# REVIT2DALEC: A BIM2BEM COMBINED THERMAL AND DAY- AND ARTIFICIAL LIGHT ENERGY CALCULATION WITH DALEC USING THE MVD

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## ABSTRACT

Building Information Modeling to Building Energy Modeling can be seen as one solution for the performance gap of planned and operating buildings. Among other aspects miss calculations in the early design phase leads to energy demands are deviating in the operating building. With the combined thermal and day- and artificial light ernergy calculation tool DALEC, the BIM2IndiLight project is developing an early desing stage simulations tool. By using open formats, validation layers and standardization combined with DALEC it is aimed to reduce the performance gap and develop a feasible tool for the AEC industry.

## INTRODUCTION

During the last decades, new standards have been released for demanding higher energy efficiency for new and refurbished buildings. For instance, the German standard EnEV 2014 requires a building heat demand of under 50 kWh/m²a. Whereas in the upcoming Passivhaus standards, heat demand is required to be under 15 kWh/m²a (Passivhaus 2020). In contrast to the political developments, net building energy consumption has steadily increased since the early 1980s (Torcellini P. 2006). This is attributed to a continuous growing of the construction volume of 3,9 % each year worldwide. From 2015, an 85% construction volume increase until 2030 can be assumed (Global Construction Perspectives). Consequently, as the heat demand per building drops, the relative energy demand for artificial light significantly increases.

Within the BIM2IndiLight project it is held to implement DALEC in Revit for a combined thermal and day- and artificial light energy simulation in the early stage of the project progress. This provides the designer with a feedback about the building performance and helps making decisions during the designing process. Modification that are made during the construction phase, deviating from the early design stage of the project, have a significant impact on the operating building, since executing changes during the construction phase probably cannot fix later performance issues caused due to an insufficient design phase.

### The Balance of light

It is currently well established that too little light exposure has a negative effect on people, with regard to physiological as well as psychological aspects. Therefore, it can be assumed that both heat and cooling demands are continuously decreasing by increasing insulation and by installing more and larger glazed areas. Better use of daylight might ask less of artificial light and by that decrease the demand of electrical energy. So far, the solutions sound easy, but in fact, they are not. Windows have a lower thermal transmittance resistance compared to walls. Therefore, an increase of the window to wall ratio (WWR) does not work without the "side effect" of a higher heating energy demand. Overheating might also be problem, when no proper shading device is implemented, or a control strategy runs unsatisfactorily. The appropriate window to wall ratio and insulation are requirements, but not yet a building design criterion. To come closer to the argument, Werner et al. (Werner 2017) put the criteria into a simulation attempt. A room with equator-orientated façade was exposed to 4 climate zones (5 cities – Stockholm Sweden, Berlin Germany, Wellington New Zealand, Las Vegas USA, Salvador Brazil); in the experiment using 2 different shading systems, external venetian blinds and daylight redirection systems by means of DALEC (DALEC 2020).

### DALEC

DALEC (day- and artificial light with energy calculation) is a web-based combined thermal and day- and artificial light calculation tool. It was developed during the FFG project DALEC, by the university of Innsbruck, Bartenbach and Zumtobel. Individual façade concepts are hourly-based simulated and the impact on thermal and visual performance can be shown in less than a second, due to sophisticated and time-saving pre-calculations (Werner et al. 2017). The total energy demand is – by common sense -a combination of cooling, heating and artificial light. The simulation revealed, that the window area was to be optimized to gain the best result. Depending on the latitude, the optimal window to wall ratio ranged from 20 % to 70 %, resulted in monthly mean outdoor temperature, hours of sun per day and the sun angle of incidence. To take benefits from DALEC simulations

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it is aimed to connect it to BIM for real-time design decision making.

**BIM**

In this regard, the building information model is a 3D model that includes geometrical and alphanumerical construction elements. Azhar (Azhar 2011) has demonstrated, that using BIM, improvements can be achieved, when it comes to interaction and time consumption or costs. It is also possible, that an automation of the modeling process might decrease human made errors. Further, it enables better post-processing for output representation (Kamel und Memari 2019). In order to make the most of an integral cooperation, the project participants should jointly access the model or individual partial models in the Building Information workflow. This cooperation can be achieved either with a "Closed BIM" or with an "Open BIM" method. In the former, all the necessary data for the process are exchanged in a closed data environment. The contributing partners are working on the same model due to manufacturer-specific interfaces. In contrast, an "Open BIM" approach does not use a specific software landscape.

