Building Information Modeling for solar energy systems

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Abstract

Building Information Modeling (BIM) is a promising method for energy analysis applications. Early and integral planning of a building's energy system with the BIM method results in many advantages with regard to the use of renewable energy sources such as solar energy because of available rich 3D building model. However, there are many limitations in using BIM for energy analysis. Almost all known stand-alone simulation programs are not compatible with the established BIM-based data formats. In addition, the available BIM-based object models of solar energy components like photovoltaic (PV) and solar thermal (ST) are neither standardly nor completely parameterized. For photovoltaic thermal systems (PVT), they make no contribution at all. Furthermore, the BIM method has so far mainly been used for the planning process. This paper presents two approaches for the use of the BIM method for the simulation and monitoring of PVT-systems. First of all, a parameterization for a PVT-system was developed based on several existing standards and approaches. In order to transfer the necessary parameters from the BIM-model to the simulation program TRNSYS automatically, a python intermediate tool was developed and validated. In order to use the BIM method in the operation phase for monitoring a facade integrated PVT-system, a BIM-model of an existing real laboratory with its PVT-facade was developed. It was further used to set up a mockup digital twin for monitoring in a Common Data Environment (CDE). This enables the display of thermal as well as electrical yield and the comparison with the simulation data, facilitating the identification of possible malfunctions and ensuring efficient system operation.

Keywords: BIM, IFC, PV thermal, TRNSYS, Digitalization, Monitoring

1. Introduction

Building Information Modeling (BIM) has become established as one of the generic terms for digitization in the value chain of designing, building and operating structures. With the BIM method, all lifecycle-relevant information of a building can be recorded, managed and exchanged in a centralized, model-based, digital and consistent manner for optimal transparent communication between the participants (architects, planners, assemblers, operators, etc.) involved in the various construction project phases (see Fig 1).

All building-related data can be stored in a Common Data Environment (CDE) and are thus accessible to all project participants at any time. Computer-based filtering and evaluation combined with the aspect of visualization helps in focusing and guiding.

Since BIM tends to be used in the planning phase nowadays, there is further potential to explore its application during the operation phase. Especially in the field of solar energy, the application of the BIM method is currently still a research topic. With reference to the operation phase this method is very promising.

With BIM for example an early integral design of the building with its energy supply system is possible in the planning phase. The information-rich 3D modeling of a building and its surroundings (shading) is also beneficial in terms of solar energy yield prediction. Thus, renewable energy and solar energy in particular can be better and thus more often taken into consideration in building design. Some companies like BIMobject (BIMobject 2021) or Bimetica (Bimetica 2021), the National BIM Library (NBS 2021) as well as some component manufacturers already provide BIM objects (3D model objects) with extensive parameters including aesthetic properties for their products, such as PV modules and ST collectors.

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Fig 1: Building Information Modeling (BIM), the networking of processes and of project participants

In addition, useful manufacturer information such as warranty information and maintenance instructions can be integrated into the BIM objects and thus increase the attractiveness of the products and contribute to their better operation. As part of a BIM-based monitoring approach for the operation of solar technologies, actual measured data can be compared with set data. The set data may result somewhat from the design or manufacturer specifications. If there is an unexpected deviation, the simulation data will be used for comparison. In the event of a deviation which is higher than a predefined limit in monitoring data, the malfunction (for example a defective module or collector) can be identified at an early stage and, if necessary, a repair or replacement can be undertaken. In the event of a repair or a replacement the BIM-model will be updated to display the actual as-is state.

In the event of the dismantling of a solar system, the creation of cost and time schedules can be facilitated analogously to the installation thanks to the BIM-based approach. Necessary information on the recyclability of the dismantled components can be stored in the BIM-model of the construction project. Basically, all lifecycle-relevant information of a construction project can be stored in a BIM-model.

