A Multi-Agent-Based Platform for the Early Integration of Photovoltaic Systems in Building Façades

Steffen Franz[1], Uwe Rüppel[2], Tilmann E. Kuhn[3], Jochen Teizer[4]

1) Research Assistant, Institute of Numerical Methods and Informatics in Civil Engineering, TU Darmstadt, Darmstadt, Germany. Email: franz@iib.tu-darmstadt.de
2) Prof. Dr.-Ing., Chair of Informatics in Civil Engineering, TU Darmstadt, Darmstadt, Germany. Email: rueppel@iib.tu-darmstadt.de
3) Head of Group Solar Façades, Fraunhofer Institute for Solar Energy Systems ISE, Freiburg, Germany. Email: tilmann.kuhn@ise.fraunhofer.de
4) Ph. D., Team Leader, Zentrale Technik, Ed. Züblin AG, Stuttgart, Germany. Email: jochen.teizer@zueblin.de

Abstract:

The envelope of a building offers a so far unused potential for the energy generation. Modern technologies allow a full integration of solar components into the façade or other parts of the building shell. This promotes the expansion of renewable energies without increasing the necessary areas for green field installations. However, their early integration into the planning process of a building is still a complex and labour intensive task. Our approach aims to simplify the procedure by improving methods and technologies like Building Information Modelling and Industry Foundation Classes, and later combining them with a Multi-Agent-based platform. This work presents the necessary steps to digitally describe building integrated solar elements in an open standard. Therefore, we mark the need of an expansion to the IFC structure and afterwards suggest a solution to classify these products correctly. Next, we introduce a Multi-Agent-System as well as the defined agents to facilitate their integration process. Using sample processes, we finally demonstrate our platform's approach and explain its related elements.

Keywords: Multi-Agent-System (MAS), Building Information Modelling (BIM), Industry Foundation Classes (IFC), Building Integrated Photovoltaic (BIPV), façade

1. MOTIVATION AND INTRODUCTION

With the enactment of the Renewable Energy Sources Act (EEG) in 2000 the German federal government laid the foundation for the expansion of renewable energies in Germany. For a successful transition to renewable energy, large areas designated to the conversion of wind and solar energy are required (Henning & Palzer, 2015). This in turn can have a significant impact on nature. Thus, free areas on roofs and façades of buildings offer enormous potential. However, the integration of solar elements in the construction process is still a complex and labour intensive procedure. For the early conceptual stage in the development process of buildings, which is important for the evaluation and dimensioning of applicable technologies, the interfaces between the architectural model, solar components, and energy simulation tools need to be homogenised and simplified. Furthermore, a close collaboration among participating planners is needed. Both demands are addressed in the context of our research project (SolConPro, 2015). Its aims are to define a standardised digital representation of energy active façade components as well as specifying the necessary processes for a holistic integration into building construction processes. To achieve our goals we make use of modern methods in the Architecture, Engineering and Construction (AEC) fields like Building Information Modelling (BIM). BIM delivers methods and technologies needed for a joint development of buildings. This includes the Industry Foundation Classes (IFC), an official and international standard for the exchange of building and construction industry related data. Yet, the AEC industry is still in transition towards full BIM implementation; software applications are either lacking IFC support or do not cover their whole potential. Therefore, a seamless data exchange is still far off. A promising approach toward such issues are Multi-Agent-Systems (MAS). Over the past years, researches have been conducted in order to solve complex problems with the help of MAS. (Geibig, 2008) published a proposal on how to support public procurements of construction works with a Multi-Agent-System. (Theiß, 2005) examined the improvement of sectorial planning with the help of an agent-based system using the example of fire protection engineering.

In this work we advance a proposal on how the IFC model could be extended to cover energy active façade components. Further, we demonstrate a possible way for software-agents to assist the integration of these elements during the planning phase of a building. We also address additional benefits offered by a modular MAS like ensuring data compatibility between different applications or checking the consistency of data.

