Energy-KPI tracking in building construction processes using Adaptive Case Management

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Abstract. Clean Energy Solutions (CES) is a competence center for energy efficiency, renewable energy and sustainable development and is cooperating with the Austrian Institute of Technology (AIT) on innovations in building planning and construction. Because of the heterogeneity of building projects, the number of involved parties and the building regulations, a solution founded on the principles of Adaptive Case Management (ACM) is applied to support a holistic workflow. The Papyrus ACM solution Papyrus Converse is used to implement flexible business processes fulfilling business goals rather than following predefined workflows. The planning processes are described as value streams by means of a domain specific ontology and actions such as "upload model version" performed by users (architects, building physicists, etc.) are constrained through formalized business rules to guarantee business compliance. Energy specific goals are defined by evaluating the performance of energy key performance indicators (KPIs), which support the decision-making during the whole planning phase. Permanent energy efficiency tracking is done by calculating these KPIs for each version of the evolving building models. Their evaluation requires formalization in the domain specific business ontology and define how they are assessed like comparison with a target value, trend checking: increasing or decreasing, etc. The specification of such assessments for each KPI is a tedious and error-prone task. In this work, we show with practical use cases how the generalization of the business concepts related to KPI management is practically achieved to provide a continuous observation of the KPIs by applying energy calculation tools to the building models during the value stream execution. These generic concepts can be reused for all the energy indicators of a building project, so that additional KPIs can be easily defined by extending the specific ontology.

Keywords: energy efficiency, planning and construction, Building Information Modeling (BIM), Adaptive Case Management (ACM), Business Ontology

1 Scenario

Clean Energy Solutions (CES)[1] is a competence center for energy efficiency, renewable energy and sustainable development and offers complete solutions out of one hand to its clients taking responsibility for the energy design and management in the building sector. CES cooperates with the Austrian Institute of Technology (AIT)[2] on innovations in planning and construction. The building projects involve a number of different parties with their own procedures and tools. Building Information Modelling (BIM) has been extended in the last years to cover the whole building project life cycle, including the geometric modelling, collaboration mechanisms and building physics information.

A solution based on the principles of Adaptive Case Management (ACM) has been designed to describe flexible business processes based on the achievement of business goals as the heterogeneity of processes, projects and parties involved in a construction project makes it difficult to maintain a solution based on predefined processes with BPM [1]. This solution was implemented with Papyrus Converse [2] to define a building ontology which is used as the vocabulary to formalize the building goals and rules that support the user actions. The business goals are (i) the creation of the building models required to calculate energy indicators, and (ii) the implementation of simulations on the models to derive the energy KPIs. The business cases defined in Papyrus Converse as Value Streams (VSs) follow the business architecture proposal [3] [4] of providing an end-to-end value for the stake holder. For example, the creation of a new architecture model shall be provided by an external contractor such as a mechanical, electrical and plumbing (MEP) engineering company. The VSs defined for the building planning are depicted in Fig. 1.

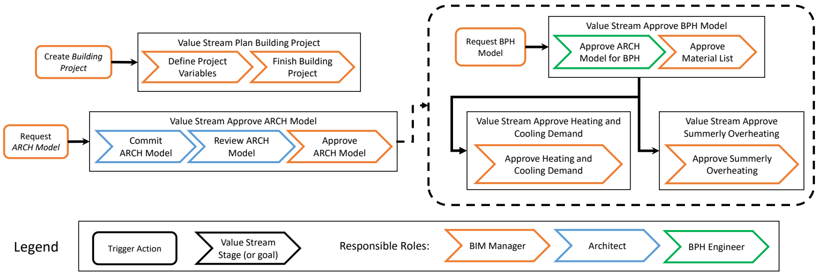

Fig. 1. Value Stream definitions

Three roles were identified: BIM Manager, Architect and BPH Engineer, each of them using their own authorized software, such as Revit for building modelling or CYPETherm for the definition of thermal properties. The Architect provides the architecture model (ARCH model) and does all the necessary changes to the building geometry; the BPH Engineer creates a building physics model (BPH model) based on the ARCH model and designs the material list based on the targeted thermal properties; the BIM

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Manager makes sure the data provided is valid and coordinates all involved parties deliver the information in the requested form. The BIM Manager handles the creation of the building project with its properties, including KPI targets in the VS “Plan Building Project”.

The creation of a new building model starts with the VS “Approve ARCH Model” which aims to create a spatial model of the building by the architect. When an ARCH Model is approved by the BIM Manager, it is extended with the thermal properties of the building elements, described by the BPH model, which is done by the BPH Engineer in the VS “Approve BPH Model”. After the BPH Model was approved by the BIM Manager, the BPH Engineer performs the simulations for heating and cooling demand and summerly overheating in the VSs “Approve Heating and Cooling Demand” and “Approve Summerly Overheating”, respectively, which have also to be approved by the BIM Manager.