For the data exchange of BIM-models a variety of possibilities exists. Most prominent are the Industry Foundation Classes (IFC), which allow an open data exchange. IFC is a vendor-neutral open source data format established worldwide as an ISO standard, which fundamentally enables collaboration in BIM projects between several participants and thus between different software. This data schema has been developed by buildingSMART (buildingSMART 2021), the international competence network for the digital design, construction and operation of buildings. The main task of this non-profit organization is the further development and standardization of open information exchange in BIM projects and the definition and standardization of corresponding work processes. The current IFC Version is IFC 4 and was published under ISO 16739-1:2018. Even though IFC 4 is more extensive, the older IFC Version 2x3 is still heavily used in the construction industry. IFC enables the object-oriented description of a construction project. A single IFC object contains diverse information about the attributes, properties, geometry, relationships and interactions. Fig 2 shows the BIM-model of the real laboratory Danish Pavilion in the (BIMPV 2023) Project. Furthermore, the basic hierarchy in a building project in the IFC standard and a schematic representation of a PVT as an IFC object instance of the "IfcSolarDevice" class (IfcSolarDevice 2019) is shown together with an excerpt of possible information.

Another possibility for the exchange of BIM-Models is the open source data format gbXML, which was developed by Green Building specifically for simulation or analysis tools (Green Building). Green Building is a non-profit organization, which contributes to support architects, engineers and energy modelers in designing energy efficient buildings.

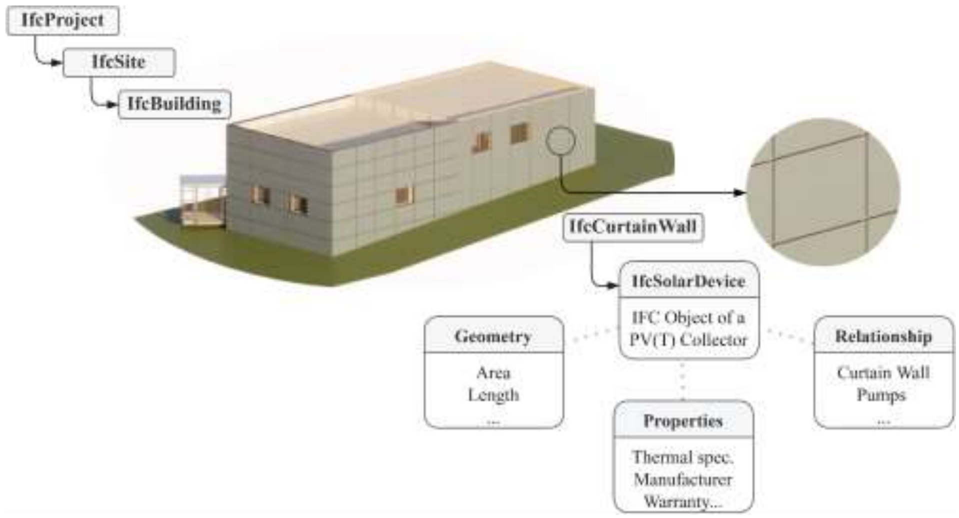

Fig 2: IFC model of the Danish Pavilion laboratory in Hanover in the BIMPV project with a schematic representation of an IFC object of a PVT collector

Designing an energy system for a building is costly and is usually postponed until the last phase of building design. The application of the BIM method supports the design of energy supply systems because the necessary data can be provided in a digital format in an early project stage. However, there are several challenges in this regard that still need to be addressed:

- The BIM objects generally available do not contain all the required data for energy simulations, especially for HVAC components properties such as thermophysical material properties (Cormier et al. 2011). Therefore, data extension via external files is required.
- Most available and usable standalone energy simulation software e.g. Polysun, TRNSYS, Matlab, Dymola, EnergyPlus and SIM VICUS are compatible neither with IFC nor with gbXML. Therefore, an (intermediate) tool must be used to connect a BIM model such as SketchUp (Soft 2021), OpenStudio, eveBIM (eveBIM 2021), etc.
- Data exchange through available intermediate tools (interfaces) is limited, e.g. for HVAC components and for thermal zone mapping (Cormier et al. 2011).
- New approaches and appropriate BIM-based object models are needed for innovative components, e.g., building-integrated (BI) solar technologies (PV, ST, and PVT).

