A DECISION SUPPORT SYSTEM FOR BIM MANAGERS ON THE EXAMPLE OF THERMAL SIMULATION

A.Shadrina[1], A.Gutierrez[2], A.Sporr[1], B.Blank-Landeshammer[1], S.Fallman[3], G.Zucker [1],
C.Ruhsam[2] , A.Ferreiro Sistiaga[4], K.Kogler[3]

[1]Austrian Institute of Technology
[2]ISIS Papyrus Europe AG
[3]CES clean energy solutions GesmbH
[4]CYPE Software

ABSTRACT

We introduce a project management decision support system using Adaptive Case Management (ACM) and show how the information about the thermal performance of a building is constantly tracked throughout the design process. The targeted key performance indicators (KPIs) are heating and cooling demand as well as summerly overheating. The overall model quality is documented over the number of inconsistencies between the architectural and building physics partial models. The practical use cases demonstrate how the collaboration between two planning teams sharing project models is facilitated to evaluate the energy-related KPIs for a streamlined collaboration to improve the quality of the project.

INTRODUCTION

The rising popularity of BIM methods in the architecture, engineering and construction industry sparked worldwide the development of software tools that support and encourage a transparent collaborative workflow between all involved stakeholders. Cobuilder, BIMCollab, BIMQ, Viewpoint or bim.server.center are the examples of software products used to store and organize the project information. However, there is not yet a platform that supports the planning and execution in a flexible way, i.e. without strict workflows, but also allows true collaboration beyond a simple file manager. We present a solution where the exchange of information and decision making is guided by the project objectives and where the decisions made by each *Actor* during the planning phase can be traced; the necessary support for a compliant workflow is provided by business rules.

This work defines the collaboration workflow as business focused value stream (VS), covering all modelling goals to be reached (e.g. Approve the architectural model) together with the related Tasks (so called "Actions"), information and involved Actors, with roles such as BIM manager, Architect and Building physics engineer, without relying on the predefined processes or workflows which is not sensibly possible due to the nature of evolving collaboration work. Thus, we replace Processes by goals and a set of available actions, which can be constrained by business rules in order to comply with regulations and laws, until the Actors reach a certain goal by fulfilling completion criteria. This methodological approach is applied to energy-related calculation Tasks of real life building projects using the ACM solution Papyrus Converse, where (1) building Actors store the information (architectural models, thermal properties, etc...) associated with each Task in the project management platform and (2) the objectives are formally defined by business rules so that they can be automatically assessed using the related information. In this way, all involved Actors of the system have the freedom to handle the uniqueness of each situation of a project in order to fulfil the performed actions (provide thermal properties, approve thermal simulation, etc.) in a compliant way. The BIM manager has full traceability of the responsibility of each Actor involved in the collaborative workflow.

STATE OF THE ART

The influence of the collaboration tools and of the communication quality on the building energy efficiency has been profoundly studied (see Haymaker et.al, 2005, Cerovsek T., 2011, El-Diraby T. et al., 2017, Charalambous et.al, 2017, GhaffarianHoseini et al., 2019).

Haymaker et.al in their publication from as early as 2005 compare the theoretical concept of the information exchange with the "chaotic" reality and approach it with the methods developed at the Center for Integrated Facility Engineering (CIFE), Stanford: *POP Method, Narratives,* and *the Decision Dashboard. POP* stands for Product, Organization and Process, which are also the vertical headers for the POP Model table. On the horizontal scale they place Function, Form and Behaviour. "Energy Analysis" in the intersection of the Behaviour and Product, for example, has "Many Options" in the Organization column and "Minimal latency" in the Process column.

Narratives method in (Haymaker et.al, 2005) servers as an input into the *Decision Dashboard,* forming a scheme of connected Nodes and their Dependencies. An example of such a Node is "Option A (Atrium)"

originating from the "Design Antrium" Node and connected, among others, to the "First Cost Option A" and "Productivity Option A (Best Case)" Nodes. *Decision Dashboard* is an organizer for the Nodes and Dependancies, allowing the User to navigate between different design options and compare them by such factors as Productivity and Costs. A lot has changed since 2005, and such software solutions as, for example, Cove tool (Cove tool, 2020) can support the decision making process with the machine learning optimization algorithms, but such methods as discussed by Haymaker et.al are still worth revisiting while looking at the communication challenges in the BIM application context.