The energy efficiency is calculated throughout the planning stages of a building project and assessed regarding specific goals such as energy regulations (e.g.: heating demand is less than 25 kWh/m^2a), or to support project internal decisions like that the heating demand for each new model iteration must not be more than 10% of the previous model. This assessment guides users in a compliant way through the building process to take decisions about which are the next actions to fulfill the business goals. The energy-related properties (heating demand or summerly overheating) are used as operational indicators to support the decision-making process towards the optimization of the various building components such as materials or heating, ventilation and air conditioning (HVAC) infrastructure. Therefore, they are considered key performance indicators (KPI) for effective measurement of the achievement of energy goals.

In this work, we track the evolution of energy efficiency KPIs, such as heating and cooling demand and summerly overheating of one of the recent projects from CES, a residential tower project, which we will call Tower throughout this paper.

2 Problem

A number of solutions attempt to manage the evaluation of KPIs for structured business process with BPMN [5] [6] where the predefined workflow of events supports the processing and evaluation of the KPIs. In Papyrus Converse, the first step to manage the energy KPIs is creating the corresponding concepts and properties in a business ontology to support the building information requirements. In Fig. 2, we depict a set of concept instances involved in the tracing of heating demand throughout the Tower project (the names of concepts and properties are in italics).

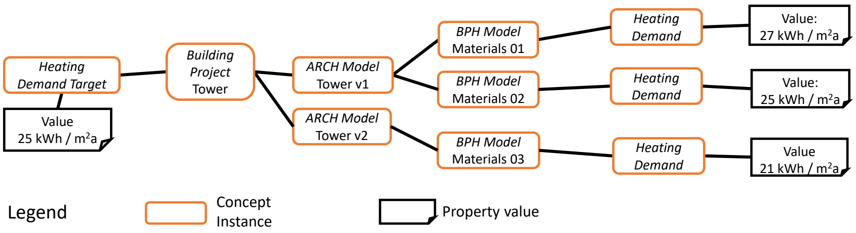

Fig. 2. Business instances of concepts related to the KPI *Heating Demand*

First, the *Building Project* Tower aims at having a heating demand lower than the *Heating Demand Target* 25 kWh/m^2a (which is defined according to country regulations, building purposes, etc.). The *Building Project* has two *ARCH Models*, Tower v1 and Tower v2, which are extended with the *BPH Models* Materials 01 and Materials 02 (for Tower v1) and Materials 03 (for Tower v2). The BPH Engineers calculate the *Heating Demand* value for each *BPH Model* as it also depicted in Fig. 2 (27, 25 and 21 kWh / m^2a, respectively). The assessment of each *Heating Demand Value* regarding their target requires checking the related concepts at runtime (i.e.: *BPH Model*, *ARCH Model* and *Building Project).* Note: other KPIs involve different VS concepts and relationships.

The implementation of the assessment of such KPIs for given ontology concepts and relationships requires defining the relationship between each instance of the concept for the measured KPI value and its corresponding instance of the concept for the KPI target (e.g. instance of *Heating Demand* and instance of *Heating Demand Target).* In other construction solutions [7], each KPI is ad-hoc managed and evaluated. As it is stated before, the concepts and relationships involved in each KPI calculation are different. However, certain operations to support the assessment of such KPIs (e.g. historic evolution of the value, comparison of current values with the target value) are independent of the KPI. As the creation of the relations between the measured KPI value and the KPI target is a repetitive and error-prone task and increases the complexity of the business application, we propose to generalize such assessments. This problem is addressed in the next section.

3 Actions taken

In order to support the management of KPIs, we extended the business ontology with generic concepts and properties for KPI management independent of the domain, as it is depicted in Fig. 3: *KPI Measurement* with property *Value*, and *KPI Target* with properties *Value* and *Operator*. The *Operator* is used to express the mathematical constrain to assess the achievement of the measured value, such as *Heating Demand* has to be ***less than*** *Heating Demand Target*. The required energy indicators are identified as KPIs with the relation between the specific concept *Heating Demand* with the generic concept *KPI Measurement*. Similarly, other business concepts can be defined as KPI concepts. Summerly Overheating and Cooling Demand are examples of KPIs also related to the BPH Model. We depict in Fig. 3 the concept *Envelope Quality*, which is related to the ARCH Model. The *Envelope Quality* is not directly an energy measure but it is evaluated before creating a BPH Model to extend the ARCH Model. The figure shows how the business concepts from Fig. 2 are extended: "*Heating Demand* is a *KPI Measurement"*, "*Heating Demand Target* is a *KPI Target*" so the generic KPI properties are inherited. Instances of these concepts can be created in the system with the proper property values, such as *Heating Demand Target* has a *Value* of 30 kWh/m^{2}a and the *Operator* is ***less than***. Based on the *KPI Target* and *KPI Measurement* concepts together with the business ontology, the connection between corresponding concept instances are automatically traced in the generic implementations of Papyrus Converse to create KPI reports (i.e. reports assessing the KPI value regarding the KPI target value). For example, for the *Heating Demand*, each instance of the *Heating Demand Target* belongs to a *Building Project* instance, which is connected to a set of *ARCH Model* instances, which are also connected to a set of *BPH Model* instances with their own *Heating Demand*. An extract of a set of connected instances is listed in Table 1.