In this study, a parametrization for an uncovered PVT was developed based on standards. Then the proposed IFC object model was built with the developed parametrization with FreeCAD. To transfer the necessary parameters from the BIM-model (IFC object model) into TRNSYS automatically, a python intermediate tool was developed and validated. To use the BIM method in the operation phase for monitoring a facade-integrated PVT, a BIM-model of a Danish Pavilion in Hanover was developed in the BIM authoring software Revit.

This paper is organized as follows: Section 2 gives a short review of the BIM data formats IFC and gbXML as well as the compatibility between the BIM-based data format and the building energy performance simulation software. Section 3 proposes a new parameterization for a PVT-IFC object model. Furthermore, a newly developed python intermediate tool is outlined between IFC and the simulation program TRNSYS. Moreover, a new case study is described using the BIM method in the operation stage of a PVT-facade. Resulting conclusions are drawn in the final section.

2. State of the art

In this section, the current status of the IFC and gbXML data exchange formats and the compatibility as well as the developed intermediate tools between the data exchange formats and energy simulation programs are presented. The Chapter concludes by presenting approaches for representing solar thermal collectors in BIM-based data formats.

2.1 BIM data formats IFC and gbXML

IFC and gbXML are open data schemas for describing building information models. Both are used internationally, but only the IFC format is defined as standard. While gbXML is mainly used for energy simulation, IFC is suitable for application over the life cycle of a construction project.
IFC is fundamentally more comprehensive and generically structured than gbXML (Maile et al. 2020). Regarding the use for energy simulation, a large number of properties (especially material properties or building object properties) are already defined in the IFC format (Hilaire et al. 2015). However, to date, the IFC schema does not support the mapping of all HVAC components, which is a major limitation for its use in energy simulation (El Asmi et al. 2015). It does not focus only on the energy domain in the main specification and does not directly define information exchange requirements specific to different project phases and between different actors and software applications (Maile et al. 2020). The latter weakness was recognized by buildingSMART, who developed the Model View Definitions (MVD) for this purpose (Maile et al. 2020). A MVD allows certain filter presets for IFC export of specific data from a BIM-model. The gbXML, on the other hand, is less complex and focuses on the characteristics of the building objects related to energy simulations. It allows easy inclusion of additional information for energy analysis and is fundamentally supported by many BIM, energy, and web-based tools (Maile et al. 2020). However, gbXML uses centerline theory when calculating building volume instead of using true 3D placement of space boundaries as is the case for IFC (Maile et al. 2020). This leads to errors in the volume calculation of a thermal zone or building. BuildingSMART and Green Building provide numerous IFC as well as gbXML classes (object models). For the representation of solar thermal collectors or PV modules there is an old class "IfcEnergyConversionDevice" in IFC 2x3 and a new class "IfcSolarDevice" in the IFC4 format (IfcSolarDevice 2019). In contrast, gbXML does not have a class for solar thermal collectors or PV modules.

2.2 BIM data formats and simulation programs

The buildingSMART website provides a list of all IFC-compatible software available on the market for a variety of architectural, engineering, and construction software. There are only two building energy performance simulation tools (BEPS) in the list: IDA ICE (version 4), developed by the Swedish company Equa Simulation, and RIUSKA (version 4.4.7), developed by the Finnish company Granlund Oy. These are IFC-compatible simulation software that support the automated import of building object geometries.

The basic model of a BIM-model is made in so-called BIM authoring software. Common commercial products are for example Autodesk Revit, ArchiCAD or SketchUp. For the direct modification and 3D visualization of an IFC object model, there are also a number of free open source software, e.g. the usBIMviewer+ software (ACCA 2021) from the Italian company ACCA Software and the 3D modeling software FreeCAD (FreeCAD 2022).

Tab. 1 shows the compatibility between IFC and gbXML data exchange formats with the most commonly used BEPS. Two main criteria are considered in the table:

- The possibility of reading/importing the IFC and gbXML data format.

- The possibility of storing/exporting the simulation results (outputs) in BIM format.