2. ENERGY ACTIVE FAÇADE COMPONENTS

This paper concentrates on MAS. But first, we want to show basic ideas about describing building integrated solar components digitally, so they can be processed by computers. Depending on the form of energy into which these devices convert the insolation, they can be divided into two major sorts: Building Integrated Photovoltaic (BIPV) and Building Integrated Solar Thermal (BIST). Combinations of both technologies, PV and solar thermal, can also occur (PVT). For all three types various technology approaches with different complexity levels exist. In this work we will focus on BIPV systems. BIST or PVT systems and their interactions with technical building systems like Heating, Ventilation, Air-conditioning and Cooling (HVAC) will be addressed in future work.

2.1 Representing BIPV in the IFC

The major application field of IFC are the construction and facility management domains (buildingSMART, 2015a). The field of infrastructure is still in process (buildingSMART, 2015b) and simulation aspects are part of current researches (e.g. O'Donnell et al., 2011). Therefore, the latest release already covers typical building elements, electrical components and HVAC parts. Despite that, a correct classification of BIPV is not yet possible. BIPV elements convert solar energy into electricity. However, they cannot be simplified as a solar device. They fulfil a multirole, which depends on the integration design to the building envelope. Most common placement options are onto or into a slanted or flat roof, or as part of the façade or shading systems (Prasad & Snow, 2014). This means, next to electricity generation they also serve as structural elements providing protection and aesthetics. Strongly abstracted BIPV can be seen as a combination of solar cells with a window, plate, or slates. These Elements have a direct representation in the IFC model via the entities *IfcSolarDevice*, *IfcWindow*, *IfcPlate*, *IfcShadingDevice*. The first one inherits from *IfcDistributionElement*. This is the superclass of all elements participating in a distribution system. The other three are subtypes of *IfcBuildingElement*, which represents the superclass for all primarily parts of the building' construction. The enclosure system and thus the façade including their elements represent such an element (buildingSMART, 2015c).

The IFC rely on the use of concepts determined by the inheritance hierarchy of the architecture. These concepts define parameters and relationships for the entities of the building model. To make use of the correct concepts, an entity needs to be properly classified. Since BIPV elements belong to both domains – building element and distribution system – they cannot be assigned to either of them. The other available element domains (civil, assembly, component, furnishing, geographic, transport, virtual) and their definitions also do not cover the requirements needed to describe a BIPV device entirely. For the stated reasons, a separate semantic definition for BIPV products as well as their category is needed. Further, there are more similar elements to BIPV, which, too, cannot be described in the IFC model like for example BIST, PVT, or thermal activated walls or ceilings. Therefore, we suggest the introduction of *IfcActiveBuildingElement* as a new subtype of *IfcElement* along with entities for the respective elements. Figure 1 illustrates our defined entities and their relations in an EXPRESS-G diagram.