**BIM2BEM**

Building Information Modeling (BIM) to Building Energy Modeling (BEM) is often seen as the key solution to increase the interaction between design and energy calculation process in order to design buildings with better energy performance, within the given time of the design phase. By using the building informations, created by a BIM tool, the integral planning approach is improved and e.g. energy simulations can be done by specific tools like EnergyPlus. If the simulation results can be reimplemented into the BIM tool, it's a bidirectional workflow, otherwise it's unidirectional

**IFC**

The IFC (industry foundation classes, ISO 16739) is defined by the buildingSMART International non-profit organization and is seen as the only non-proprietary BIM based data exchange format (Asmi 2015). IFC is an open and interoperable 3D building exchange format, supporting semantic, topology, properties, time, cost and schedule data.

**MVD**

Model View Definition (MVD) is a buildingSMART concept to validate the IFC by addressing exchange requirements during the Information Delivery Manual (IDM) process. The current version IFC4_ADD2_TC1 – 4.0.2.1 implements 776 entities defining objects, relations, values, quantities, properties, etc. The MVD breaks the IFC total schema down to a schema where just needed or necessary entities are in. Furthermore, it is used to validate the incoming model for all necessary informations.

## STATE OF THE ART

As BIM is more and more adopted by the AEC (Architecture, Engineering, Construction) industry (Hardin und McCool 2015), a new challenge arises concerning BEM. Since buildings need to be more and more efficient, the influence of reliable energy results, comparing design and operating building (performance gap), is getting more important. When utilizing BIM as an input, there are different tools to realize building energy performance simulation, such as: EnergyBuilding, OpenStudio, Building Energy Analysis Model, GBS, Modelica/Dymola, TRNSYS, EnergyPlus, COMETH, IDA ICE, DOE2, eQuest, PHPP (via bim2PH) and more. These tools can be called BEM tools more or less since in research it is shown (e.g. Van Dessel (2019), Chen (2018) and Kota (2014)), that implementing exchanging BIM data still leads to several problems or big workarounds. These tools are classified into two groups. One group uses the US Department of Energy (DOE) engine, such as EnergyPlus, Revit Green Building Studio (GBS), eQuest, DesignBuilder and those that use their own engine (Gao 2019).

**Interoperability Challenges**

Gao et al. (Gao 2019) did a summary of IFC-based BIM to BEM approaches in different literature. Most of them are Revit or IFC-compliant BIM tool that creates IFC as an Input for EnergyPlus, EnergyPlus RIUSKA combination, EP and Radiance, EP and TRNSYS, PHPP, COMETH, OpenStudio, DOE-2.2.

However, most of these tools are not capable of importing IFC directly. Geometry has to be decomposed by tools like the Common Boundary Intersection Projection Algorithm (CBIP), Geometry Simplification Tool (GST) and be converted, e.g. to EP specific interface IDF. Besides, most of these approaches are not considering day- and artificial light for a combined thermal and light energy calculation. If they do, they mostly use Radiance for the light calculation. These processes are complicated, slow, need a lot of input informations and don't bring informations back into the BIM tool, hence their use is not really practicable outside research for the AEC industry, especially in the early design phase.

Literature has addressed the establishment and applicability of BIM-to-BEM workflows. Still, it is uncommon to achieve these workflows in industry due to numerous obstacles.

**User-based Challenges**

Over the course of design process, it is frequently observed that the planner has no time to run simulations locating the optimum for final energy demand. Furthermore, the loop of the designing process and energy simulations is frequently not closed. In addition, the planners are often overwhelmed by the amount of information and do not have the knowledge to interpret the results. Abu Hamra (AbuHamra 2015) presented via a case study that there exist many barriers to bring BIM into

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utilization, the same can be said of the use of BIM to BEM:

- Lack of knowledge of how to apply BIM software
- Lack of architects/engineers skilled in using BIM programs
- Lack of the governmental regulations for the full support the implementation of BIM

In recent literature such as Kamel et al. (Kamel and Memari 2019) we find similar observations:

- BEM tools need to support all the attributes/information provided by BIM files and BIM file schemes need to define all the required information for energy simulations.
- Application of corrective middleware tools or manual process is needed to avoid data loss between two tools during data exchange.
- Although BIM file schemes (e.g. gbXML) could be capable of transferring all the required data for energy simulations, data might be missing during the data exchange between other tools.
- Introduction and development of standards for data exchange process.
- Comprehensive and proper error or warning messages need to be generated if the BIM file does not include the required information.

