable 2)

Approach

During the kick-off it was explained that the focus of the technical report and the project should be on the future. Looking back is important to get a clear understanding of where we stand today, but foremost we should look forward. This project is part of a larger program which aims at completely digitizing the e-construction industry within Estonia, as explained earlier in chapter 1. During the kick-off this larger program was further explained in detail via the image below. This showed the relations and impact of this project related to other projects of the program and the program as a whole. The BIM-based building permit process is an important part within the program, therefore it is worthwhile to invest in a solid foundation for this solution.



The schedule of the Estonian e-construction program

The technical report describes the most feasible technical solution for developing a BIM-based process for building permits in Estonia. As part of the technical report the following methods and tools were used:

- Analysis of existing technical BMC solutions
- BIM Quickscan®: to get a better understanding on the state of the BIM usage in Estonia and the ambitions a BIM Quickscan® has been sent out to a select group of



relevant stakeholders. These invitations were sent in consultation with the national governmental body.

- BIM Analytics tool: for a selection of users that already had experience with the use of the open BIM data standard IFC, we executed an additional analysis: the 'BIM Analytics' tool. In this tool they uploaded their IFC data and we evaluated the quality of that data. This gave us insight into their BIM models and which modelchecks were feasible to incorporate in the PoC.

Based upon the results of the analysis, the BIM Quickscan® and the BIM Analytics tool a proposal was given of the most feasible technical options for developing a BIM-based Model Checking solution within the Estonian context. For this proposal we also took into account the minimal requirements which had to be set for delivered BIM models in relation to the current situation in Estonia based on the results from the BIM Quickscan.

Also more details of the what and the how in regards to the two processes 'building permit request' and 'building use and occupancy permit' were gathered. This way a proposal could be made about linking the BIM-based Model Checking solution with these processes.

Finally, a consultative stakeholder meeting was organized on the 11th of July, to ensure that all needs were taken into account and we all had a belief that we continued working with the best feasible technical solution.

Resources

Especially the PWC report² which describes the optimization of the EHR (Ehitisregister / Estonian Building Registry) and the EHR prototype which was setup gave a good impression on the chosen path. Based on the information we could extract from the PWC report, the Building Registry (EHR) prototype, Annex I from the tender specification and the overviews created during the graduation research by a student from Tallinn University we got a better understanding of the checks currently executed for building permits.

1. The first thing which was organized was the BIM quickscan analyses. An extensive questionnaire was sent to around 50 people from the BIM industry in Estonia.
2. In total 15 BIM Quickscans have been filled out by 15 different users. The 15 quickscans covered 12 different companies. The Quickscan measures Chapters and Aspects. The Quickscans have been filled in between June 4th and June 20th.

² "Mapping, optimizing, and adjusting for the introduction of e-construction of the procedures of the Register of Buildings", report by AS PricewaterhouseCoopers Advisors, 11 March 2019



3. In total four participants provided seven projects with a total of 40 separate IFC files. Four of these files contained invalid GUIDs. In total 36 files have been analysed. These datasets have been provided by the Estonian users. It has to be noted the data is not from a design phase, as it would be in the case of BIM Based permit checking.
4. For the research, interviews were executed with several people working at different organizations and functions in BIM from Estonia. Most of them also sent the IFC data as preparation which have been analyzed. This gave a good overview of their level of BIM usage and the way BIM works in Estonia. The following interviews were executed:

Organisation	Function
Estonian Ministry of Economic Affairs and Communications	Head of Digital Construction Product owner EHR
Esplan (Architects)	CEO
Novarc group (Architects and Engineers)	BIM Manager
Geospatial.ee (Consultants)	Owner
Nordecon AS (Construction company)	Development manager
Riigi Kinnisvara (Real estate developer)	BIM Manager

Research on state of the art outside Estonia: There were a couple of returning factors in the development of code compliance checking based on BIM:

- Rule based versus algorithm based
- Validity of the input data versus validity of the rules and tools
- Focus on workflow and process support versus focus on automated checking

These factors were related and needed to be looked at in an integrated approach.

Outcomes

- The execution of the BIM Quicksan, the BIM analysis and the interviews gave good insights in the current state of BIM within Estonia. The level of BIM maturity is quite high and the use of the open IFC standard is quite common. This gives a good basis to build on for a nationwide BIM Based permit checking solution.
- From the interviews and the stakeholder meeting we learned that such an initiative could count on a warm welcome. The main opportunities mentioned here were to speed up the permitting processes and to increase transparency in decision-making. Being able to test designs against the building code yourself in advance of the formal permit application was also found a great



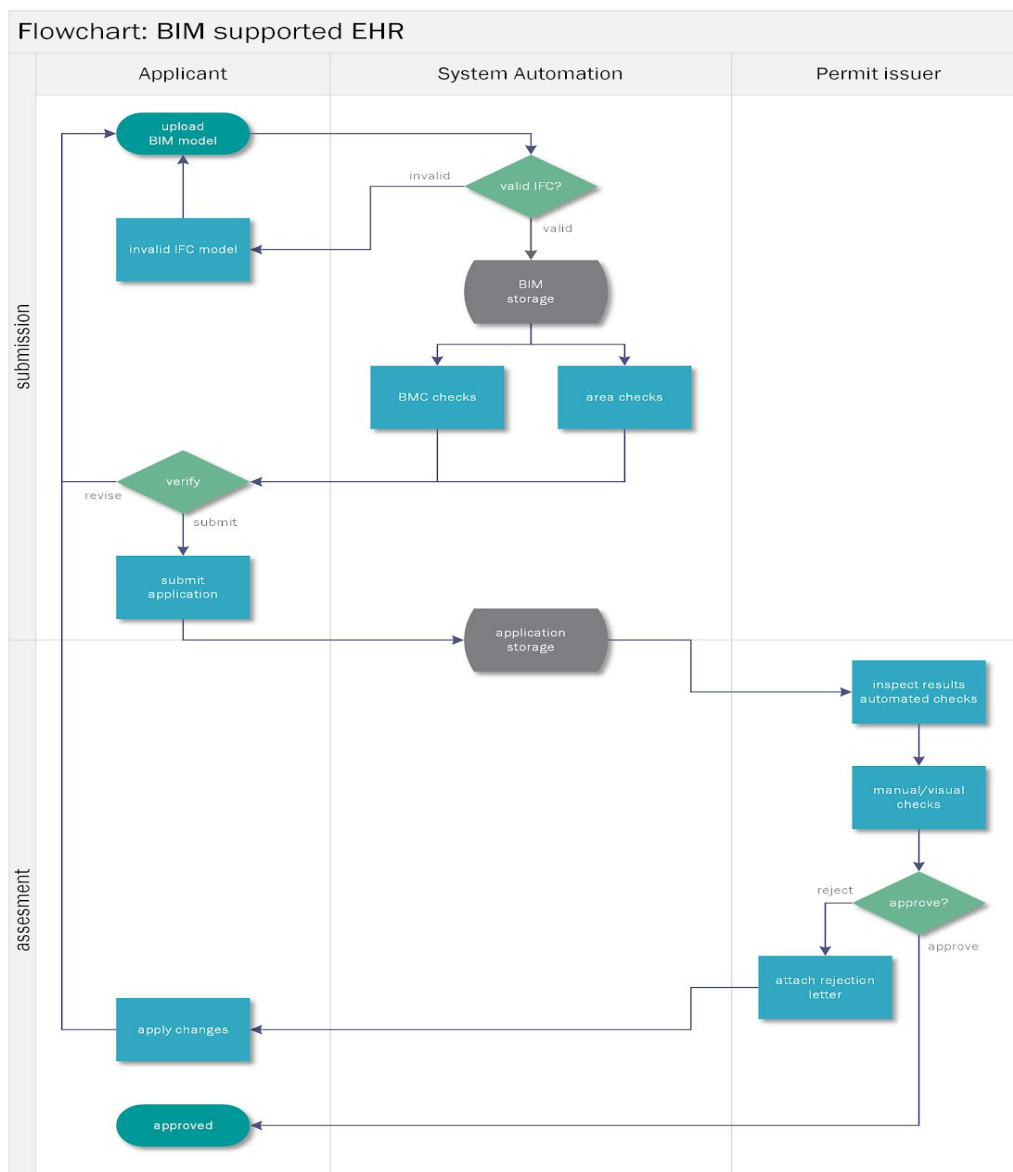
added value. Hereby it was assumed that the service would be available online and that the results could easily be used in own design software.