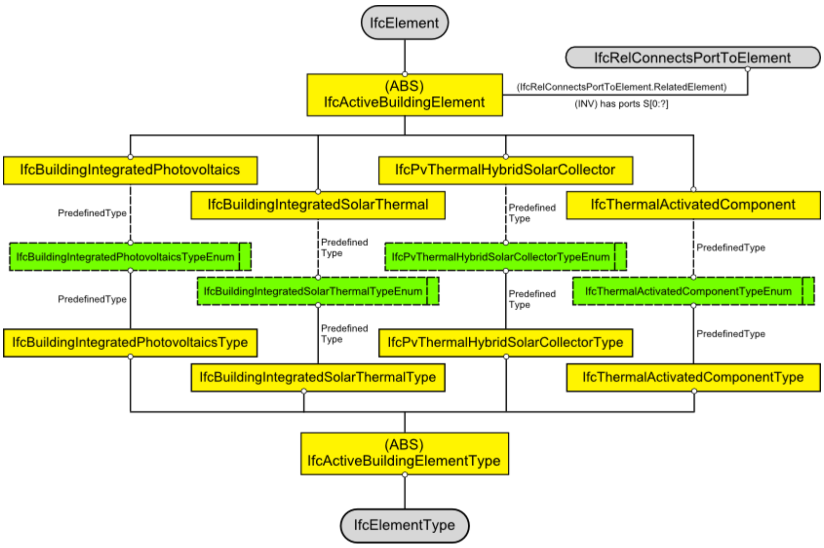

Figure 1. EXPRESS-G Diagram of the IFC Extension for Active Building Elements

Our suggestion applies to the IFC type concept. The various technologies are covered by enumerations. In addition, they provide the related property sets needed. Next, the façade can be represented as an assembly of multiple active and non-active building elements using the entity *IfcElementAssembly*. Continuative work is still needed to define enumerations covering available technologies. Also, corresponding property sets need to be described. The proposed extension to the IFC enables the software-agents, introduced in the next section, to handle energy active façade components.

3. MULTI-AGENT-BASED PLATFORM

The applicability of our platform with a Multi-Agent-System at its core presumes the use of BIM methods like building modelling and collaborative planning. Nowadays, exchange of building data by 2D plans is still typical, but will not be part of the platform's scope, since they lack essential information.

During the design, construction, and operation of a building, many parties are customarily involved. Looking at the processes and software used during these phases, one finds a heterogeneous environment. Processes are influenced by regulations, common methods, and in-house experience. Software is fast moving and differs depending on the task it was built for. Furthermore, competing applications are available, which are often not compatible with each other. This results in a complex and modular environment with different interfaces and formats. A technological promising approach to address these challenges is a Multi-Agent-System. A MAS consists of different agents fulfilling individual internal goals. Taken as a whole, the collaborative effort of several agents leads to a flexible solution for difficult tasks. As mentioned by (Shehory & Sturm, 2014), agents cannot be defined by a single fundamental set of dimensions. (Kirn et al., 2006) propose several properties for an intelligent agent: The agent must live within an environment and should not dissolve once a task has been finished. Next, the agent has to offer a useful service, which is encapsulated within him. He needs to act autonomic and should follow a goal-based practical reasoning. Moreover, an agent should react to environmental changes. He may also be proactive, for example trigger an event in its environment to pursuit its goal. To fulfil his role in a MAS he subsequently needs so called social abilities to interact with other agents. Figure 2 displays our extended implementation for an intelligent goal-based agent, originally suggested by (Shehory & Sturm, 2014), to achieve these tasks.