Oraee et. al (2017) offers a comprehensive review of the collaboration tools and approaches, pointing out that "collaboration has been almost entirely addressed from a technology-oriented lens" while the lack of information management and process misalignments is one of the main obstacles in addressing the challenges outlined above. In the qualitative part of their research, the authors define five key notions – *Context, Process, Task, Team* and *Actor*. In particular, *Context* is understood as organisational environment and BIM education and *Process* as tools and software, while the other notions address the influence of the task types (*Task*), defining roles and responsibilities in the teams (*Team*), and the role of the individual team members (*Actor*). According to their analysis, *Task* and *Actor* are receiving less attention in the collaboration studies in comparison to *Process* and *Context*.

In this study and in an associated research project, we are addressing *Actors* in a *Team* and their *Tasks*. An IFC-based thermal simulation of three projects is used for the configuration of an energy-calculation application built on the Adaptive Case Management (ACM) approach (Swenson, 2010). ACM supports the execution of business cases – the *construction projects* - based on the analysis of the data for each case and on the decisions taken by the *Actors* according to their expertise instead of a predefined strict workflow. The orchestration of a traditional process-based workflow that adapts to the individuality of each building case and involved *Actors* is difficult or even impossible, so that ACM proposes the assessment of the current situation to support the *Actors* in their decisions which next best action is to be performed to reach the specified goal. The information regarding the execution of each *Task* and the taken decisions of each *Actor* is stored in the case and can be fully traced through the project life cycle.

Finally, there is currently no or little support of the IFC data exchange among the tools used in Austria for the calculation of the heating and cooling demand as well as the checking of summerly overheating. On the international scale, there are already some simulation software tools such as CYPEtherm, Eplus or IDA-ICE which are able to exchange data with the help of IFC,

nevertheless the approach of creating Plug-ins to link two particular applications, and even two particular versions of these applications, is still the most prominent solution to this problem. The focus of this work, however, has been placed on the communication between the *Actors* and the distribution of *Tasks,* rather than on the technological challenges and their *Context*.

METHODOLOGY AND APPROACH

Project setup

In terms of thermal simulation, this project focuses on the setup and configuration of the common project collaboration workflow to ensure precise and timely communication between the members of the architecture team and the building physics team. Thus, an attempt is made to study how an improved communication and a clear definition of *Tasks* can ensure that IFC models exported by an architect can be used for thermal simulation rather being forced to recreate a thermal model manually in different tools.

Another goal of this research is the rapid verification of energy efficiency benchmarks as key performance indicators (KPIs) that quantitatively assess the influence of planning decisions on energy efficiency (e. g. thermal losses across the building envelope, expected heating demand or summerly overheating in critical areas), giving direct feedback to the planner or architect on the impact of design decisions.

Figure 1 shows the used modelling software and the associated data formats involved in the thermal KPIs tracking integrated into the ACM platform Papyrus Converse (ISIS Papyrus, 2019). It also presents the formats and tools required to check the completeness of the building material information.
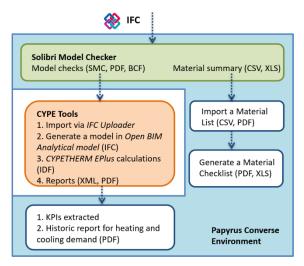

Figure 1 Software setup and data formats

Papyrus Converse (blue background in Figure 1) offers (i) a Business Designer (Papyrus Converse Composer) which empowers the business analysts with a graphical user interface to build their own

conversational business applications as business value streams. They use domain specific business language defined by an ontology, a rule book for business rule definitions and (ii) a conversational user interface (Papyrus Converse Player) for an easy and intuitive chat-style type of collaboration work available as Web- and Mobile-application.

Integration with existing applications and infrastructure is facilitated by a broad variety of Papyrus Adapters and Type Managers in order to automate actions whenever technically feasible. These compiler and platform independent interfaces reduce the amount of time and effort required for interfacing with existing applications, data and devices. For example, Papyrus Converse manages the execution of the Solibri model checker (shown in green in Figure 1) (Solibri Inc, 2020) and the associated input/output files using its autorun feature. The CYPE Tools were not so tightly integrated because the required interfaces were not in scope of the project.

CYPE Tools (shown in orange in Figure 1) are the thermal simulation tools and the associated model import/editing software programs. Initially the "IFC Builder" was used to create the analytical model for the simulation, however another tool called "OpenBIM Analytical model" in combination with the "IFCUploader" showed better results (see the section "Use Case 2: Model Import and the analytical model" for more details).

The output of the **Solibri model checker** is a list of detected issues in three different formats: a PDF report, a BIM Collaboration Format (BCF) report and a native Solibri file.