Furthermore, the possible need is specified for an additional intermediate tool for data transfer. The data read or stored back from IFC or gbXML files are geometry and specific HVAC data.

The French research center CSTB has recently developed the eveBIM (eveBIM 2021) tool. eveBIM can visualize and edit IFC files. CSTB has also developed an intermediate tool (plug-in) for eveBIM to connect it with the BEPS, TRNSYS and EnergyPlus. This intermediate tool allows both building geometric (thermal zones) and HVAC data to be transferred from a BIM model (IFC object model) to TRNSYS as well as EnergyPlus. However, this intermediate tool is currently no longer supported.

Moreover, there are many approaches in which the geometry was transferred from a BIM-model into TRNSYS using different intermediate tools such as SketchUp and IFC4javatoolbox, from the JAVA tool developer APSTEX (Apstex 2021). Additional tools as intermediate tools such as ArchiCAD were used between IFC files (geometry and HVAC data) and gbXML files (geometry data only) and EnergyPlus. The commercial and widely used energy performance simulation program Polysun has a BIM plug-in for importing an input file (importing load profiles in Excel format) from a data base connected to a CDE. However, Polysun is not compatible with either IFC or gbXML and, to date, does not have any intermediate tools (Vela Solaris 2021). An intermediate tool based on the Python library IfcOpenShell (Krijnen 2022) was developed for Modelica to transfer geometry and HVAC data from an IFC file. The open-source simulation program SIM VICUS, developed by the Institute of Building Climatology at the Technical University of Dresden, has an IFC plugin in the development phase. However, this is only used to transfer geometry data.

Tab. 1: Compatibility between BEPS and BIM data exchange formats IFC and gbXML

	TRNSYS	IDA ICE	EnergyPlus	Modelica	PolySun	SIM Vicus
Import IFC	Intermediate tool* Geometry & HVAC	Geometry	Intermediate tool* Geometry & HVAC	Intermediate tool *** Geometry & HVAC	-	Geometry (Development stage)
Import gbXML	-	-	Intermediate tool ** Geometry	-	-	-
Export IFC	-	Geometry	-	-	-	-
Export gbXML	-	-	-	-	-	-

*eveBIM **ArchiCAD ***Python tool

So far, only IDA ICE can store the simulation results back in an IFC file (e.g. for an optimization). For the gbXML format there is an intermediate tool just for EnergyPlus. However, a storage of the simulation results in gbXML format is not possible to date.

A review of the literature shows, that BIM-based design, installation, and operation of HVAC components can save time and money, however still have many limitations. Some of the existing limitations are summarized here:

- Some HVAC components, such as PV modules or ST collectors, do not have specific classes in the IFC2x3 or gbXML schema (Hilaire et al. 2015; Green Building). Certainly, there is an IFC object for PV as well as ST in IFC4.
- The available IFC as well as gbXML objects lack some required parameters and the description of the thermal zones of a building is not always possible (Andriamamonjy et al. 2018; Hilaire et al. 2015).
- Loss of information when exporting data via IFC format (Andriamamonjy et al. 2018).
- In multidisciplinary fields, as in the case of solar building envelopes, a clear definition of information categories (e.g., development stage or Level of Development (LOD)) should be adapted and standardized in the main phases of the process (BIPVBOOST 2019).
- The data transfer between BIM and BEPS is still limited especially for HVAC components.

2.3 BIM Method in PV and ST

The design and virtual optimization of technical components in BIM-based planning enables efficient and error-free actual construction and operation.

Few studies have been published on BIM-based energy simulation for technical systems and specifically for PV and ST. Different approaches on BIM-based solar collector (ST) models can be found in the literature.

The tool developed by Castro and Alvarado (2017) allows the integration of solar thermal systems by determining the thermal yield according to the roof pitch and orientation in the design phase of buildings. No information was given about the validation of the planning process. Robert et al. (2014) developed an interface between BIM, eveBIM and TRNSYS software and EnergyPlus. The approach developed could be used in BIM-based energy simulation for planning. In order to validate the approach developed, a building with a solar thermal system was represented as a BIM model and a derived IFC file was used as the input basis for the simulation.