- Make sure to minimize the additional requirements to be added to the BIM files necessary for official submission. This has been a weak spot in earlier BMC initiatives and the most mentioned risk by the stakeholders. When the extra work to prepare the BIM files exceeds the potential time savings would defeat the purpose. An algorithm based checking approach which is less relying on added values from the BIM files is a good countermeasure for this risk.
- A distinction can be made between BMC (Building based Modeling Checks) and Area checks. For the BMC it is necessary to have the BIM design in IFC and specify rules that needs to be checked, for example from the building code. Another kind of check which is important is the 'Area' check. This check needs different technology components since it checks the BIM design in relation to the area it is placed in and therefore needs information about the area from the 3D Digital Twin. For example a 3D zoning plan or allowed noise barriers.
- Traditionally usually a Rule based checking approach is used for BIM based model checking. In this approach manually added values from the BIM file are used to check if they meet the requirements. Besides that it is a lot of work to add all these additional values, the results of the checks are also very error prone. Actually all these added values should first be manually checked before the automatic checks are executed, because otherwise the checks can easily be bypassed. Experience also teaches that most of the time it is very difficult for submitters to add all these additional values in a proper way, resulting in corrupt files which won't pass the checks.

Therefore we advise to use an algorithm based checking approach. This means a smarter algorithm, which is less dependent on values from the BIM model, is used. This will result in more reliable outcomes of the checks and less additional time spent on adding extra values to the BIM files. This approach was warmly received by the stakeholders who visited the consultative stakeholder meeting. In the Proof of Concept example checks for both the rule based as the algorithm based checks were configured.



- The overall workflow of the BIM based checking solution within the EHR should be like the scheme on the next page. Both the permit applicant and the issuer should be able to access the solution from within the EHR. The UX design from deliverable 3 has been used to visualize how this could actually look like.



The workflow in EHR to be visualised in the UX design

- The proposed solution was to create an online web service for users to upload IFC data. This online service should perform a Code compliance check and return results to the user. The solution is strongly relying on buildingSMART open standards for data (IFC), results (BCF) and API (openCDE API).





Cost/benefit analysis

One of the questions from the contract was to give some insights on the potential savings based on the BMC projects from other countries. Unfortunately these researched BMC solutions mainly focussed on the technical development of the solution and didn't give reusable cost / benefit analysis that could be used for Estonia. To nevertheless give an impression of the potential savings we have setup a custom calculation for Estonia. Typically there are three kinds of savings. First, the time saved handling the submission by the government. Second the time saved with the design and construction on the contractor side. And finally there is of course the decrease of design flaws in relation to the regulations which will be detected earlier instead of revealing themselves during realisation.

1. The first potential saving is estimated based on the average time spent submitting permits in Estonia. These averages were supplied by the city of Tallinn, the largest city in Estonia and extrapolated for the whole country. Based on a percentage saved time of **55%** and an average hourly wage of **€ 11** in Estonia the potential savings **per year** are **€ 537.826** for the building and usage permit. For the calculation of the estimated savings for the simple buildings we have (based on our experience) used a lower savings percentage (**25%**) than for the complex buildings (**80%**) since the automatic checks will be much more helpful for the complex buildings.

	Average time spent (hr)	Average time saved (hr)	Average € saved per permit	# of permits Estonia	€ saved per year Estonia
Building permit				6377	€292.066,00
Simple Building	7.3	1.1	€11,00	3316	€36.375,10
Complex Building	17.3	8	€83,50	3061	€255.690,90
Usage permit				5425	€245.760,50
Simple Building	7.4	1.1	€11,20	3107	€34.785,70
Complex Building	18.9	8.8	€91,00	2318	€210.974,80
Total saving					€537.826,50

Since there are no real world savings percentages available we have used a (from our experience limited) percentage of 55% for the calculation. Based on the interviews and the stakeholder consultation we believe that in the end the savings could be much higher. Also this calculation only takes into account the building and usage permit. There are probably more permits or processes which can benefit from the automated BMC solution.

Regarding the costs to setup such an BIM-based permit checking solution the Estonian government currently has a budget of € 400.000 available. This should be sufficient to setup the basic infrastructure based on the open source components used and the first checks. Assuming that other required parts of the ecosystem, like



the redevelopment of the EHR, the 3D Digital Twin and the digitization of regulation have been deployed well connected to this project.

2. The second potential savings of a BMC solution are on the business side. Project developers and architects will benefit. Currently a lot of rules and regulations are not completely clear, differ per area or are depending on explanation by government officials. Because regulations will be much more clear and easier to check this results will be much more predictable. Developers and architects can even check against regulations online themselves giving immediate feedback.. This way it will cost less time to have the designs meet the regulations also resulting in a shorter permit processes. It is difficult to really quantify these savings because the average time spent is not available. Nevertheless, it is clear that the time spent on the development and designing process is much more than handling the permits. Sending back and forth designs and adjusting them cost a lot of time. By having immediate objective feedback on the checks this process can be much more predictable and effective. Therefore it is safe to say that this potential saving is a multitude of the permit handling savings. This is also reflected by the enthusiastic reaction of the stakeholders present during the consultation meetings and during the interviews.

3. Another potential saving which is definitely valid is the decrease of design flaws in relation to the regulations which will be detected earlier instead of revealing themselves during realisation. Since these cases are currently not registered it is also not possible to make a real estimation about the potential savings. Currently tough a lot of more detailed possible checks are not executed, since the in depth knowledge is not available within the governmental organizations. Instead a check is being executed if submitting organizations have the right quality marks and followed the right guidelines. Based on these facts the assumption is made that the design should meet certain detailed requirements. When this kind of checks will be available, more design flaws will be detected earlier in the process instead of later by an overseer resulting in ad-hoc changes.



3.3 UX Interaction design (deliverable 3)

Approach

The UX interaction flows should give a good idea of how an automated BIM validation tool could be integrated in the Estonian Building Registry (EHR) and e-construction platform. This should also help the future developers of the EHR how to set up for example the building- and usage permits processes including the automated BIM checking functionality.

The resulting flowchart from the Technical report (deliverable 2) has been translated to mockups for various user screens. The good thing about this chart is that it's a generic approach to how both a permit applicant and a permit issuer can work in the same system. This workflow can be used for all processes using the BIM based model checking functionality.

Resources

The mock ups for the UX interaction designs have been created in Figma. Figma is a collaborative interface design tool. Figma enabled our project team to work on the mockups and give contextual feedback at the same time.