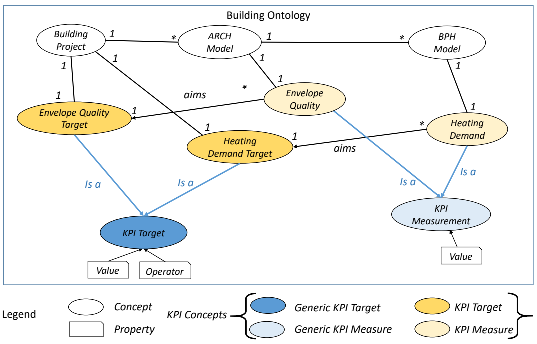

Fig. 3. Ontology enhanced with KPI concepts

Such a list of instances is extracted from building project data, starting from the instances of *Heating Demand Target*, which is the KPI target for the concept *Heating Demand*. This map results of exploring the connected instances of *Heating Demand Target* and *Heating Demand* for the current case. For instance, in the case for the instance of *BPH Model* Materials 01 with *Heating Demand* of 27 kWh/m^{2}a, the connected instance to the *Heating Demand Target* is the *Building Project* Tower. Then, all the instances of *BPH Model* for the *Building Project* Tower are extracted. The Tower (with a *Heating Demand Target Value* of 25 kWh/m^{2}a and an *Operator* ***less than***) has two *ARCH Models*. The first one, Tower v1, has two *BPH Models*, Materials 01 and Materials 02, with their corresponding *Values* for *Heating Demand,* 27 kWh/m^{2}a and 25 kWh/m^{2}a, respectively. The second *ARCH Model*, Tower v2, has only one *BPH Model*, Materials 03, with a *Heating Demand* of 21 kWh/m^{2}a. Therefore, the generation of the report for *Heating Demand* will include three different *Heating Demand Values* for the Tower and only the third of them, 21 kWh/m^{2}a, fulfills the assessment "***less than*** 25 kWh/m^{2}a" (*Heating Demand Target*).

Heating Demand Target (Value, Operator)	*Project Building*	*ARCH Model*	*BPH Model*	*Heating Demand (Value)*
25 kWh/m^{2}a, less than	Tower	Tower V1	Materials 01	27 kWh/m^{2}a
25 kWh/m^{2}a, less than	Tower	Tower V1	Materials 02	25 kWh/m^{2}a
25 kWh/m^{2}a, less than	Tower	Tower V2	Materials 03	21 kWh/m^{2}a

Table 1. Property values to evaluate *Heating Demand*

These reports are automatically provided in Papyrus Converse after the concepts are properly defined as KPIs so the BPH Engineer can uses them to analyze the evolution of the *Heating Demand Value* and its assessment regarding the *Heating Demand Target*, as it is depicted in Fig. 4. which includes a larger sample of *BPH Model* instances than Table 1.

Furthermore, rules based on the evaluation of KPI measurements regarding the KPI target can be added in Papyrus Converse to constrain the possible actions for the user. In Papyrus Converse, these rules for actions have the following syntax:

- In order to [Action], [Constraint over KPI].

For example, the BIM Manager can define the following rule:

“In order to *approve a BPH Model*, its *Heating Demand* must be *less than Heating Demand Target Value*”. In the current state of the project, these rules are evaluated for actions modifying the involved concepts (e.g.: Action “Provide *Heating Demand*” for rules evaluating *Heating Demand*) to guarantee the business compliance when users go along with their project work. Alternatively such business rules could also be defined as goals which have to be fulfilled only at the end of a certain value stream.