Having considered the challenges, the authors are now about to address them by several approaches. Still, the key challenge is the interoperability of data exchange.

**Model Validation Challenges**

Due to the exchange process, there is a data loss, an inconsistency during translation (e.g. language, designation, etc.) and missing data. Thus, three approaches that require different amount of efforts (Andriamamonjy 2019)can be presented:

1. An "integrated model" method, which links several models through a common data model.;
2. A "specific data sharing" method, which uses a custom information model to exchange information; and
3. A "generic data sharing" method, which prioritizes flexibility and, consequently, aims at being compatible with the large majority of software applications.

In this context, the third approach can be seen as the most reliable, as being highly robust to achieve interoperability with the use of IFC or gbXML (Asl, Mohammad Rahman et al. 2015). Third approach can be split into three solutions:

1. Proprietary tool-chain
2. Middleware tool
3. Exchange requirement identification

Proprietary tool-chain is an application programming interface (API) based solution and cannot be understood as an interoperable solution, since it just ensures the data exchange between the specific BIM tool and the other specific BEM tool (Andriamamonjy 2019). An API can be understood as the interface to a program. That way the developer can use the methods, functions and classes of a specific program without direct access to the original code. Even this approach is probably the most stable one, its main disadvantages are the inflexibility of working with other tools, not knowing complete exchange information and high costs.

Whereas middleware tools work with interfaces like IFC or gbXML, those can be exported by BIM tools, and convert them for the specific energy tool, while adding or manipulating data. During this process it can come to data duplications or information loss resulting in errors. Usually this approach is unidirectional (Andriamamonjy 2019).

Since there are just few restrictions to the IFC, requirements are quite variable, which might end up in data exchange challenges. Therefore, the third approach arises as the most promising one, which is exchange requirement identification and implementation in the IFC.

**Exchange Requirements Challenges**

Exchange requirements can be type of elements, information of elements, quantity determination, exchange formats and all of this specified for all participants. During the Information Delivery Model (IDM) all necessary exchange data is identified. These exchange requirements are defined by the client and the responsible project partners. It is defining which information at what phase of the project have to be delivered between different participants and the exchange format that has to be used. Within the Model View Definitions (MVD), the IDM is implemented in a strict IFC data structure that serves all the needs for the BEM tool (Pinheiro 2016).

In the literature several approaches can be found that use MVD. Baumgärtel et al. (Baumgärtel und Pirnbaum 2016) used the MVD to generate an ifcQL (query language). With the ifcQL, the ifcQL-processor is able to read, filter and change the IFC like a database. Since the project ended, unfortunately the program can't be accessed anymore. xBim Xplorer (xBIM 2020) can be used to validate and filter the IFC with the MVD. xBim is an open source project that can be found and loaded on GitHub. With the xBim mvdXML plugin the IFC can be validated and filtered by the MVD. Even there is a high need in the AEC industry for IFC data checking and filtering by using MVD or queries, it is not well

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examined in science literature as shown by Sattler (2019).

Also, there are commercial tools able to work with the MVD like Simple BIM or Solibri Model Checker, using the MVD in a project requires a high knowledge of the IFC. The MVD represents an abstraction of the IFC full schema that just includes the needed entities of the IFC for this specific exchange.

Most of the MVD studies published over the last few years still struggle with the amount of exchange requirements. Any participant during a construction project, and in every phase has an amount of information that needs to be delivered for calculations and simulations. Hundreds of needed exchange requirements are not unusual. Even if buildingSMART with the IFC is covering a lot of properties for objects in their standards, still most of these project properties are not covered. IFC solves this problem by giving the user the opportunity to create individual property and quantity sets (IfcPropertySet, IfcQuantitySet) and fill them with individual properties and quantities. It is also possible to generate specific elements, if they are missing in IFC schema (IfcBuildingElementProxy). Since every specific definition is a deviation from the standard, this leads to interoperability challenges. Considering this, as many IFC definitions as possible should be reused (buildingSMART 2020a).