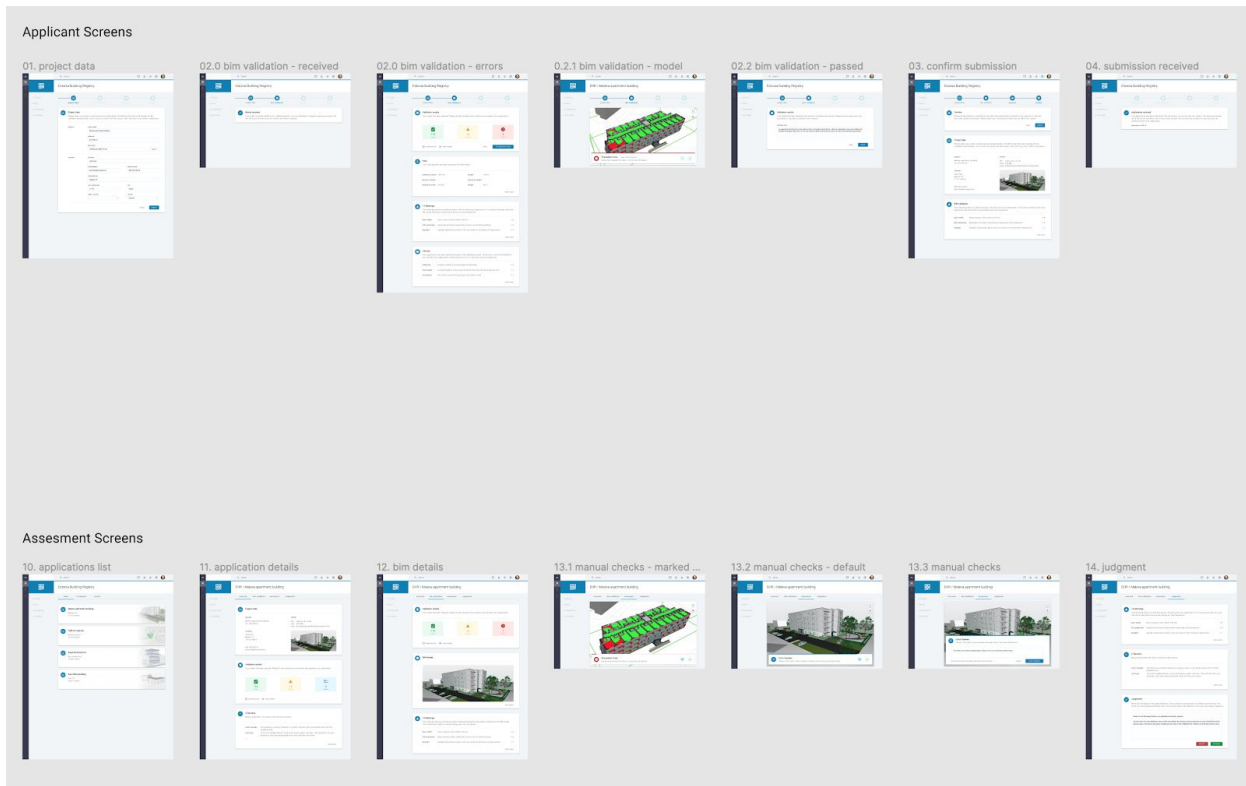
The CTO of Future Insight created the mockups based on his experience in developing various applications and collaboration platforms. The main elements of creating user friendly applications are, according to the CTO:

- Less is more: only add an element when it is needed
- Use recognizable colours and symbols
- Build a page in compartments, order the compartments in a logical way
- Make the process work, don't work on the process

Outcomes

Based on the flowchart and the designs in Figma, a total of 14 screens have been designed. Seven screens for the applicant and seven screens for the permit issuer. The screen of the payment process has not been added, because this already exists in the EHR design.

Instead of two separate workflows for each permit, one generic and easy to use workflow is designed. This way it has been simplified for the user, because it can be used for the execution of multiple processes, for example the Building permit process and the Usage permit process. Depending on the necessary checks within a permit process, more or less checking results will popup, yet the interface will remain the same. The designs have been delivered both as static PDF and online in Figma, as an interactive environment.



<https://www.figma.com/file/ZUo3HJeYto1LVXRuOiXmTg/estonia>

3.4 Proof of Concept (deliverable 4)

3.4.1 Approach

The Proof of Concept was built to actually show the function of an automated BIM-validation check. It was used to get a better understanding of the algorithms but also as a communication tool for creating support with key stakeholders.

The goal of the Proof of Concept was to demonstrate how the proposed BMC solution could work. This way, the PoC would be used to show these possibilities and their benefits to stakeholders and thus building support among them.

Since the size of the project was limited, it was important to keep the scope of the Proof of Concept focussed on demonstrating that the concept of an automatic BIM based checking solution is realistic. During the project plenty of other important topics to be solved were found but not addressed since they fell outside of the scope of the project. Some examples are the necessary link with the 3D Digital Twin, the digitization of required legislation and the development of 3D zoning plans. A lot of these developments are nevertheless already looked after for in the larger e-Construction program of Estonia. The different projects within the program have a tight connection a should be developed in close mutual coherence.



3.4.1.1 System limitations

The Proof of Concept was focused on providing a realistic representation of the algorithm based approach for code compliance checking. At the moment, the system:

- Is only tested/developed on the latest stable release of Google Chrome;
- Is not tested/developed for mobile devices such as phones and tablets;
- Requires a working websocket internet connection. This usually means the URL has to be available without the use of a proxy server (or a proxy server configured to allow websockets);
- Is optimized for 'normal' to larger screen resolutions;
- Requires a working WebGL v2 implementation in Google Chrome. This may require a reasonable video card and up to date graphics drivers. Visit <https://get.webgl.org/> to see whether your system is supported;
- Is scaled for checking some BIM designs. For real use with much more BIM designs the server environment should be scaled up.

We advise to use the proof of concept according to these requirements.

3.4.1.2 Solution scope

The Proof of Concept had a few objectives:

- show the caveats of rule based checking;
- show the potential of algorithms based checking;
- proof that some technologies (like voxels and other advanced geometry analysis) are capable of providing reliable results for code compliance checking;
- proof that code compliance checking in an online environment can work for realistic IFC datasets.

The following remarks have to be taken into account when evaluating the Proof of Concept:

- Most variables like allowed material, maximum height and maximum length of the evacuation route are fixed within the Proof of Concept checks. In the real future solution these should of course be taken from digitized regulations in some way, for example 3D zoning plans or a digitized building code.
- We mainly focussed on the BIM based model checking, since this was our assignment. During the process with the stakeholders we found that the 'area checks' using a combination of the BIM checks and the 3D Digital Twin are also an important part of the total solution. To show that this is possible we



have implemented a fixed zoning plan check. For the real future solution a real link with the 3D Digital Twin should be setup.

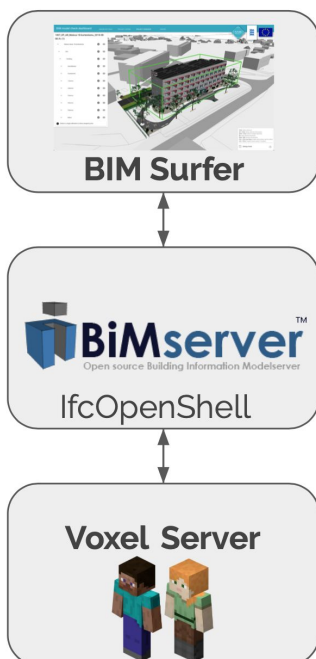
- Currently BIM designs don't have the correct location attached to them. Therefore they are now usually located at 0,0. All BIM designs which are uploaded are now put at the same position and are checked with the same zoning plan. This way it's demonstrated that the design can be checked with a zoning plan. For the real future solution prerequisites for the geolocation or a geolocationing service should be provided.

3.4.2 Resources

3.4.2.1 Architecture

The architecture is setup using open source tools and frameworks. The Proof of Concept is based on the use of open standards like IFC, CityGML and BCF, but also visualisation standards like WebGL 2. On the request from Estonia, the React javascript framework is used. Everything is based on open buildingSMART and W3C guidelines and standards.