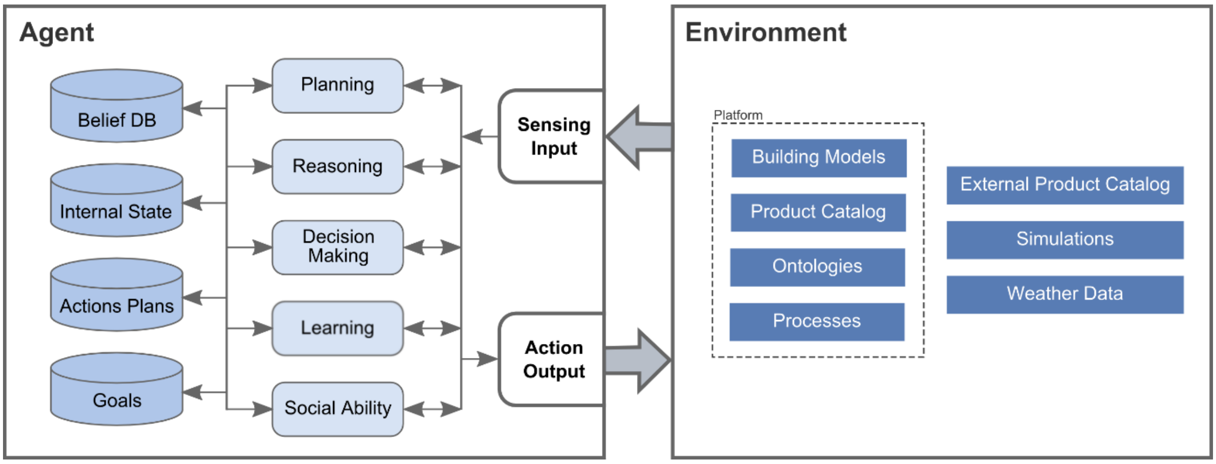

Figure 2. Concept for the Agents' Architecture and Parts of the Environment

Figure 2 also shows the environment, which acts as sensor and output for the agents. The elements within the dotted line are part of our platform whereas the other objects are databases or other tools docked to our platform. Their integration is either realised via web-services or client agents residing in a plugin of these elements. We utilize the open source BIMserver (Beetz et al. 2010) as our IFC-based storage for project related building data. Planner work with their proprietary software on their specific part of the model. At defined points in the process chain, these sub-models are exported to IFC and uploaded to the BIMserver. This triggers tasks like merging a coordination model, clash-detection, or validation in the platform. The BIMserver offers helpful plugins to fulfil these operations (van den Helm et al., 2010), (Zhang et al., 2014). The next part of the environment are platform integrated and external product catalogues. They provide product models of furniture, HVAC components or other building components. As for now, most of the external product catalogues are closed proprietary solutions offering products for specific modelling software. (Gökçe et al., 2012) addressed the need for an IFC-based product catalogue. Their work in mind, we are developing an IFC-based product catalogue for BIPV, BIST and PVT for our platform. One of the ontologies' objectives is to deliver the same meaning for terms across the involved disciplines and domains. Another is the enhancing of the agents' reasoning algorithms. Beyond this, additional databases are integrated such as weather or external product databases. To control the whole system, processes are defined to manage the workflows. (Leifgen et al., 2016) give an overview of the project, platform, and associated processes. To comply with the different processes in planning, a building, the agents behave different depending on the Level of Development (LoD). The following section will describe several agents of our platform and their interactions in supporting the integration of BIPV into the building envelope.

3.1 Evaluation of the Applicability of BIPV

First, a client-agent is placed on every machine integrated into the platform. This is accomplished by the use of plugins for the respective software. Applications that cannot be accessed via an Application Programming Interface (API) cannot be connected to our platform. The agent listens via the API to actions or changes made by the user in their modelling or simulation software and communicates them to the multi-agent-network. A typical task would be to inform the system about the creation of a new element or changes made on an existing one, including the transmission of the relevant object data. Another purpose of the client-agent is the import of IFC-based product data into its associated software tool, if it cannot be parsed before by a translator-agent. A so called element-agent is created for every entity of the project. One of its duties is the administration of the element ID. The Global Unique Identifier (GUID) given by the IFC is an elements primary ID. But since the IFC are used for the model exchange and the building modelling itself is rendered with proprietary software, it is not available from the beginning. The first upload of the model to the BIMserver triggers the creation of the GUID. To enable a real-time integration of our platform into every phase of the building live-cycle this agent needs to know every ID given to the element by the respective deployed software applications. Other tasks of this agent are observing certain parameters and reacting to their changes. Figures 3 a) to d) illustrate the workflow of the first step for integrating BIPV at an early planning stage. The scenario starts with the creation of a new element by the planner. Once the MAS registers such an event, a new element-agent (a) for this component is deployed. He then checks if his associated element is part of the façade and if so he tests whether it can be replaced with a BIPV product. This includes triggering other agents for estimating the usefulness of BIPV at the selected position as well as a search for compatible BIPV products. The assessment-agent (b) checks the applicability and roughly calculates the benefit gained by placing a BIPV element at the desired position. The quality of the assessment relies heavily on the available data. Typical needed information for estimating the impact of shading and the expected insulation include a model of the surrounding, geo-location, and orientation of the element in question. Parallel to this process a catalogue-agent (c) checks available product catalogues for compatible BIPV elements. Every positive feedback triggers the element-agent (d) to check if all conditions for integrating BIPV are met. As soon as this is the case, a parameter of the element changes, indicating that this element could be replaced by a BIPV element. As long as this is not the case, the agent provides information about unfulfilled conditions.