Almost all recent studies were conceived for using the BIM method for the planning of the PV or ST.

3. BIM use cases: simulation and monitoring of PVT-systems

In the last two chapters different examples for the use of BIM-models for photovoltaic and solar thermal system simulations will be presented. The upcoming chapters introduce a BIM-based approach for the simulation and monitoring of BIPV- and BIPVT-systems. The approach is currently under development as part of the BIMPV collaborative project. The BIMPV project tackles the lack of acceptance of BIPV(T)-systems through a lifecycle oriented use of BIM methods. For this purpose, a variety of BIM use cases have been developed. In this paper are illustrated excerpts from the BIM uses developed of "yield simulation "and "yield monitoring ".

As already stated in chapter 1 a BIM-based approach for the yield simulation of PV(T)-systems offers a range of advantages. In the BIM use example of „yield simulation "the digital representation of a BIPV(T)-system forms the base for a BIM-based yield simulation. The digital portrayal of the BIPV(T)-system, its surroundings and the given location through georeferencing of the BIM-model supply essential geometric information. Furthermore, deposited semantic information e.g. the module's efficiency can easily be retrieved and used for the simulation.

The „yield monitoring "use case is situated in the operation lifecycle phase of a BIPV(T)-system. By combining the BIM-model with live monitoring data, a digital twin of the system is created. For the display of the digital twin a suitable CDE is recommended. As part of the BIMPV project a CDE is developed with further capabilities for coping with the necessities of digital twins of BIPV(T)-systems.

For the adequate application of the BIM use cases presented, the BIM-models (PVT BIM-model) need to be parameterized with corresponding semantic information. In addition, an intermediate tool is needed to transfer the necessary information from the BIM-model (IFC object model) into TRNSYS and to transfer the simulation results into the BIM-model. In the next chapters a proposed approach for the necessary parameterization use cases and a prototypical tool developed for the realization of the BIM use cases is introduced. Finally, the potentials of a CDE as a monitoring platform are presented. For this purpose, a mockup digital twin was created on the CDE.

3.1 Own parameterization of PVT

In this paper, a parameterization for an uncovered PVT BIM-model is proposed based on VDI 3805 sheet 19 (VDI 3805), IEA SHC Task 60 (Kramer 2020), buildingSMART and BIPVBOOST (BIPVBOOST 2019). First, a BIM-model of a ST collector was obtained from the website (BIMobject 2021) as an IFC file and extended with semantic information using the software FreeCAD.

The guideline VDI 3805 specifies the general product data and the associated data structure for HVAC products. Sheet 19 contains a parameterization for the digital product data exchange for thermal solar collectors. Based on previous work, the parameterization of a PVT can be subdivided into the following property sets: Generic, Manufacturer, Warranty, Safety, Certificate, Environmental data, Optical specifications, Installation, Location, Geometry, Mechanical, Material, Thermal specifications, Electrical specifications and Economic data.

Regarding the Generic data, it contains information such as the area of application and the ID of the module as well as the ID of the string. Information about the manufacturer such as name, address and article number is included in the Manufacturer data. Information about the warranty like start as well as end date and content is included in the Warranty. Some information about safety like fire reaction class is included in Safety. Important information about certification like the institute that performed the test and the test flag is to be found under Certificate. Parameterization related to the environment like total primary energy consumption per unit as well as hazardous waste are considered in the Environmental data. The Optical specifications include parameters like the solar absorptance and solar refraction. Under the Installation category, a lot of parameters such as position (e.g. vertical), the type of installation (e.g. in-roof), collector orientation as well as inclination and the number of collectors are considered. Regarding the location of the project, there is information such as the coordinates as well as the height and the local hemispherical solar radiation (for the planning) aggregated in the Location category. The area of the collector, the length, width, thickness and other parameters like the volume are considered in the Geometry data. As Mechanical specifications, the total mass, the pressure of the heat transfer medium, among other things, are considered. Under the Material there is the possibility to add the material data such as the name as well as properties for each component layer like insulation or glass. The Thermal specifications contain the usual performance parameters such as conversion factor and heat transfer coefficient, the temperature- and wind-dependent heat transfer coefficient, the effective heat capacity and the minimum as well as the nominal volume flow. The Thermal specifications were taken from the VDI 3805 as well as from task 60 (under the steady-state test method for unglazed liquid heating collectors). Electrical parameterization such as maximum power voltage as well as current and the module efficiency is included in the electrical specifications. The electrical specifications were taken from project (BIPVBOOST 2019) as well as from IEA SHC task 60 (effective solar cell model). Parameters like economic efficiency (costs per m²) are considered in the Economic data group.