When an IFC dataset is checked in, it will be sent to a BIM server instance. After check-in, the geometry is calculated by the IfcOpenShell plugin running inside BIMserver. Results of that are being stored in the BIM server database. The next step is that the geometry is sent to the Voxel server for voxelization and further analyses. Results of the analyses are stored as 'extended data' in BIMserver. Finally the data is streamed back to the GUI for visualisation. 3D information is streamed in binary format to visualise in BIM Surfer. Text data is shown using the React framework which is also used for the implementation of the new Building registry system.



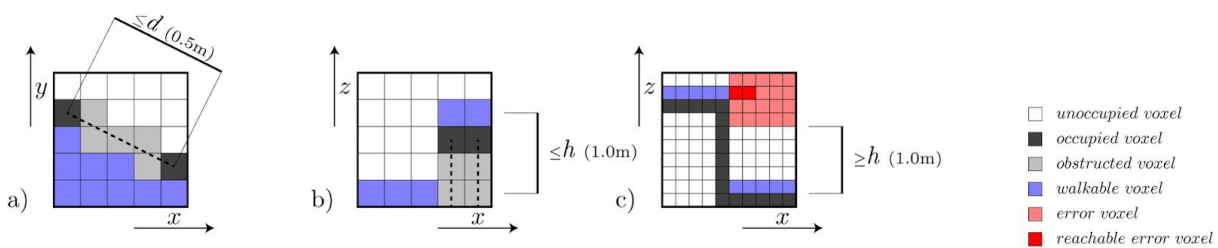
A custom made GUI (Graphical User Interface) is created using the javascript React framework and the open source BIM Surfer V3 WebGL visualisation component. (<https://github.com/opensourceBIM/BIMsurfer>)

We have used an installation of the open source BIMserver.org platform installed with the IfcOpenShell geometry engine inside. (<https://github.com/opensourceBIM/BIMserver>)

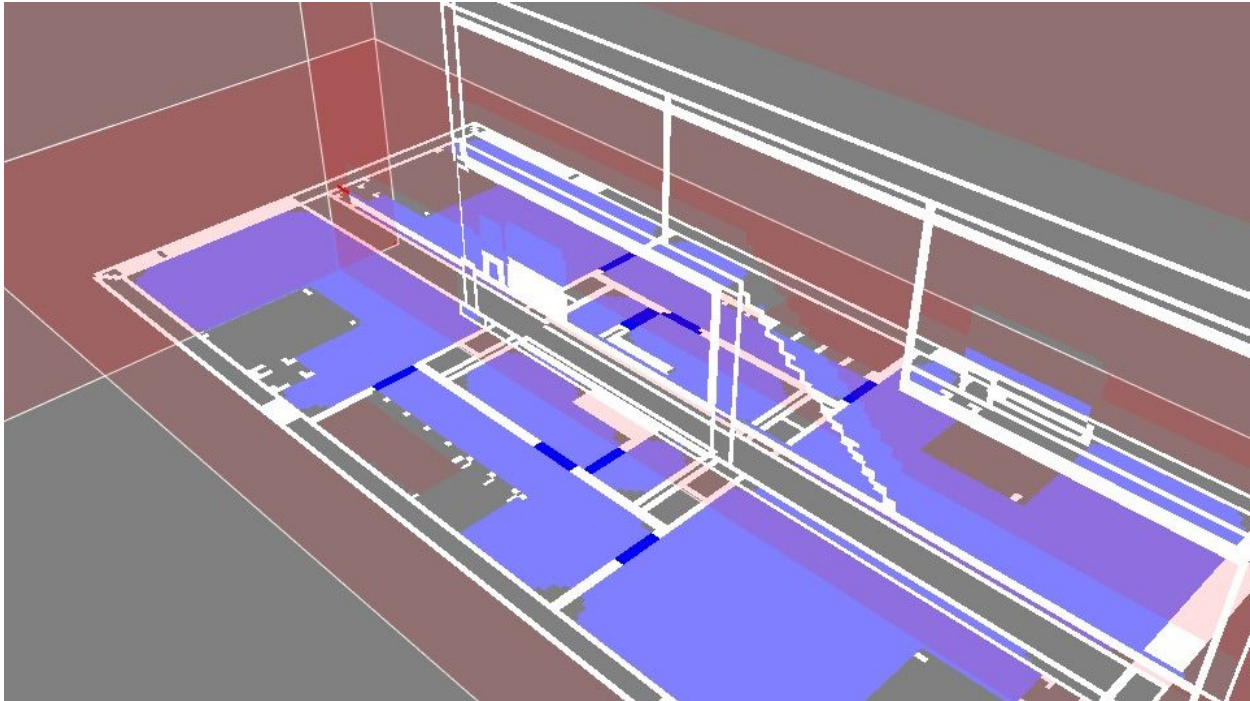
A custom built open source Voxelization server is setup with a Python interface to execute the smart algorithms using 'agents'. (https://github.com/opensourceBIM/voxel_server)

3.4.2.2 Voxels

Safety barriers and evacuation routes are checks that use a voxelized representation of the IFC model. "Voxels" are uniform three-dimensional blocks of space that are calculated from the building element geometries. The advantage of using voxels is that new calculations can be made which are less dependent on information which is already in the 3D model, decreasing the dependency of the quality of the IFC models. Also they make it possible to execute new kind of checks which are not possible using the traditional rule based checking approach like the safety barrier and evacuation route check.



Graphical representation of the propagation algorithm used for the Safety barriers check for both horizontally (a), vertically (b) and the detection of errors in (c)



Voxelized representation of the Duplex model when operating the Safety barriers check. Note how the walkable area is determined starting from the doors (dark blue). As such, height differences between slabs that are not walked upon are not reported

3.4.2.3 Cloud infrastructure

The BIM server checks currently run on a server that is located in Germany. The Voxelization takes place on a server in Brussels. The GUI (user interface) is hosted in the Netherlands. The links between the server in Brussels and Germany are very fast.

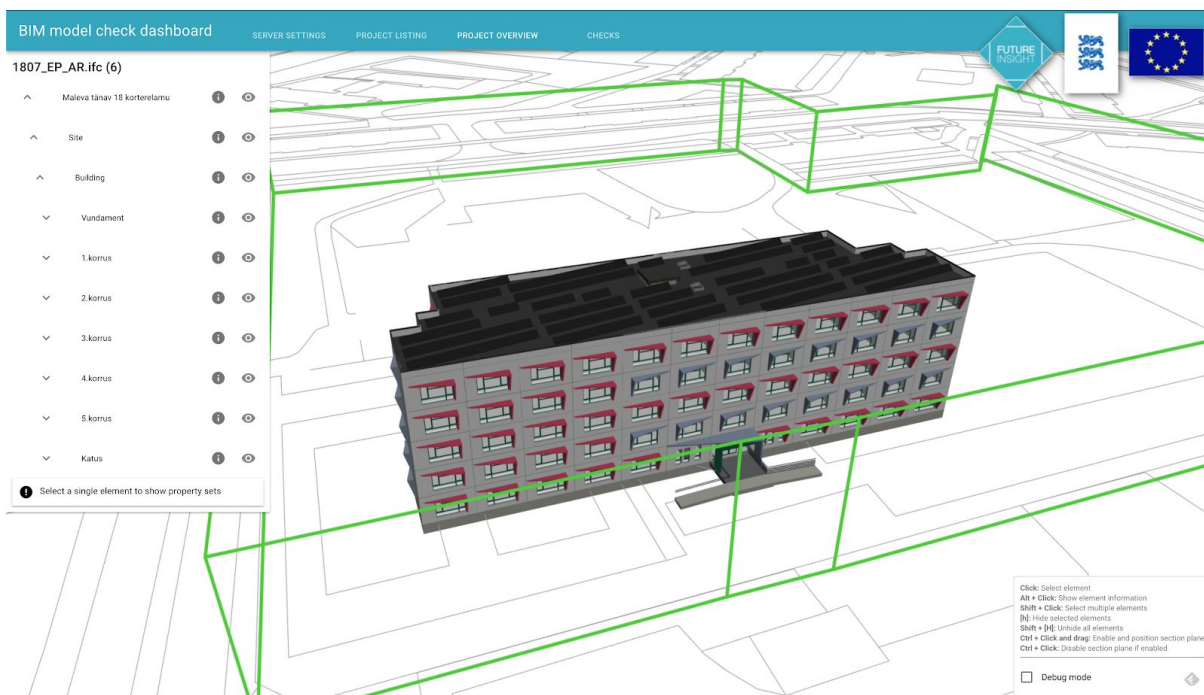
The checks are evaluated separately. Some run on the German BIMserver, some start a new python based process to apply geometrical reasoning in Brussels.