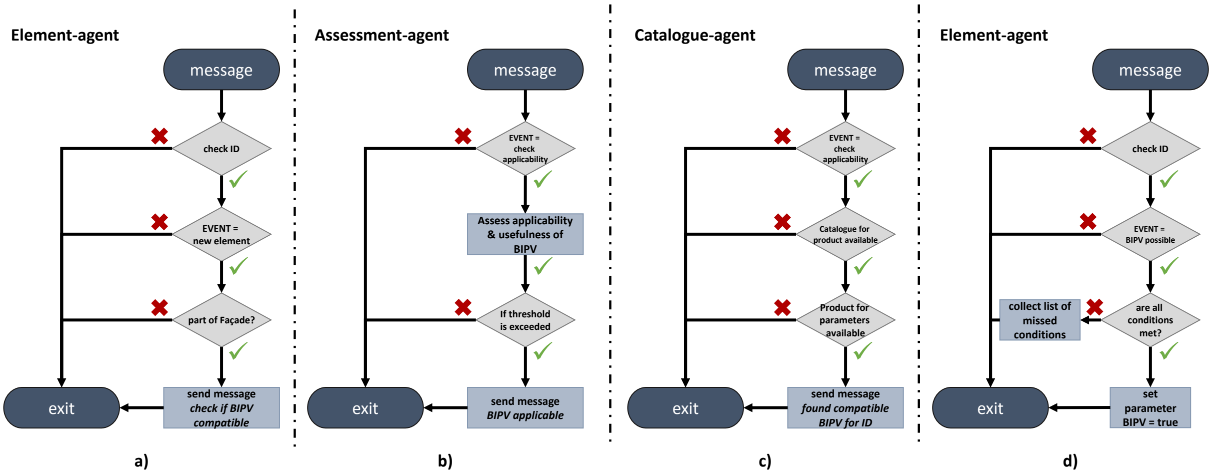

Figure 3. Workflow of several agents for integrating BIPV in an early planning stage

This workflow is also triggered when important parameters like the geometry of the element has changed or the product catalogue for BIPV modules is updated. Further assignments of the element-agent are gathering of related data as well as observation and communication of changes regarding its designated element.

3.2 Integrate BIPV Products into the Building Envelope

Once the planner finishes the modelling he can request a list of feasible components. The catalogue-agent takes into account all the parameters already set such as geometry, colour or material. The selected solution then replaces the original elements like plates, shading devices, or windows. If desired, the platform can draft multiple practicable solutions. The planner can then select different solutions for simulation and comparison. Figures 4 a) and b) visualize this process and the involved agents.

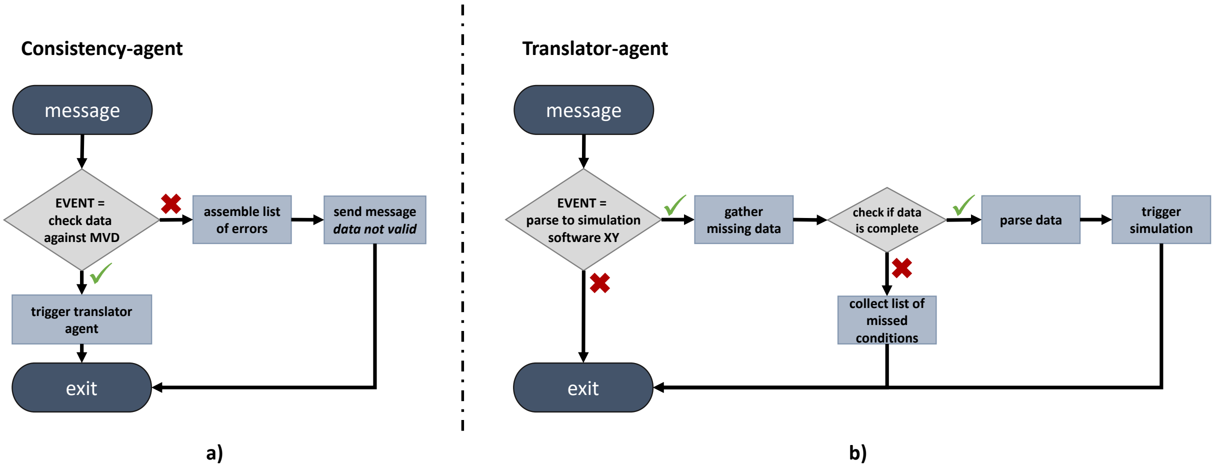

Figure 4. Workflow of Agents Checking Data for Consitency and Parsing It for a Desired Application