3.2 Development of a Python intermediate tool between IFC format and TRNSYS

Common design software in the construction world already has interfaces for BIM-related data exchange formats (e.g. IFC and BCF). On the other hand, building energy performance simulation programs (BEPS), such as TRNSYS, EnergyPlus, Polysun and Modelica, have compatibility issues with BIM-based models as a starting point (see Tab. 1). For this, interfaces and reliable connection methods between energy simulation software and BIM-models have to be developed and validated.

For data transfer between the BIM-model (IFC) and TRNSYS Robert et al. (2014) developed an approach for an interface between TRNSYS as well as EnergyPlus and the BIM software eveBIM. Using eveBIM, the IFC file was visualized and processed. This approach was validated with a use case that included the building geometry (building envelope) and a solar domestic hot water system (HVAC). With reference to the use case described, this approach showed a good correspodence between the values simulated in TRNSYS as standalone software and the use of the coupling results (IFC file - eveBIM - TRNSYS). However, this approach requires a large effort to implement the system. In other studies, an Input Data File (IDF) containing building specifications is created with various software such as SketchUp and passed to TRNSYS like Cormier et al. (2011).

The interface between eveBIM and TRNSYS is no longer supported. The approach with IDF generation is just for building geometries and not for HVAC components. Furthermore, due to data loss and errors in generating the IDF file, a second tool was needed. In addition, some missing objects were added manually. The required parameters of the HVAC components were also added manually.

Based on the literature research conducted and on the analysis of the existing deficits, a Python-based intermediate tool for the integration of an IFC object model into TRNSYS has been developed within the scope of this study. For this reason, the free open-source Python library IfcOpenShell (Krijnen 2022) for reading and editing IFC files was used.

The intermediate tool developed is used to obtain the relevant parameters of an IFC object file of PVT modules, to analyze them, to check whether all the parameters required for TRNSYS simulation are available or not, to filter them and to transfer them to TRNSYS (see Fig 3). The TRNSYS PV-thermal model (type 203), developed by the Institute for Solar Energy Research in Hamelin (ISFH), is a model for uncovered liquid cooled PVT that is based on the combination of the parameters resulting from standard thermal and electrical performance measurement data (Stegmann et al.).

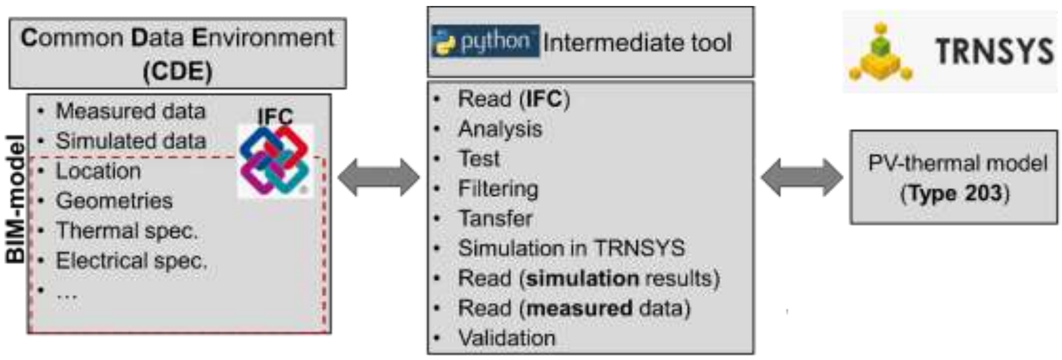

Fig 3: Schematic representation of the IFC-based Python interface between a CDE and TRNSYS