The material summary is generated with the Solibri user interface from the architectural model and exported as an Excel spreadsheet (see section "Use Case 1: Basic model checking"). Then this material summary is compared with the "material list" which is generated with the building physics software. The comparison result is exported into a PDF report ("Material Checklist") containing a summary pie chart and a table with a combined table from a Material list and a Material summary. The marking indicates which material was found in the architectural and/or building physics list, so that the BIM manager can take decisions based on this report.

At the current stage of research, the material list for the building physics (BPH) model is created manually as materials cannot be exported in this format from the CYPE software. Nevertheless, it was discussed with CYPE to become available in future software releases.

All of these files and their subsequent versions are transparently stored in Papyrus Converse, while editing is done in the native applications.

It is important to note, that the term "Material" in this paper defines "a building element type", hence the "Material List", "Material Summary" and "Material Checklist" are different stages of what is often referred to as "Bauteilliste" in the Austrian building physics practice. For example, a description such as "external wall of reinforced concrete with mineral wool insulation" is referred to as a "material", while "reinforced concrete" is referred to as a "material layer".

Use Cases

The goals of the thermal simulation value streams are defined based on the following four use cases (*Table 1*): (i) *Basic model checking*, (ii) Definition of *thermal properties of building envelope*, (iii) Simulation *of Heating and Cooling demand* and (iv) Simulation of *Summerly overheating*. Different KPIs are defined for each use case in order to measure the project progress.

Table 1 KPIs of the use cases

Use Case	Use case name	KPI in the project
UC1	Basic model checking	• nr. of gaps between the building elements • nr. of overlaps in building envelope • nr. of correctly assigned material names
UC2	Thermal properties of building envelope	• U-Values of the envelope $[W/m^2K]$ • g-Values of the envelope
UC3	Heating and cooling demand	• total heating demand $[kWh/m^2a]$ • total cooling demand $[kWh/m^2a]$
UC4	Summerly overheating	• cooling demand in critical zones $[kWh/m^2a]$ • operative room temperature in critical zones [°C]

The UC1 includes reviewing the building model created by the architect (ARCH Model) to ensure the building envelope is closed and material names for the building elements are assigned. The definition of thermal properties (UC2) is performed after the assignment of materials to building elements, which allows calculating U-values and g-values for the transparent building elements. These two values are the KPIs for this use case. Finally, based on the thermal properties and further settings (see section "IFC-based thermal simulation"), thermal simulation applications evaluate either *the heating and cooling demand* or *the summerly overheating*, which are the KPIs for the corresponding use case (UC3 and UC4, respectively). This set of properties is covered by the building physics model.

PLATFORM IMPLEMENTATION

Value stream definition

Papyrus Converse implements the ACM methodology described in (Gutierrez Fernandez, et al., 2019a) and (Gutierrez Fernandez, et al., 2019b), where each case

is described as a value stream (VS). VSs are defined as an end-to-end value for the building project owner, i.e. each single value stream is expected to provide a benefit for the involved partners when successfully finished. The value streams for the four use cases are illustrated by a Figure 2: (i) *Approve ARCH model* (UC1) after basic model checking, (ii) *Approve BPH model* (UC2) after providing thermal properties, (iii) *Approve Cooling and Heating demand* (UC3) and (iv) *Approve Summerly Overheating* (UC4), respectively. A value stream is formally defined by a sequence of goals which the *Actors* have to fulfil through the execution of actions like uploading the building model. The fulfilment of the goals is assessed by the Papyrus Converse platform through permanent observation of goal completion actions which represent formally defined completion criterions like "ARCH model must be approved". As long as they are not fulfilled, they are clearly marked to the *Actors* as open actions.

Figure 3 shows the last three VSs (UC2, UC3, UC4) in detail. Actions marked with grey colour are to be manually executed by Actors, in order to provide the data needed for the execution of the next action. Those actions marked with a rhombus symbol require the fulfilment of an explicit business rule in order to progress with the value stream.
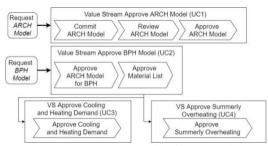

Figure 2. Value streams for the thermal calculation collaboration workflow

With the two action integration possibilities, namely (i) direct invocation of external programs from Papyrus Converse or (ii) loose integration where Actors are only instructed to deliver certain values for the execution of a certain action, we could prove the flexibility of the solution. This is especially important for a tool-agnostic approach in order to avoid dependencies from tools and which integration interfaces they offer. Thus, constructing collaboration workflows as depicted in the Figure 2 and Figure 3 supports the BIM Manager and the contractors to comply with the project-related Employer Information Requirement (EIR) document (BS EN ISO 19650-5:2020).