Since all data exchange is based on IFC, the consistency-agents use Model View Definitions (MVDs) to check the data for integrity and completeness. MVDs usually serve for the correct exchange of building data. However, they can also be utilized to describe requirements for certain cases of application involving the IFC. In our case, a MVD has to be described for every simulation tool that should be integrated into the platform. But the IFC only cover building related data. Next to parsing the IFC data, a translator-agent also needs to gather all the missing information to perform the demanded simulation.

4. IMPLEMENTATION

To test our approach, we started the conceptualisation and implementation of basic aspects of the multi-agent-based platform and workflows mentioned above. The building modelling is realised with Autodesk Revit 2016. A lighting simulation is achieved with RADIANCE (Larson, 1998). The Multi-Agent-System is implemented with JADE (Bellifemine, 2007). As for the BIPV product catalogue, we described exemplary elements based on available products. Figures 5 a) to c) show the elementary test case and the evolving of the model from the original draft (a), over possible placement options (b) to actual placed semi-transparent BIPV elements (c).

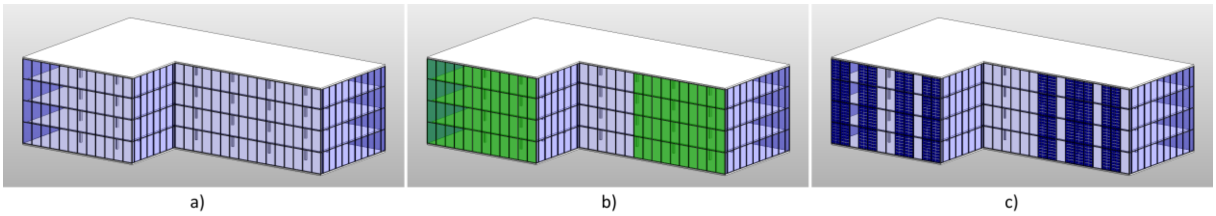

Figure 5. Integration of BIPV Elements into the Building Envelope

The model consist of spatial structure, floors, roof, structural columns and façade. For testing the concept, no advanced detailing is needed. The façade is modelled as a post and beam façade. As explained in chapter 3.1, parallel to the modelling process, element agents are deployed. To quickly estimate which parts of the façade are unshaded aligned with the sun, the functionalities of the Revit API will initially be used. To achieve this approximation, the MAS processes the orientation of the building, geo-location and location of the element in the building that needs to be part of the envelope. To further check if the found elements can be replaced with BIPV elements, the MAS checks the parameters describing geometric dimensions in form of bounding boxes, colour, and material against those of the products contained in the catalogue. Figure 5 b) highlights all elements applicable for BIPV in green. This decision is made regarding the attributes mentioned before. After selecting the desired positions in the façade and choosing a compatible BIPV product from the catalogue, the original façade elements are replaced by the BIPV elements. Thereafter a RADIANCE simulation is triggered by the MAS to receive a detailed result of the insolation onto the BIPV elements.

5. CONCLUSION AND OUTLOOK

We have shown a suitable approach to the heterogeneous environment of a building life cycle with a multi-agent-based platform. The platform so far covers the possibility to integrate BIPV depending on the insolation situation and compatible products. In addition, we made a suggestion on how to digital describe BIPV elements with an open standard. Our work is still limited to the planning phase and a selected range of software tools. Nevertheless, the first steps are taken to assist an architect in integrating BIPV elements. Additional work will extend the MAS to also cover construction and operation phases of a building as well as new modelling and simulation tools. Besides, the agents have to be extended for giving a quantitative and reliable statement on the effects BIPV has onto a building. Concomitantly more parts of the BIPV systems like inverter and interconnection between modules must be taken into account by the MAS. Regarding the integration of BIST or PVT, the cooling and heating concept must be considered.

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