## DESIGN OF PLUGIN

Currently, it is not possible to work smoothly on a common BIM model within different software vendors. The models from the various programs are coordinated and exchanged together using the open format IFC. Bidirectional data exchange between BIM and BEM is not examined in since literature so far. In this paper a Revit to DALEC (BIM2BEM) bidirectional data exchange approach will be introduced. By using the MVD for validation and filtering and by using the freeBIM propertyserver for data standardization. This way a feasible approach for AEC industry is aimed.

### freebim / ASI propertyserver

The ÖNORM freeBIM / ASI propertyserver, developed during the freeBIM-Project in collaboration with ASI (Austrian Standards International) as a part of the Austrian BIM-Norm, is an approach to help solving data exchange problems. For the users, this property server works as the basis for harmonized, standardized and machine-readable attributes in order to provide a clear standard for the parametric description of digital components. With the integration of the "bsDD (Build Smart Data Dictionary") GUID" (buildingSMART 2020b), all properties of the ÖNORM property server are clearly assigned with the bsDD making the data unique, multilingual and machine-readable. These properties are hierarchically structured and supplemented by further information such as data type, unit and IFC property sets. The property server is implemented as a graph database. The graph database is illustrated to user during a hierarchical drop-down menu interface (Figure 1). The MMS data is stored and defined in the same way as it is used in everyday speech: (window) - HAS PARAMETERS - (width) - HAS DIMENSIONING - (real number [cm]) (freeBIM 2020; Fröch 2017; Fröch et al. 2019).

Herein, the BIM2IndiLight project needs properties for day- and artificial light simulations. Therefor the needed properties for building physics, shading systems, lightning systems and controlling are identified by the contributing partners, who are specialized in the mentioned topics, and their information are implemented on the "freeBIM Merkmalserver".

The provided stock of information can then be used in future projects. The MMS is organized by different "libraries" in order to better differentiate objects and their parameters. By doing so, the database can be easily expanded, when it comes to integrate new standards or other product data. In order to connect the different characteristics of the libraries with each other, the possibility of "equality network relationships" is implemented.

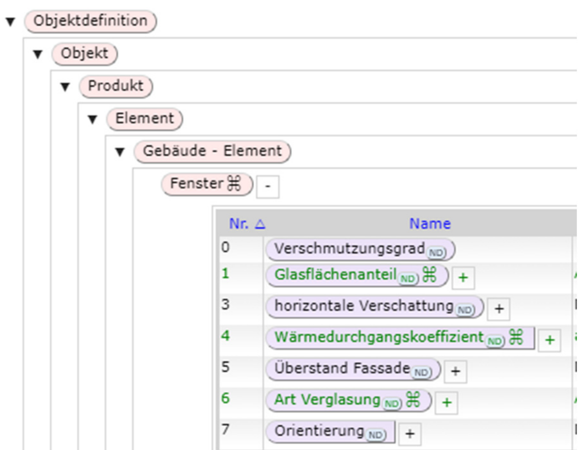


*Figure **1:** Properties on the freeBIM MMS (freeBIM 2020)*

For further use, of the content from the property server, it is necessary to be integrated in a form in the BIM software. In a front-end, the characteristics can be structured and selected according to components and phases. The features that are not relevant for the user concerned remain hidden in this view and enable a clear overview. In order to transfer this information into the various applications, various tools were developed in the freeBIM-Project (freeBIM 2020 (Fröch et al. 2019)).

The Revit2DALEC plugin for Revit aims for the designing phase that can be split into 3 phases.