Ontology definition

Business goals and rules are described using business concepts, e.g. "building envelope". These business concepts are described in a domain-specific business ontology in order to ensure uniqueness of terms and their alignment between all involved parties.

An ontology is a formal description of knowledge as a set of concepts within a domain (e. g. architectural model, building materials), their specific properties (e. g. creation date, model file, model author) and the relationships that hold between concepts (e. g. a building envelope has materials). The formalization of such business concepts in an ontology is also a first step to automate their management (persist building data, evaluate the business rules, etc.).
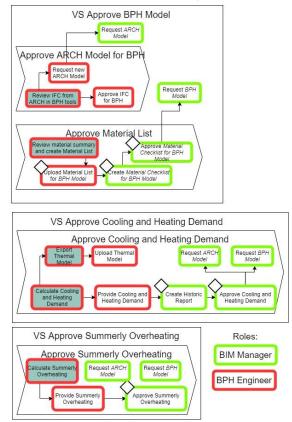

Figure 3 A detailed view of the value streams for the use cases 2-4

The novelty of the taken approach with Papyrus Converse is that value streams with their business goals and rules can be defined and managed by business analysts and do not require IT-development. This way VSs can be amended in short iterations, which is important in order to react short term to changing business requirements and laws. Rules are defined with a formalized natural language editor. This allows to define business logic like: "In order to calculate *Heating Demand*, the *BPH Model* must have a *Material List Report*", which uses the involved specific business concepts (e.g.: *BPH Model*, *Material List Report*, *Heating Demand*) to assess, if the heating demand can be calculated.

The formalization facilitates a structured approach supported by modelling tools to ease the definitions. Figure 4 shows an excerpt of the domain specific ontology focusing on the *BPH model*, its properties

(*Material List Report*, *Material Checklist Report*, *Cooling Demand KPI*, etc.) and that it *extends* the *arch model*.
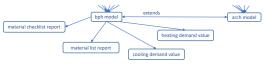

Figure 4. Ontology graphical editor

Rule-based collaboration workflow

Based on the relations between business concepts and their properties, the business analyst can define business rules with natural language patterns. For example, as stated before, the building physics model with U-values and g-values is defined through the related architectural model (walls, window and door openings, etc.). A typical relation is "A *BPH Model* extends the *ARCH model*".

The rules can be used (i) as goal completion criteria for a certain value stream instance or (ii) as constraints for actions, e.g. "To calculate the heating demand, the building physics model must have a material list report". The defined rules and the evaluation of their status (*satisfied* and *unsatisfied*) support the *Actors* in the execution of a VS instance either as a recommendation of a best next action or to prevent the execution of certain actions which are not yet eligible.

IFC-BASED THERMAL SIMULATION

Test cases and associated files

Three test cases were provided by the participating construction and engineering companies as IFC files: a fragment from a multi-storey residential building, or "tower" (ten floors from the original project), a hotel building and an office building (Figure 5).

As a coincidence, all three of them where modelled in Autodesk Revit, but originate from different architectural companies. However, none of them directly participated in the research project, so the possibilities to adapt these models were limited (the models were only available in IFC, not in the native authoring format). Nevertheless, the value streams were configured to allow the tracking of iterative collaboration and to ensure the support for the improvement of the models based on the requirements by the BIM manger and building physics engineer. We explicitly wanted the thermal calculation being done on the original architectural model rather than on a geometry recreated with a special building physics tool only for the purpose of thermal simulation.

However, further models were still necessary in order to test the workflows and to detect the steps where the data loss occurs: a simplified box model with four walls, windows and doors and a simplified tower model created in the IFCBuilder. In the following section the model-checking approach is described.
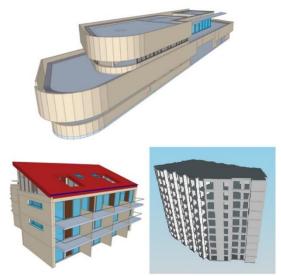

Figure 5 3D views of the test cases: office (top), hotel (bottom left), residential tower (bottom right)

Use Case 1: Basic model checking

The Solibri Model Checker is used to check the model quality of the IFC models. Predefined model-checking rules in the Solibri environment can be used or combined through configuration. Furthermore, checking rules can be freely defined through the API (Application Programming Interface) offered by Solibri. In the first step predefined rules are combined in a way to identify three different errors, which are relevant for heat demand calculations:

Gaps between outer walls: Gaps between outer walls can be identified by using different methods and identifiers: first, only walls, which have "is external" property set to "true", are included into the checking process. These walls are checked depending on their base areas distance and the relations stored in IFC to each other. Distances that exceed the predefined value or missing links are resulting in an error.