The first time the GUI is loaded into the browser of the user it can take a while since it has to come from the Netherlands. After the first time the javascript is in the cache of the user and performance should be good enough. There might be some latency in the internet connection between Estonia and Germany.

3.4.3 Outcomes

3.4.3.1 The web application

The live Proof of Concept is available through: <http://bimchecks.futureinsight.nl/>. Login information is necessary to access it, which is available at the beneficiary. The solution is operated using the menu in the blue bar in the top of the screen. Usually you work from the left to the right side of the menu:



The graphical user interface of the Proof of Concept



Server Settings:

This screen is used to login to the Proof of Concept using a username and password. The link is used to connect to the right BIM server on the backend. Depending on your role and rights you can add BIM designs to the Proof of Concept.

Project listing

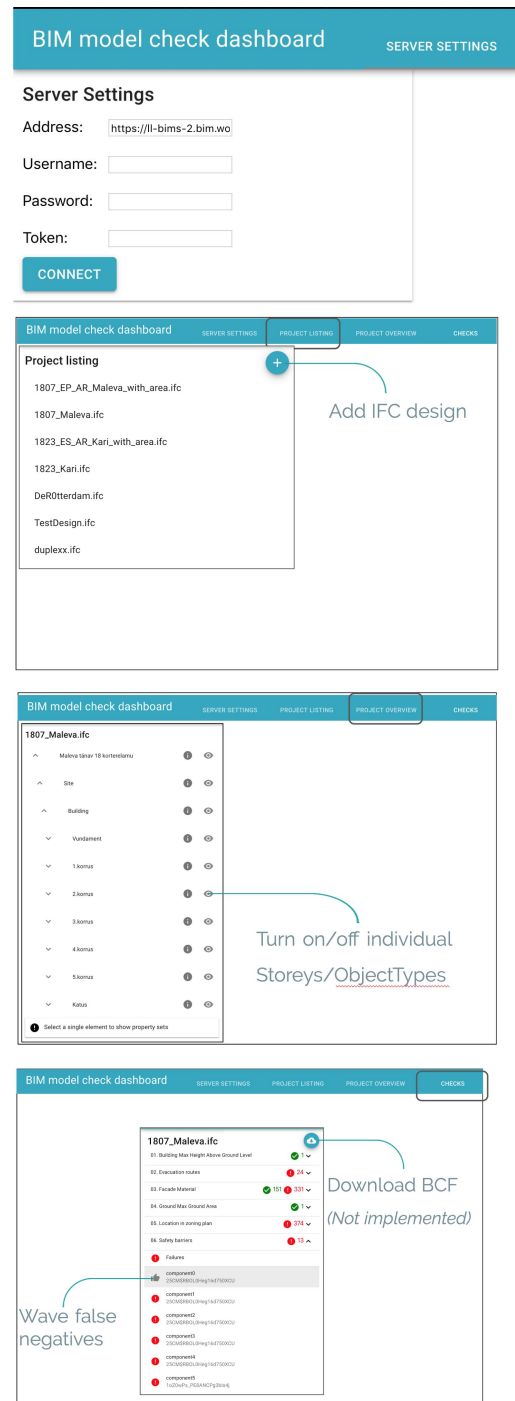
Under the second tab the available BIM projects are shown. A new BIM design can be uploaded here and available BIM project can be selected. Once a project is selected the 'Project overview' tab is automatically opened.

Project overview

In the Project overview a closer look can be taken at the BIM design. Storeys and even individual object types can be turned on and off, to take a good look at the design.

Checks

The rightmost and final tab shows the results of the automatic checks. Each check can be opened and depending on the kind of check it is possible to select a result after which the viewer will zoom in to it.



3.4.3.2 The checks

As described in the technical report a difference can be made between rule- and algorithm based checking. Rule based checking is the most commonly used way of checking but it has some disadvantages. Since this method checks values which are mainly manually added to the model it is very error prone. Also it is very labor intensive since it is a lot of work to add all these additional values. Therefore we advise to use the algorithm based checking approach as much as possible. In this approach smart agent based checks are developed which are not relying on values



but calculate the outcomes themselves, which is much more reliable. Finally, we also use some rule based checks which are based on values which are automatically generated by the authoring tool during the model export process. In our experience these rule base checks are much more reliable than standard rule based checks.

Also we believe that by supplying a BIM based permit checking solution to the stakeholders from the industry, which they can use themselves and see if their BIM design meets the regulations will improve the quality of the data. Since they get direct feedback if a check fails because of a data error, will be a great incentive to do better.

We have developed nine different checks for the Proof of Concept. All of them can be used both for the building permit and the usage permit check with the distinction that for the building permit an 'as designed' BIM model should be uploaded and for the usage permit an 'as built' BIM model should be uploaded.

01. Building maximum height

The maximum height check is an algorithm based check. When an IFC dataset comes into the system it is stored in the BIM server database. After that the geometry is calculated using the IfcOpenShell plugin. This generates explicit triangles for the visualisation of the geometry. These triangles are stored with the IFC objects in the BIM server database.

The check for maximum building height analyses all the resulting explicit triangles and coordinates. When it finds geometry with a z-value (height) of more than 18 meters it will result in an error. When units are in other values then meter it will recalculate.

It is worth noting that this check is only checking height from the 0,0,0 origin. The building can be taller, but only when part of the building is under the ground surface.

This check can be cheated by changing the origin point / ground level of the model and IFC dataset. Therefore it is crucial to have the proper GIS coordinates defined in the IFC model. Errors in the location can then be identified with the help of visualization..

02. Evacuation routes

Evacuation routes are usually not solvable with a rule based approach. Possible evacuation routes are not explicitly modelled in a BIM so these cannot be found in an IFC dataset. For the Proof of Concept we setup an algorithm based check using the voxel server. It 'walks' through the





model and calculates if there are any spots within the building which are more than 30 meters away from a fire safety door wider than 1,2 meters (this is configurable) or the building exterior. For a real world check there will be more variables which need to be taken into account which will have an effect on the maximum length of the evacuation route, such as sprinkler installations.

The weak spot for this check are the values linked to the doors. For example the fire resistance value of the door is manually added, is not always consistently modelled and therefore error prone. The distance calculation is voxel based and not using any semantic values from the model and therefore very reliable. It is guaranteed to check all reachable parts of the building, including parts not covered by explicit IfcSpace elements and follows a realistic route around obstacles.

03.Facade materials

This check is performed by the BIM server plugin. Since a material is a property in IFC it can be checked in a rule based way.