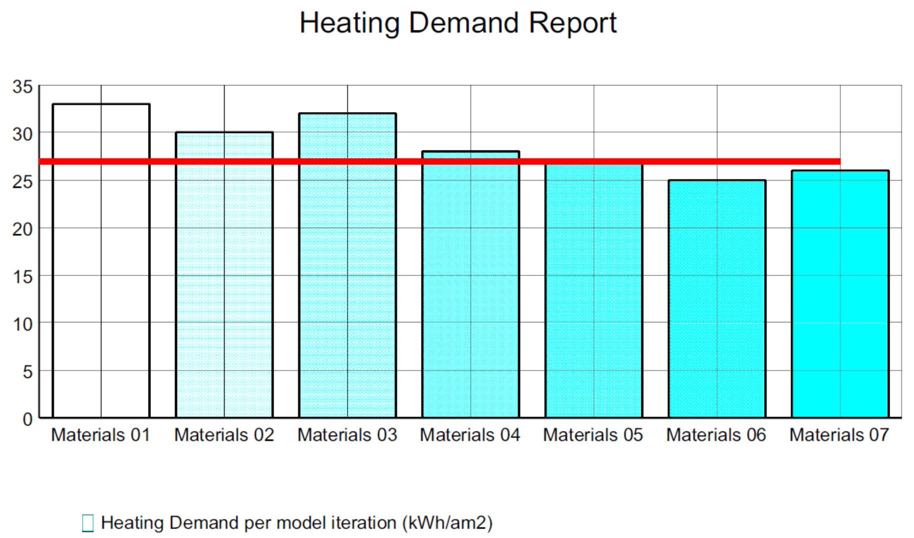

Fig. 4. *Heating Demand* Report

4 Results achieved

As described above, Papyrus Converse [2] has been used to implement the ACM-based continuous tracking and evaluation of the KPIs *Heating* and *Cooling Demand* and *Summerly Overheating* for the Tower. The energy simulation has been performed with products from the CYPE ecosystem (CYPETherm, IFC Builder, etc.). Additionally, CES makes use of the ACM flexibility to execute additional manual and/or automatic steps in the workflow, as it is very important for the participants in the construction industry because the software might vary greatly from one project to another and a fully integration and automated implementation becomes inconvenient and inefficient.

The KPI's are calculated in the VS “Approve BPH Model” using the available *ARCH Model* and the appropriate energy calculation software. As the ontology is used by all the Value Streams in the application, the definition of new Value Streams can also make use of the existing KPI values. Typically, several iterations of an *ARCH Model* as well as of a *BPH Model* are created and tested for compliance with the heating demand regulations and goals resulting in multiple design iterations (e.g. by changing the material, changes in the geometry, etc.). Each new result is stored in the Papyrus Converse value stream instance, so that the KPI evolution can be clearly traced as shown in Fig. 4. The resulting heating demand report offers valuable information to support the future design iterations or further decisions made within the project. It also provides an easy access to the project decision-making history as the changes to the material list and resulting energy demand KPIs are documented in the value stream, offering the necessary tracking and for any auditing purpose like in liability issues. Furthermore, although this solution addresses the energy KPIs in construction projects, the presented approach can be applied in other business domains as well, as it is purely based on the business ontology and thus, its KPIs are freely configurable.

5 Lessons learned

Owing to the state-of-the-art in building simulation tools and certain gaps in the data transfer between ARCH and BPH models, it is technically difficult to incorporate building energy definitions in the early stages of the architectural design. This influences the achievable quality of the building and might cause unwanted last-minute optimizations: when the floor plans and the overall design of the building are already finalized, not much can be done in terms of optimization of the energy use. A clear definition of KPI targets for the energy efficiency in buildings and the ability to track the impact of the changes in the ARCH model on the BPH model fosters the incorporation of the energy design into the early stages of planning.

A flexible, constantly adaptable system of ontology definitions, the relationships between them and finally, the value streams provide a solid structure for the relationships and communication conventions. The need for such systems has been identified by the construction industry, and communication mechanisms are adopted but the use of supporting platforms to formalize them is not sufficiently yet. With the herein described novel ACM-based solution, the important files such as the model files of the ARCH model versions and associated material lists for BPH model are not only kept organized, but also each version associated with a certain decision and a target KPI, is clearly documented. This is a high benefit compared to the current way of storing all this information as unstructured e-mails or project protocols.

The KPIs evaluated in this paper use similar assessments but more complex assessments of KPIs, such as “Cooling Demand has to be ***20% lower than previous*** Cooling Demand”, can limit the development of general mechanisms. Furthermore, the BIM manager wants to define scopes for their evaluation, which the current implementation at CES does not yet consider but will be implemented in the future.

Acknowledgements

This work is funded by the Austrian Research Promotion Agency (FFG) within project BIMSavesEnergy (grant agreement number 861710) where ISIS Papyrus delivers the business architecture enhanced ACM methodology and CES and AIT the construction industry and energy domain specific aspects, respectively.

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