Overlaps of different IFC entities: Overlaps of different IFC entities are checked depending on their base ground again. If there is any intersection, an error is generated.

Existence of material names: The existence of material names is checked by investigating the material, which is referred from Solibri to particular elements.

All errors are accumulated into a report, which can be exported in different formats as BCF (BIM Collaboration Format) or PDF (Portable Document Format). The results of the above-mentioned checks depend on the model quality: if IFC properties like "is external", or different relations are not assigned, the checks will fail, and the result will not be meaningful. In this case, the change request is sent to the Architect with the indication on what should be changed in the

BCF format (see Figure 3 the topmost green rectangle "Request ARCH model").

In a second step, a Java programexports a list of materials from the IFC file (see Table 2) using the API offered by Solibri. This program is executed in Solibri like a regular Solibri rule and creates an Excel-file with two sheets of data. In the first sheet a list of all checked components with their identifier, name, respective material definitions, as well as their gross area is listed. The second sheet contains a list of all the different materials used in the components of the IFC model that were part of the checking, as well as the overall gross area of components each of those materials is assigned to. As shown in Table 2, only slabs, walls and roofs were considered so far.

Use Case 2: Model Import and the analytical model

As the models provided by the participating companies were not created and exported according to the standards required for the seamless import into IFC Builder, many initial attempts of importing the IFC models into the IFC Builder resulted in most of the model components missing. But attempts for a holistic modelling approach using the default Revit family, provided by Autodesk, for a simplified "box building", containing only four walls, two slabs, doors and windows, has proven a successful import into IFC Builder. Similar issues are documented for other IFC-based simulation software (see Chen.Q et al., 2017).

Table 2 Material summary structure

Property in the output file	Source in the IFC
GUID	GUID
IFC Type	IfcElement type: IfcWall, IfcSlab or IfcRoof
Name	Name of the IfcElement
Gross Area (m2)	Solibri calculation based on geometry
Material name	Name of the IfcMaterial
Material thickness (cm)	Thickness of the IfcMaterialLayer containing the IfcMaterial

Further attempts were made to import the IFC model using the new "Open BIM Analytical Model" tool (CYPE Software, 2020). This tool is currently in a prototype stage, however, the import of the already mentioned simplified box building as well of the simplified Tower model clearly shows the advantages over the IFC Builder. The rooms (IfcSpaces) are also correctly imported and do not have to be manually redefined, which results in considerable time savings compared to the IFC Builder approach.

As a result of the data exchange using IFC, it can be summarized that simulation programs for determining heating and cooling demand as well as checking the summerly overheating require a very simple or, in other words, generic model to avoid the manual trimming and tuning work within the BIM software

tools. In reality, however, architectural models are often very complex and contain many components that are irrelevant for the simulation, such as handrails, equipment elements, facade details, etc. One of the solutions could be standardized export settings utilizing Level of Detail specifications (LODs) and relevant Model view definitions (MVDs), so that only components necessary for the simulation are part of the export. This would benefit if the import into the simulation software would be standardized as well.
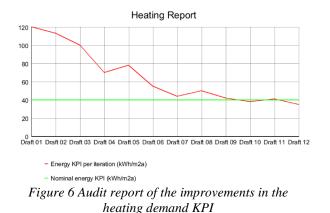
Use Cases 3 and 4: Model Setup and simulation

Once the analytical model has been successfully created, the calculation was done in CYPETherm EPlus, using the necessary target values for heating and cooling temperatures and room occupancy, as well as inputs for shading, internal thermal loads, orientation and location including current weather data sets. Unfortunately, the "Open BIM Analytical model" tool does not recognize neither the materials nor the material layers which are indispensable for the simulation. We solved that with a manual creation of the material layers and therein contained materials in a list in PDF-format. Once all the setup has been completed, the operative room temperature can be simulated as well as the heating and cooling demand.

Simulation results can be exported in a variety of formats, including text formats, a PDF as well as an IDF- and an XML-format. An XML has the advantage of an automatic KPI-extraction from the simulation report in order to document it in the Papyrus Converse project platform.