It searches for the property '02 Materjal' in the propertySet 'Architektuur' from all IfcWall and IfcWallStandardcase objects where the property 'isExternal' in 'Pset_WallCommon' is set to 'true'. If the text in that property value contains the term 'Raubetoon' the check will pass. Otherwise the check will fail.

This is a typical example where modelling guidelines need to be followed. When the wrong propertySets are used, the material has a spelling error (or is not filled in correctly), or when the property 'isExternal' is not filled in correctly, the check will result in an unreliable result.

When modellers don't use 'isExternal' the walls materials will not be checked because the system only checks materials for walls that have this property. Not modelling correctly will in that case result in a false positive. This is again an example why the Proof of Concept also presents alternative solutions like Voxels.

When the outer walls will be detected using Voxels, this part of the check will become more reliable. It is intentionally chosen to use explicit properties in this case to present the different approaches.

04.Maximum ground area

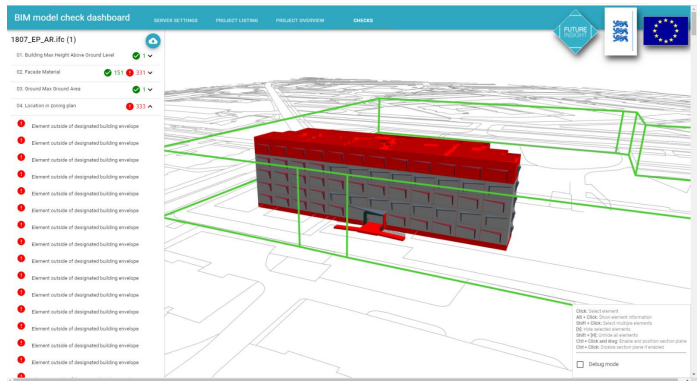
When an IFC dataset comes into the system it is stored in the BIM server database. After that the geometry is calculated using the IfcOpenShell plugin. This generates explicit triangles for the visualisation of the geometry. These triangles are stored with the IFC objects in the BIMserver database.

In this check BIMserver is replacing all the z-values of the geometry to zero. The resulting geometry is a 2D footprint of the building. Overhangs and balconies will also be part of the 2D footprint in this case.

The area of this 2D footprint is calculated and checked if it is smaller than 1000m². When units are defined different the algorithm will recalculate.

05. Location in bounding box

In the Proof of Concept a fixed template zoning plan has been placed at the location. After uploading a BIM dataset, BIMserver checks if all the geometrical data is positioned inside the geometry of the zoning plan. This is done using the explicit geometry calculated by IfcOpenShell. It is therefore not depending on values from the design and algorithm based.



This building is too high for the 3D Zoning plan

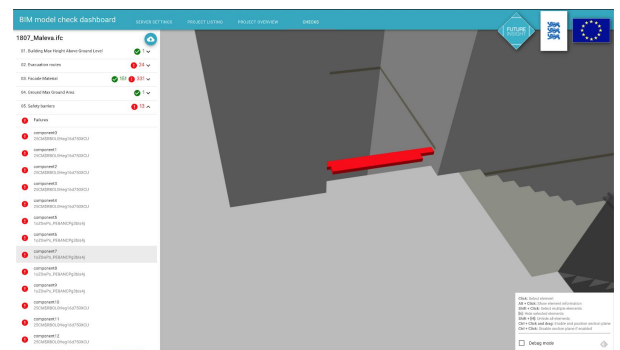
06. Safety barriers; fall protection

In most building codes, there is a check to make sure people cannot fall down. In a rule based approach this is check as 'railings and walls should be at least 1 meter high'. However, this creates a lot of false positives and unreliable results (see the first report of this project for more info).

Therefore we chose to check this in the way it was originally intended: everywhere where a person can fall down more than 1 meter, a decent fall protection should be in place'. In practice this means that there cannot be any place in the BIM dataset where people could fall down more than 1 meter. So this is how we approached this check.

First the geometry of the dataset is transformed to Voxels. After that, an agent based algorithm is used to find the surfaces that people can walk on. every location that has a drop of more than 1 meter is a location where someone can fall down. We also take into account that a person can take steps between 20 and 70 cm (this is defined in most building decrees). As a result the algorithm behaves like a virtual person that walks around at every location it can reach to see if there is a place to fall down.

When the virtual person can find a walkable route to the roof, it will probably fall from the roof. IfcFurniture elements and IfcSite are exceptions.





We don't take into account that people will climb on furniture, and falling of an IfcSite is also not realistic. In the end this provides a very reliable result for places where people can fall more than 1 meter.

Currently the only glitch in the system is that people will fall down elevator shafts and from doors on the ground level. An elevator door is seen as a regular IfcDoor where people can walk through and since there is no real environment yet outside the ground level doors, persons can fall there as well.

07.Spacing minimum door width

This check is performed by the BIMserver plugin. Since the door width is a property in IFC it can be checked in a rule based way. The 'width' property of an IfcDoor is generated by the authoring tool during export. It is not a property that the user can easily change or manually override. In our experience, based on years of data analytics, the width values of IfcDoor are quite reliable.

In the Proof of Concept, a rule based check in BIMserver checks if the door is 990mm or wider. When the width is defined in different units it will recalculate.

08.Maximum storeys above ground

This check is performed by the BIMserver code. Since the IfcBuildingStorey is an entity in IFC it can be checked in a rule based way. The IfcBuildingStorey is generated by the authoring tool during export.

In some software tools users need to make sure they model correctly to have the correct amount of building storeys represented in IFC. For inexperienced users this might result in twice as much building storeys in IFC compared to the actual number of storeys. Some users model the roof as an extra storey. Having wrong IFC in this case will result in a false negative, which only stimulates users to model and export the IFC data in a better way.

In our experience, based on years of data analytics, the IfcBuildingStorey elements in IFC are quite reliable (when modelled correctly).

BIMserver identified the ground surface (0,0,0 coordinates) and starts counting the IfcBuildingStorey elements from there. The number of storeys found must be 6 or less. This check makes sure that storeys under the surface (basements, etc) will not be taken into account for the check.

This check can be cheated by changing the origin point / ground level of the model and IFC dataset.



09.Differences

This check is especially interesting for the usage permit, since it detects the differences between two BIM models, for example an *as designed* and an *as built* model. On the 'Project Overview' tab it's possible to add a revision of the BIM model for the project. Once a revision is uploaded the 'Difference' check is automatically executed. Also with this check we have detected that the structure of the designs differed significantly, making it difficult to make a good comparison. The unique identifiers (GUID's) for different versions of the same design were different. Therefore when we tried to detect the changes almost all objects were changed. This has a to do with the way designers work but also with the export settings to IFC and even the version of the software. Therefore we have only



The added objects in the IFC model

used the geometries and object types to detect the changes which are reported within the viewer..