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1. Conceptional design (shading system, cubature, orientation, window-wall-ratio, occupation type, building standard, construction method)
2. Pre-design (U-values, windows, rooms, room occupation type)
3. Late Design phase (artificial light system, individual seetings for rooms,…)

**DALEC Conceptional Design**

DALEC plugin can be split into 2 (3) parts.
The first part is the DALEC Optimizer that includes the phase 1 and 2. By pre-selecting the occupation type, construction method, building standard, shading system and project location all needed information for the simulation are set by default. During an optimization process the designer gets a clear feedback for orientation and window-wall-ratio for the conceptional design. During this first part, a good knowledge of building physics is not explicitly necessary. Most of the DALEC settings are done by default and the user can play with different cubature's. The planner will get a clear and easy to understand result feedback to support well decision making.

**DALEC Pre-Design**

Proceeding with the conceptional design, the planner can now become more precise, with differentiation of rooms and room-occupation type, window size and position, shading elements, etc. Still most of the settings are set by default and the planner can focus on the design. Simulations are now getting more accurate. The planner can start the simulation manually and can check the energy results.

**DALEC late Design**

After the first two phases the model or rather project will be further developed by different disciplines like HVAC. Specific settings can now be made and simulated with DALEC Modeler. Within this stage the planner has a deeper knowledge of his/ her discipline and specific settings can be made for simulations. No optimization process will be performed automatically at this stage of progress any more, but can be started manually.

**DALEC**

DALEC has to be installed as a plugin on Revit, but the DALEC simulation kernel is running on a server and is accessed during an IFC exchange. Converged simulations can be then be reimplemented in Revit for result visualization as seen in figure 2. DALEC has a big amount of simulation results. Some can be visualized as a grid for each room, like daylight autonomy or illuminance. Others like yearly heat demand will be shown as graphs.

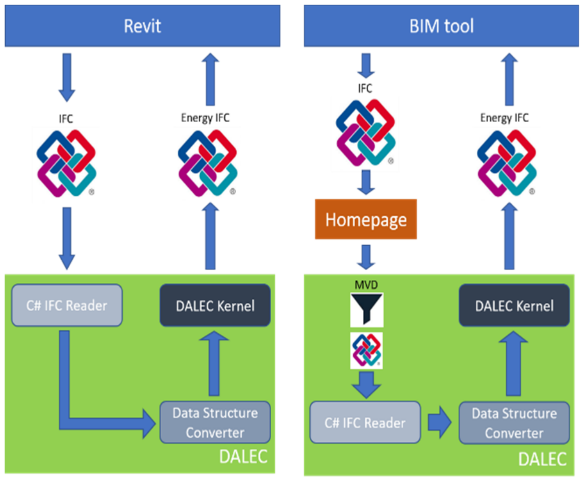


*Figure 2: Revit 2 DALEC (left), any BIM tool to DALEC (right)*

A validated DAELC IFC from Revit is exported due to 3 security instances or rather steps:

1. freeBIM MMS with standardized property sets and properties for IFC entities
2. Load property sets and properties from freeBIM MMS and enrichment of the specific Revit objects/ families
3. Revit IFC export mapping text file, for correct mapping of the properties into the IFC

The freeBIM MMS can be seen as the regulation instance, since even the MVD (Figure 2, right) is based on it (Figure 3).

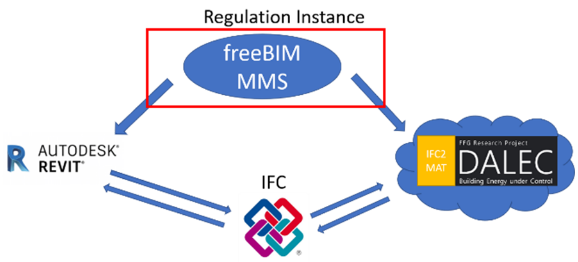


*Figure 3: freeBIM MMS regulation instance*

**Getting properties into Revit**

First step is carried out using one of the tools from the "freeBIM 2" (freeBIM 2020) research project. First, the shared parameter file is imported into Autodesk Revit, in which all the necessary properties of the property server are available. The shared parameter is a definition of a container for information that can be used in multiple families or projects [Autodesk.com]. These properties must be assigned to the objects in the BIM software. For this purpose, the object or family is selected in an additional tool - after selection, the category becomes visible in the tool (Figure 4).

Next step, using the hierarchical structure of the MMS, the parameters necessary for the evaluation, are easily added to the CAD objects/families with the tool. Using the hierarchical structure of the MMS, the features can be added to the objects/families in the


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CAD. However, the properties are not automatically but manually linked to the internal parameters of the CAD software in Revit (Autodesk 2020), or the calculation of the individual values must be added. This way the building characteristics are filled with information (e.g. thickness, width, length of a wall).