It should be noted that CYPETherm EPlus can be used for building load calculations and sizing equipment, which uses the heat balance method recommended in the ASHRAE handbook fundamentals (ASHRAE, 2017), but does not support the exact procedure for the summerly overheating calculation required in Austria (OIB, 2015). Nevertheless, as the focus of this study was not to produce a set of documents for an official project submission, it was decided that a maximum operational room temperature in summer serves as measure for summerly overheating in both residential and non-residential test cases.

The results of each thermal simulation run for a specific version of the building model are historically stored in Papyrus Converse as part of the value streams. Evaluated against the specified KPIs, these results show the impact of model changes for each model iteration, as it is depicted in the Figure 6.

Figure 6 Audit report of the improvements in the heating demand KPI

Analysis and discussion

The assessment of the energy indicators continuously present during the execution of the collaborative workflow for the described use cases in order to guide the *Actors* when performing their work. Some of these indicators are calculated with the help of third party tools, such as Solibri Model checker, IFC Builder, Open Analytics Tool, or CYPETherm Eplus. The use of these indicators in each use case is as follows:

- UC1: The assessment of the quality of the building envelope is supported by the integration with Solibri model checker based on the predefined model checking rules, which are executed as soon as the architectural model is committed.

- UC2: Automated comparison between material lists: one list was generated from the architectural IFC and one based on the building physics model. The goal of such a comparison is a unified list of materials used by the project consortium from the beginning. Furthermore, an overview of all materials in the IFC model and their areas is automatically generated with the help of Solibri.

- UC3, UC4: The KPIs from the XML reports exported from the thermal calculation tools are uploaded into the project platform Papyrus Converse.

The execution of the use cases showed the following obstacles handicapping a fully automated integration with external tools:

UC1: There is a large discrepancy between the modelling conventions for architectural models and the requirements for the seamless import into the IFC Builder or into the Open BIM Analytical Model tool: export to IFC is a fragile process that depends on various export parameters that are proprietary to the authoring tool. Further standardization with regard to a consistent Employer's Information Requirements (EIR) is needed.

Furthermore, the resulting BCFs exported from the model checks need to be manually processed by the BIM manager before they can be used as a basis for

the basic model quality assessment and for thermal simulation.

UC2-4: The approach to the automation of these use cases would be to store the materials and the settings for the simulations (such as occupancy schedules, location, target operative temperatures, etc.) separately from the geometry. All of these settings should be combined and described as a building physics partial model prepared by the building physics engineer. After the architectural model is approved, it would be automatically merged with the building physics model and the result could be exported as a consolidated IFC file.

However, that approach turned out to be hard to implement not only in the CYPE tools, but also by the majority of the thermal simulation applications which was confirmed by our industry project partners who are actively using such tools. Not only that the simulation tools do not generally offer a possibility to export a building physics partial model as an IFC or any other machine-readable format, but the idea of exporting and sharing the company's know-how with the planning team may raise questions about liabilities.

Further discussions and experiments are needed to clarify possible alternative approaches to the automated IFC-based thermal simulation.

CONCLUSION

Assessing the energy performance of buildings in terms of their heating and cooling demand within the open BIM practice in Austria often involves remodelling the building envelope using a thermal simulation software, although the envelope was already modelled by an architect in a BIM authoring tool. The presented study and an associated research project contribute to the ongoing efforts of extending the application of an IFC-based automatic thermal simulation in the Austrian construction industry by analysing the business processes leading to the thermal simulation and assessing the requirements to the model without the remodelling effort.

The application of the ACM principle by using Papyrus Converse for the presented energy calculation value stream offer valuable insights into how a rule-based collaboration and adaptation of the employer's information requirements for an individual project can foster clear communication between such *Actors* as BIM manager, Architect and Building physics engineer. Such improved communication will then lead to the improvement of the energy efficiency of the building due to the better-informed decisions from all the *Actors* involved.

Papyrus Converse provides functionality beyond the conventional BIM repository, where the underlying processes can be defined by business analysts using domain specific ontology definitions and formalized

natural language for business rule definitions in order to guide and document the communication process between different teams. The integration of all involved tools can be flexibly handled by the Papyrus Converse platform but depending on the used tools may require manual steps.

The potential use of such a flexible collaboration workflow extends far beyond the thermal simulation. For example, standardized processes for the information exchange in the architecture and construction industry, such as ON A 6241 in Austria and ISO 19650 can be easily implemented by Papyrus Converse as another value stream template together with the associated model checks.

ACKNOWLEDGEMENTS

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