Besides the open source software components for the infrastructure, code has been created to configure the different checks. This can be found at:

BIM server checks: <https://github.com/opensourceBIM/IfcValidator>

Voxel-based checks: https://github.com/opensourceBIM/voxel_server/



4 Contract

In this chapter an overview is given where or how the results of the expected deliverables and tasks can be found. This is done by the given tasks listed in Annex 1 from the contract. The link to the shared folder that is mentioned in the text below is: https://drive.google.com/drive/u/0/folders/1NkYeHg_5o8CzPCoBB31VBBHxcZNeuNZC

Deliverable 1: Inception Report

In order to produce an Inception Report to guide the implementation of the contract, the contractor is expected to carry out the following tasks:

- Organise, participate and actively contribute to a kick-off meeting upon start of the project, which should take place at the premises of the Estonian authorities.
 - This was done on May 17th 2019. The report of this meeting can be found in the shared folder.
- Organise any consultative meetings that may be needed to prepare for a successful kick-off meeting or to clarify the information delivered during the kick-off meeting.
 - This was done via a conference call on May 10th 2019. The report of this conference call can be found in the shared folder.
- Prior to the kick-off meeting, the contractor shall draft and circulate a detailed agenda to the SRSS and the Estonian authorities. The main purpose of the kick-off meeting will be to discuss and finalise the approach taken for each activity, establishing possible data and information needs.
 - The relevant agenda was distributed on May 10th 2019.
- The Contractor shall then produce an inception report to take stock of the situation and confirm or adjust the methodology and approach accordingly. The inception report shall include at least the following:
 - A brief account of all meetings held, counterparts and stakeholders met during the inception phase;
 - A project charter outlining the roles and responsibilities of the respective stakeholders;
 - An updated work-plan and timetable with milestones, agreed with the counterpart;
 - An updated detailed description of all deliverables and working methods, agreed with the counterpart;
 - A list of relevant data, documents and other information, reviewed during the inception phase
 - An updated account of possible project risks and remediation approaches.



- A preliminary identification of issues that are to be addressed by the project.
- **The inception report including all elements described above was shared via e-mail on June 6th 2019 and can be found in the shared folder.**

Deliverable 2: Technical Report on possible solutions for automating BMC in the “building permit” and “use and occupancy permit” processes in Estonia

In order to produce the requested deliverable, the contractor is expected to carry out the following tasks:

- Describe and compare at least 5 existing BMC technical solutions (e.g. from Singapore, Norway and Finland) implemented or tested by the public sector in the building permit process;
 - **This is described in the Technical Report in paragraph 2.3**
- Identify the best open formats for model data exchange (e.g. IFC, LandXML etc.) and define their requirements.
 - **This is described in the Technical Report in paragraph 3.1**
- Perform a detailed SWOT analysis on the identified solutions illustrating the possibilities and limitations that each solution poses. The SWOT analysis will cover at least the following aspects:
 - What kind of legal and technical design requirements and in which categories can be automatically checked using BMC?
Answered in paragraph 6.1
 - What is the estimate potential time-saving in the case of automated checks of the 10 requirements with the biggest saving potential as compared with manual checking from PDF plans?
Answered in paragraph 3.2.
 - How and in which format local authorities need to define the requirements (values) so that they can be automatically checked using BMC?
Check recommendations paragraph 6.2 for the answer
 - What are the initial investment costs and regular maintenance and potential licencing costs of the solution?
 - **More details on this business can be found in this document in paragraph 3.2.**
- Propose the most feasible technical option for developing a BIM-based Model Checking within the Estonian context. The most feasible option will be defined in co-design with the representatives of the Ministry of Economic Affairs and Communication.



- The proposal is done in Part C 'Conclusions and recommendations of the Technical Report.
- Design to-be business and technical processes for the "building permit request" and "building use and occupancy permit" processes which could be used by ERB if applying BMC. The design must also include a description of the algorithm used for automating BMC.
 - In the chapter 3.4 of this Final Report a full description of the used software components and the checks is given.
- The currently used as-is processes are described on a high level in Annex A. Related checklists will be made available by the MoEAC by mid-March 2019.
 - In the delivered PWC report these processes were described on a very high level. This was taken into account for the design of the UX designs. It was not detailed enough to use for the BIM checks. Therefore we have jointly picked nine commonly used checks to configure.
- Organise a consultative stakeholder meeting on the premises of the MoEAC to present the detailed analysis and associated recommendations to the stakeholders.
 - This was done on July 11th 2019. The report of this meeting can be found in the shared folder.
- Finalise the analysis taking into account stakeholder feedback and including a short report on the process and content of the stakeholder consultations. This should be part of the technical report, deliverable 2.
 - This was done during the meeting immediately afterwards the stakeholder meeting. The minutes of this meeting can be found in the shared folder. This input is then processed in the final version of the Technical Report.
- The Ministry of Economic Affairs and Communication can facilitate initial contacts between the contractor and the entities which can provide information on the existing technical solutions (both public administrations and software providers). The related research can be conducted as desktop work or via remote communications.
 - The ministry facilitated initial contacts with several professionals from the industry, which was very useful. They participated in the Quicksan and provided BIM models for executing the analytics. Also a large group of interested stakeholders visited the consultative stakeholder meetings.



Deliverable 3: UX interaction flows for permit applicants and permit issuers

In order to increase awareness of the benefits of introducing a BMC based process among the users of the Estonian Building Registry and to illustrate how the user interface of the Estonian Building Registry could look within a BIM Model Checking-based process, the contractor is expected to create user/UX interaction flows for two procedures of the Estonian Building Registry – namely the procedure for the building permit and use and occupancy permit. The UX interaction flows will have to be provided for two user types: the permit applicant and permit issuer (reviewer of permit).

To achieve this, the contractor is expected to carry out the following tasks:

- Create sequenced user interface screenshots (UX interaction flow) of the to-be situation with description for the two processes defined in Deliverable 2 when transformed to a BMC based process.
 - The screenshots can be found via the Figma link: <https://www.figma.com/file/ZUo3HJeYto1VXRuOiXmTg/estonia?node-id=0%3A1> There is one workflow, as the two processes were already combined to one main workflow in Deliverable 2. Also a separate PDF with all the designs has been delivered
- Organise a consultative stakeholder meeting on the premises of the MoEAC to present the UX flows to the Ministry of Economic Affairs and Communication and its key stakeholders for validation.
 - This was done together with presenting the PoC on October 23rd 2019. The report of this meeting can be found in the shared folder.
- Finalise the analysis taking into account stakeholder feedback and including a short report on the process and content of the stakeholder consultations.
 - No feedback was given on the interface screenshots so the draft has become the final version of Deliverable 3.

Deliverable 4: Proof of Concepts of automated BMC for the building permit and use and occupancy permit procedures

In order to provide proof of technical feasibility of the most feasible technical option designed under task 2, the contractor is requested to carry out the tasks listed below:

- Create a Proof of Concept (PoC) of the BMC solution for the building permit procedure using a real BIM model. The purpose of the PoC is to demonstrate the functionality and to verify that the solution proposed in Task 2 can be achieved with development. A real as-designed BIM model will be provided in ifc-format by the MoEAC at the start of the assignment. In the interest of narrowing the scope of the Proof of Concept, only line-item models (such as pipes and roads) will need to be used. An illustration of the real BIM model is provided for information in Annex B.



The PoC must include the following functions:

- Define the required parameters for the BIM model, taking into consideration that in order to issue a building permit it is essential to ensure that the design meets certain technical requirements. For instance, in order to automate the checking of the proposed parameters based on a BIM model, they first have to be described in a way that is machine-readable and can be included in the BIM model (the parameters are to be defined under Deliverable 2);
 - For the PoC we have chosen standard values for the checks. In the final implementation, there will be many more values. Structural sources will need to be defined and developed, from which these values can be taken. (3D Zoning plans, detailed plans, etc)
- Enter required parameter values that are to be checked automatically for the building permit application;
 - Check the description of the checks for the used parameters.
- Submit the application along with the as-designed BIM model (to be provided at the start of the assignment);
 - The as-designed BIM model can be checked in on the 'Project listing' tab of the Proof of Concept.
- Read relevant parameter values from model file (eg. Co-ordinates, dimensions etc);
 - All relevant parameters are automatically taken from the model and saved in the BIM database after uploading.
- Check conformity of the BIM model parameter values using the algorithm described in deliverable 2;
 - All nine different checks are executed with the given parameters as described in paragraph 3.4.3.2
- Visualise the BIM model in a 3D environment on the GIS base map⁴ at the correct location;
 - Once uploaded the BIM model is visualised in the Proof of Concept in a fixed area since the models usually don't have the correct coordinates attached to it.
- Produce a report of the model check results and visualise nonconformities on the 3D model.
 - The results of the checks are reported on the 'Checks' tab of the Proof of Concept.
- Create a PoC of BMC solution for the use and occupancy permit procedure using a real BIM model. A corresponding as-built BIM model will be provided in ifc-format by the MoEAC at the start of the assignment. The PoC must include the following functions:



- The Proof of Concept can be used for both the building permit check as well as the use and occupancy permit check since these are mainly the same checks. Only the differences check is extra for the use and occupancy permit since the as designed and as built models need to be compared.
- Organise a consultative stakeholder meeting on the premises of the MoEAC to present the PoC-s to the Ministry of Economic Affairs and Communication and its key stakeholders for validation. It is noted that the consultative stakeholder meeting could be combined with the stakeholder meeting to be organised before finalising deliverable 3 (see above).
 - This was done together with presenting deliverable 3 on October 23rd 2019. The report of this meeting can be found in the shared folder.
- Finalise the analysis taking into account stakeholder feedback and including a short report on the process and content of the stakeholder consultations.
 - This was done during the meeting immediately afterwards the stakeholder meeting. The minutes of this meeting can be found in the shared folder. This input is then processed in the final version of the PoC.
- After validation, the PoC-s should be made available for testing purposes on premises of the Estonian Building Registry or provided as an on-line service (SaaS solution) for a period of 3 months.
 - The Proof of Concept is available for three months through <http://bimchecks.futureinsight.nl/>. The login credentials are available at the beneficiary.

Deliverable 5: Summary of support activities and key lessons learnt

The contractor is expected to prepare a short separate presentation, using simple and illustrative text (i.e. PowerPoint) with the takeaways from the project that could be useful and relevant for implementing similar initiatives in other EU Member States.

- Deliverable 5 is extended to a complete final report (this document) with all relevant details necessary for a successful follow up and key lessons learned to share.
- Also an extended and a summary presentation of the project have been made available.



5 Lessons learned

Project process	What went well	Points of attention
Project team management	The high level of knowledge and ambition within the project team makes it an optimal setting for collaboration.	In all enthusiasm there is a risk to bite off more than one can chew. Keep it feasible and agile.
Scope management	The creation of the inception report after the informative kick off session was crucial for a clear and focussed scope management.	The agile approach works very good. It keeps the right and realistic focus and provides the necessary flexibility. Make sure new insights are communicated to involved stakeholders.
Time management	The rhythm of 'draft - stakeholder meeting - final version' is a good foundation for realistic time management for all parties involved.	Preparing successful stakeholder meetings costs time. But it has proven to be worth the energy. Keep up organizing the preparation meetings well to make sure it is clear what you want to communicate.
Resource management	EMEAC was very helpful in sharing their network for reaching out to key stakeholders.	It will be an enormous task to setup all the different technology and digital regulations. Make sure to organize all these resources on different levels and fields of expertise.
Communication management	The weekly conference call between the Future Insight and the EMEAC kept the communication accessible and efficient.	Since the program is quite innovative it is very interesting for other countries. Make sure to keep important documentation in English to make the initiative easily accessible for others to join.
Quality management	Because the creation of the deliverables was done in close cooperation with all members of the project team we were able to optimize the quality of the work process and the results.	Specific knowledge (especially used for developing the POC) is so high on expertise that a risk is created for future developments when losing this expertise within a new project team.



6 Recommendations

The successful implementation of this kind of complex technology is quite a challenge. It consists of both organizational and technical challenges and therefore we also make a distinction between organizational and technical recommendations.

6.1 Organizational recommendations

- Take both the permit applicants and the issuers structurally into account when designing the system. They provide crucial input for the successful implementation of the system. Together with them, determine the priorities for the order of the checks to be configured.
- Ultimately, a large number of checks will have to be configured in the system. First, set up the basic system with a number of basic checks and start using this. Increase the number of checks step by step in close cooperation with the applicants and the permit issuers. This way they can get used to the system and support is created. Also, much feedback about the operation of the system and the priorities for the checks to be developed will be collected this way.
- Create a transparent overview of all requirements for both the building and usage permit. Based on this, determine which requirements save the most time and gain the most quality. Based on this you can prioritize and design the most interesting checks. Some checks might be possible to build but are not economically viable since the gains don't outweigh the expenses.
- On the basis of this list it also becomes clear which additional data / regulations must be made available digitally as the basis for performing the BIM checks. This includes for example zoning plans, urban development plans, material regulations, etc.
- Keep the extra requirements for the BIM design as limited as possible. Too many extra requirements will have an effect on the support of the applicants and often these extra requirements are also prone to error, which means that they are not effective.



6.2 Technical recommendations

There are some things to take into consideration when adopting this approach:

- The building code might be updated and rules might change. In a rule based approach this would be easy to change (simply edit the rule). With an algorithm based approach more complex checks will be possible but since this will also introduce more dependencies, it will be more complex to update them. Make sure that most values to check are stored separately from the code. There is no standard available yet to store this kind of rules. Since the type of information will be very different as well, there will probably be multiple places to store these values. For example in a regular database, via some external service using linked data or as layers in your 3D Digital Twin. It is important to setup a well defined structure within the 'regulation digitization' project to keep the overview to make sure the solution will be flexible but also scalable and future proof.
- Although an algorithm based approach does not make that many demands to the IFC data structure, it can still only check on the available data in the dataset. Missing parts can not be recognized and will not be checked. This is the same with rule based checking, but good to pay attention to it.
- Keep focus on using open standards like IFC, BCF, CityGML and 3D Tiles, these are the foundation of your solution. Separate your data from your tools. Several tools should be able to connect to the same data source for different applications, creating a flexible ecosystems ready for the future.
- IFC is the standard to use and prescribe as a base for your 3D BIM designs entering your permit system. It is already widely used both inside and outside of Estonia. To make sure it fits the needs of the automated permit checking solution additional prerequisites and demands will need to be prescribed. Your central IFC database will be the data foundation for your permit checking solution.
- CityGML is the standard to use and prescribed as a base for your 3D Digital Twin. It is less mature than IFC but a growing community worldwide is starting to use the standard. Stored in a database it is a very powerful and easy to maintain foundation for your 3D Digital Twin. Make sure to search for collaboration with other cities using it. Most frontrunner cities are willing to share experiences and tools,
- BCF is the best way to share the results of the permit checking algorithms. It is open and accepted and used worldwide and most BIM software support it.
- Large scale datasets stored in a database usually aren't too fast to visualize online. A new open streaming standard which can help to transfer your 3D data to a local web browser is 3D Tiles. It is an OGC community standard and used by for example Cesium; the open source 3D solution which is already



used for the 3D Digital Twin concept of Estonia. More tools are starting to adapt to the standard which means you can use the same 3D tiles stream of your 3D City model in different software tools.

- The automated BIM checking solution will be a combination of the rule based and algorithm based approach. Try to stick to the algorithm based checks as much as possible since it is more reliable and has less prerequisites regarding the BIM models. Add rule based checks when an algorithm based check is not possible, but then also think about how to check the automatic checks during the manual assessment of the permit application. This manual assessment can also be supported in the future web solution by turning on the right layers and information and for example add a comment function.
- In the future the online system is gathering so much data it can be used to perform advanced analysis. Machine learning potentially could provide additional information (like type of building, orientation, etc) for higher reliability checks. This could also be used to provide validity checks for data that is provided by the industry. For example lfcWall objects that are very wide and very low might now actually be walls. Machine learning can automatically detect these kinds of deficiencies. More advanced statistical analysis like Bayesian statistics could also provide faster insights.