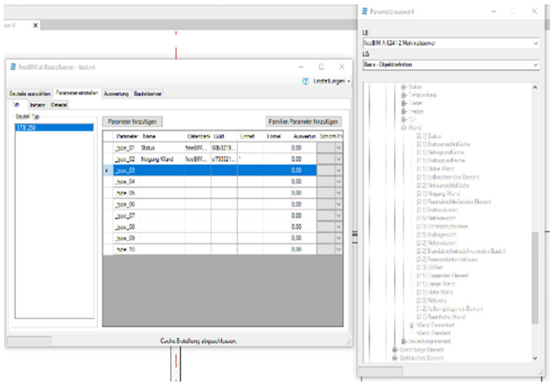

*Figure 4: freeBIM MMS Tool Second Step (freeBIM 2020; Autodesk 2020)*

The third step is executed by a manually written mapping text file, which can always lead to possible errors and is time consuming, when updates need to be done. Still, due to these steps it is not necessary to validate the IFC file, if it comes from Revit DALEC plugin. After simulations in DALEC are done, an "energy IFC" is sent back to Revit for integration of simulation results into the Revit model (Figure 2).

The energy IFC file does not has any geometrical information. Simulation results are connected to the corresponding spatial structures due to the GUID and name information. "The generated GUID is compressed for exchange purpose following a published compression function. The compressed GUID is called "IFC-GUID" here." (buildingSMART 2020b). Most of the visualized results are grid-based information like the illuminance or daylight autonomy. These information's are saved in the IfcGrid entity. The IfcGrid is mapped to the grid of Revit spaces by the Revit API. With this approach the amount of data and the communication time can be reduced. Furthermore, the probability of errors and duplication of data is avoided.

**DALEC Kernel**

DALEC as a server-based application is built on 3 instances, as follows:

a. The first instance is a C# written IFC reader using the xBim class library

b. Second instance converts the C# data structures into Matlab MathWorks MWStructure

c. Third instance starts DALEC as Matlab complited .NET assembleys (dll class files) that can be executed inside the C# code

For the result export, the 3 instances are going backwards as it seems to be, but instead of the reader there is a simple IFC writer. Since the BIM2IndiLight project aims to overcome the interoperability challenges, it is not meaningful to just rely on Revit. The DALEC server application can also be accessed with a manual IFC upload by using the homepage (Figure 2, right). That way it is possible to calculate models even when they are not from Revit. For this variant the workflow does look quite different and needs a different way of ensuring data interoperability.

**MVD-based validation**

If IFC data comes from another source than the REVIT DALEC plugin, then there is a high chance of missing or getting unnecessary information. To avoid a program crash, the file needs to be validated. By using IfcDoc, an MVD creating program from buildingSMART (Figure 5), a model view "DALEC" mvdXML file is generated and used for the validation and filtering. While working with the Revit DALEC plugin, interoperability for Revit to DALEC can be ensured without an MVD validation.

For IFC validation and filtering the xBim/mvdxml librabry is used. If it does fail, xBimXplorer and its mvdXML plugin can be used for further information.

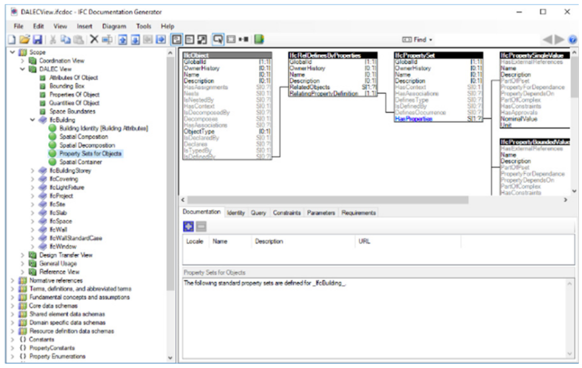

*Figure 5: IfcDoc (buildingSMART 2020c)*

Only if all checks for every building element of the incoming IFC are passing, DAELC server application will be accessed and started. Otherwise it will be stopped and the user will be prompted to check the logs and update his model.