After that the tool generates a backup copy from the TRNSYS deck file and searches for the parameters required for TRNSYS simulation. It then extracts then the necessary parameters from the imported IFC file. In the next step, the parameters are transferred to TRNSYS and the simulation can be started. Once the simulation is finished, the selected results are visualized in the intermediate tool. At this step it is possible to perform a parameter variation. The intermediate tool is not only intended for the planning but also for the operation phase. For this purpose, the data measured e.g. thermal as well as electrical energy (see Fig 3) as well as the IFC file stored in a data base linked with the CDE can be read from the intermediate tool. The intermediate tool runs the simulation in TRNSYS and then imports the simulation results, compares them with the measurement results and then sends them to the data base linked with the CDE. The simulation as well as the measurement results can be uploaded and visualized on the CDE with predefined time resolution. The intermediate tool is validated with measurement data. Moreover, the usage of the BIM method allows PVT plants to be optimized, flexibly monitored or maintained as needed. To date, the connection between the intermediate tool and the data base linked with the CDE has not yet been automated.

So far, the interface can only read an IFC file from a single ST collector, PV or PVT module and transfer it to TRNSYS. As a next step, the interface will be developed in order to read an IFC file from a collector array, recognize the system configuration (number of strings, number of collectors in a string, etc.), perform the required calculation of specific parameters (e.g. area of string) and finally transfer the parameters to TRNSYS.

3.3 CDE as a central base for yield monitoring and other use cases

A CDE serves as a central communication and collaboration platform as well as a single source of truth in any BIM-project. The main functions of a CDE cover aspects such as information exchange, collaboration, visualization, and quality-assurance. BIM-models, documents and collaboration-notes are exchanged over the CDE, whereby it provides the opportunity of exchanging various open data formats such as IFC and BCF to ensure successful project processing regardless of the software products used by the participants.