## DISCUSSION AND CONCLUSIONS

It is important to highlight that this work is still in progress, several tools and workflows have been tried, but are not finished so far. Some of the approaches have shown great potential to be further developed in the future. Some approaches could not be further pursued since support is stopped, and others did not match studies conditions. Three main conditions have emerged, firstly, it should be state of the art. Secondly, it should be feasible for planners in the early design phase. Finally, it is good to work with existing solutions as much as possible and use open-source libraries. Working on and with the various workflow approaches, challenges have shown up.

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IfcDoc (buildingSMART 2020c) is currently the only MVD creating tool. The latest release v12.2 10th September 2019 suffers from numerous issues. It was not possible to export a functioning mvdXML that matched the requirements for a full validation. Properties are not exported, while using export Version of mvdXML v1.1, but using v1.2 is not supported by any tool so far. The MVD should solve the problems of interoperability by checking for standardization. IfcDoc gives the user a lot of different opportunities to build up a MVD, starting by names for Concepts and Exchange Requirements and creating schemas.

Depending on the individual created mvdXML file, informations can end up in different tags. All that influences the outcomes of the mvdXML and can cause difficulties while using mvdXML's in different tools. During the paper it was decided to build up a MVD that is working for the xBim/mvdXML Validation test, since it is open source and the library is up to date. However, in order to achieve a working IFC validation, it was still necessary to extend the mvdXML manually by adding parameters.

In this first attempt, it was aimed to finish a running version from Revit to the current version of DALEC. For DALEC 64 properties were detected and only 25 values were already existing in the buildingSMART standards, while 39 are missing. Also, 17 property sets are needed in which 15 exist already and 2 are missing. The missing properties and property sets are documented on the freeBIM Merkmalserver and the DALEC MVD. Manually mapping Revit parameters to IFC, results into human-based errors. Due to the amount and variety of properties, properties can be identified as the largest "trouble makers". With the tools from the "freeBIM 2" project it is possible to map properties form the Merkmalserver to Revit objects. This workflow still needs to be optimized, since a high amount of manual settings is needed. This can produce errors. Furthermore, the properties from Revit have to be mapped to the IFC file by a text (txt) mapping file. It is also human written and will be automated with the Merkmalserver. Since everything starts with the freeBIM MMS and is based on it, it is necessary to compare and define the clear and standardized attributes of the MMS with the existing IFC structure (e.g. parameter MMS - "external component" - IFC 4 - "is external"). As a result, the content of the characteristics is in the right place in the IFC file and can be further processed. All of this enables an error-free data comparison of the internal CAD-parameters with that of the property server.

Even when the MVD approach is quite common as seen in the literature and though more and more companies are starting to work with the MVD, it is crucial to underline, that without a good knowledge of the IFC schema, IfcDoc and the skill to master complications, the number of failures can be still big. It might be the reason, why MVD is not very common in practice, as we got feedback from project partners and companies. Nonetheless MVD is a promising in future. The freeBIM MMS is a partial image and extension of the entire IFC schema. Since there were some challenges with the MVD from IfcDoc, it is considered to autogenerate an MVD from the server. This will reduce human made errors, and the MVD will be easy to update, when changes in the freeBIM MMS requires it. Another approach will be the use of the freeBIM MMS directly as a "like" MVD to validate and filter the IFC.

With IfcBuilding, IfcShadingDevice and IfcEnergyC onversionDevice missing in Revit, another problem appears that needs to be solved. There are no properties for IfcBuilding in Revit provided. Property mapping does not work with the IfcProject properly. Further, IfcShadingDevice and IfcEnergyConversionDevice are not supported under Revit.

Overall, several challenges are still existing and need to be addressed. The property standardization with the freeBIM MMS is a constant ongoing process. Even tools for mapping properties from freeBIM MMS to Revit exist, they need to be optimized in context of usability. Furthermore, the property mapping process can be split into three parts:

1. freeBIM MMS to Revit
2. IFC entites to Revit families
3. Revit properties to IFC export properties

All three of them still needs more or less further developments. Exported mvdXML files from IfcDoc are incorrect and need handy adjustments for xBim validation. And also, DALEC is in an evolution process for BIM adaptation.

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