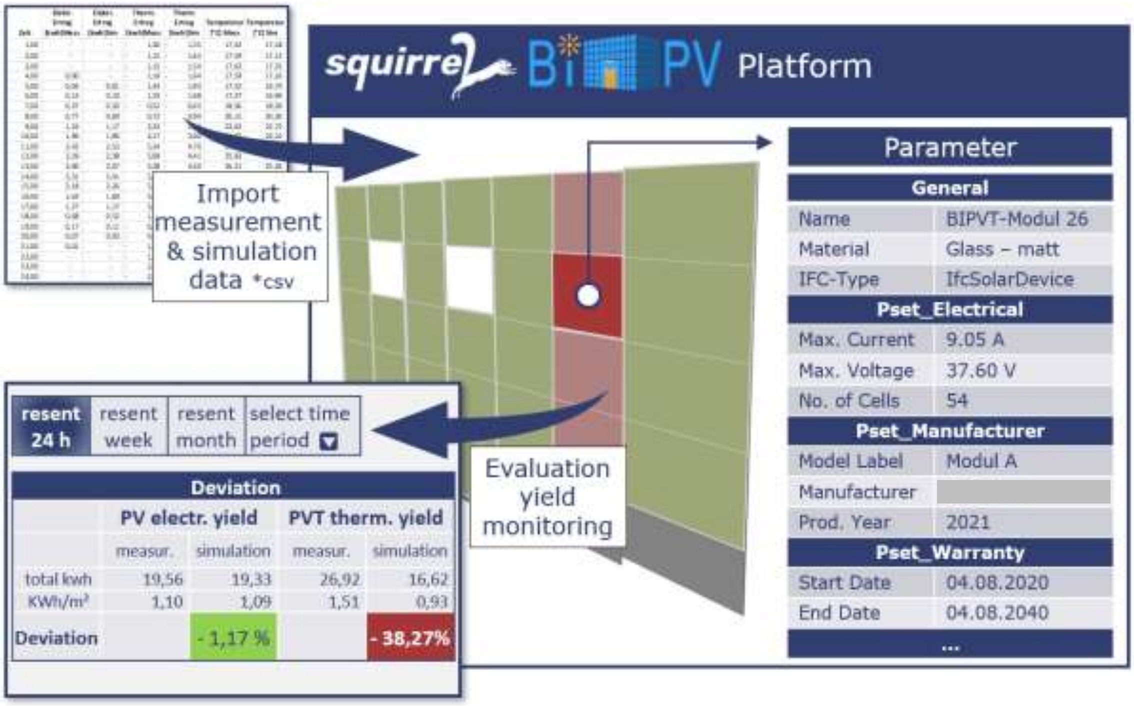

Fig 4: BIM-based monitoring concept of a PVT-facade

The browser-based CDE enables users to visualize the monitoring data retrieved in real time (dynamically). In addition, deviations from the presumed yield can be identified and the deficiency of certain modules can automatically be diagnosed. In the event of a real malfunction the deficient modules can easily be tracked and visualized through the 3D representation of the BIPV(T)-system.

The possibilities of using a CDE as a platform in projects including PV(T) and its monitoring are various. As shown in Fig 4 a CDE (in this case Squirrel) displays and links the objects and their properties to an IFC-model. For the monitoring the assumed yield, a CDE mockup was built, that allows the import of PVT simulation and measurement data. This platform highlights deviations in actual yields from forecast values that exceed a predefined tolerance level. All objects with strong deviations are colored red to enable a clear evaluability and thus a practicable operation of the PVT-system can be guaranteed. Further BIM-model-based use cases can be performed in similar ways. The CDE offers added value in the ability to connect data of various types and sources as well as provide and connect them in a handy way for evaluation and further use for any stakeholders.

4. Summary and outlook

Building Information Modeling is a very promising method for energy analysis applications. It improves the collaboration and data exchange between the stakeholders involved in the whole construction process. It can be used for the design, manufacture, installation, operation and dismantling phases. In energy analysis, BIM methods can reduce errors caused by data loss, manual data transfer or model duplication, and in this way save time and costs.

With the help of the BIM method, the specific planning of a building's energy system can be carried out more efficiently thanks to a larger amount of available information, which reduces the need for assumptions. Early and integral planning results in many advantages with regard to the use of renewable energy sources such as solar energy.

However, there are many limitations in using the BIM method for energy analysis. Almost all known stand-alone simulation programs such as TRNSYS or EnergyPlus are not compatible with the established BIM-based data formats, IFC and gbXML. In addition, the available IFC object model of the solar energy components like PV or ST are neither standardly nor completely parameterized. Furthermore, the use of the BIM method is so far limited to the planning process so far because of its complexity.

In this study a parametrization for an uncovered PVT was developed based on standards such as VDI 3805, IEA SHC task 60 and buildingSMART. Then the proposed IFC object model was built with the parameterization developed with FreeCAD. In order to transfer the necessary parameters from the BIM-model (IFC object model) into TRNSYS automatically, a python intermediate tool was developed and validated. This tool can start the simulation, visualize the simulation results, compare them with the measurement data exported and send them to the CDE.

In order to use the BIM method in the operation phase for monitoring a facade-integrated PVT, a BIM-model of a Danish Pavilion in Hanover was developed in the BIM authoring software Revit. The BIM-model was further used to create a mockup digital twin for monitoring the PVT-facade in the CDE. The CDE permits the display of the measured thermal as well as electrical yield of the PVT. Moreover, the measured data is compared with the simulation data and the deviation is used for monitoring of the PVT-facade. If the deviation between the measured and simulated data is higher than allowed, then the affected PVT-string is marked in red. In this event, the person responsible will be asked to check the strings.

As a further development of the intermediate tool, parameters of entire PVT fields should be transferred from an IFC file to TRNSYS. In this way, a solar plant can be monitored during the operating phase and adjusted or optimized if necessary. If, based on simulation results or from the comparison between measurement and simulation results, the need to change the IFC file on the CDE (areas, performance parameters, etc.) arises, this change can be made with the interface developed.

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