Applying Adaptive Case Management to Enable Energy Efficiency Performance Tracking in Building Construction Projects

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Abstract. Buildings and housings account for a significant percentage of global energy demands. However, building projects often suffer from deviations between planning and reality. In recent years, Building Information Modelling (BIM) has been extended to cover the whole building project life cycle, including the geometric modelling, collaboration mechanisms and building physics information. Although BIM enables the digitization of building planning and operation, the heterogeneity of supporting software, the different procedures of each company involved and the individuality of buildings themselves hinder a seamless collaboration between the parties, making it difficult to trace the impact of decisions. Adaptive Case Management (ACM) is a methodology to handle flexible business processes based on the achievement of business goals during case enactment, without defining strict process models. Therefore BIM management can take advantage of the ACM approach to support the accomplishment of business goals including the traceability between decision making and goal completion, such as compliance with energy-related KPIs. In this paper, we present the first results of applying business architecture principles to ACM for BIM project management that integrates domain-specific BIM tools for the content analysis. This is the first step towards a generic BIM project management solution to support energy efficiency tracking throughout the lifecycle of a building project.

Keywords: Adaptive Case Management • Ontology • Construction Industry • Building Information Modelling • Project Information Management

1 Introduction

In December 2015, 195 countries adopted the first legally binding climate agreement at the Paris climate Conference [2], in which the achievement of greenhouse gas emission mitigation potential in the buildings sector is essential for meeting the targets of the agreement. Energy efficiency in the building sector is one of the key areas to support the transition to a low-carbon economy and contribute to the goals of the Paris Agreement. The building and housing sector alone accounts for 40% of European energy consumption and 36% of its greenhouse gas (GHG) emissions. The recent actions of the European Commission [3] also show a clear strategy and commitment to support the achievement of the goals defined in the Paris Agreement.

The European Commission strives to enforce sustainable principles in the finance industry for the financing of construction projects. As part of this, the Commission plans to develop guidelines for investors and asset managers on how to integrate sustainability as well as risks related to it in the areas of organizational requirements, operating conditions, risk management and target market assessment. To best illustrate the concept of introducing principles of sustainable finance in construction projects, we refer to an example from the Netherlands as presented in the Sustainable Digital Finance Alliance report: ING Real Estate Finance worked with a technology partner to help their borrowers identify the energy improvement measures for their buildings that provided the most attractive financial returns and greatest carbon emission reductions [10]. Following this approach, ING was able to offer discounts on sustainable loans. However, what is not being addressed here is the method used to ensure that the energy improvement measures meet the objective defined in the early project stages. With this approach of applying sustainable principles, it can be expected that there will be an increased number of cases where they may be consequences for the design team, contractor or the building operator in case the sustainability and energy performance indicators do not meet the initial predictions. The lack of information and information asymmetry have been identified as key constraints and barriers for implementing sustainable financing, mostly due to the lack of information disclosure and analytical capability [3].

The heterogeneity of software products and data formats, different internal procedures of project participants, and the individuality of buildings themselves hinder a seamless collaboration between the involved parties and make the management and sharing of different information, documents and models challenging. In recent years we have seen a significant number of software solutions and tools that aim to increase the digitalization level in the construction industry. However, the McKinsey Global Institute industry digitization index [5] demonstrates that the construction industry is still at a very low digitalization level. Partly due to this fact, projects are often confronted with significant deviations between planned and achieved time and budget. What is often not addressed in this context, however, is the significant energy performance gap between how buildings are designed, built and operated. Considering the lack of information management and process misalignments as one of the main obstacles to addressing the challenges outlined above, we propose an approach built on the digitalization of the construction sector to help bridging the gap between design and built performance, and thus support the transition to a low carbon economy.

Because of the aforementioned heterogeneity, strict business process models are difficult or even impossible to define and maintain within a building project life cycle. Adaptive Case Management (ACM) is a methodology to handle flexible business processes based on domain specific business goals in opposition to strict task flows whose enactment is tightly coupled with supporting systems and which are difficult to maintain. BIM processes can take advantage of ACM to support the interoperability of the different parties and facilitate the building project management from the perspective of driving the accomplishment of goals instead of forcing specific action flows.

The remainder of this paper is organized as follows. The challenges that arise in the building project management are described in section 2. Our proposal for addressing these challenges with ACM methodology is described in section 3 and the benefits of applying this methodology are discussed in section 4. Finally, the analysis of this case together with future work are discussed in section 5.

2 Situation faced

The building project management domain typically suffers from non-integrated and fragmented construction processes due to a lack of formalization. Furthermore, task forces are driven by the experience of knowledge workers which is exchanged in small workshops to refine problem recognition. There are no formally defined cross-organization or cross-disciplinary protocols and any interim information such as decisions or reports are delivered manually. This lack of centrally monitored processes hinders tracing of responsibilities and decisions taken by certain parties at different project stages [1]. Current approaches to building design management are coupled to existing and widespread engineering software tools which do not support cross-organizational communication between the different parties. Nor do they enable more transparent project management, where the degree to which the project objectives, such as the energy-related KPIs, have been achieved can be traced back to the associated decisions.

The company Clean Energy Solutions (CES) is the competence center for energy efficiency, renewable energy and sustainable development. CES is operative worldwide and offers complete solutions out of one hand to its clients taking responsibility for the energy design and management in the building sector. It owns several certificates like Austrian Climate Initiative Certified Designer and eco facility consultant, Austrian Sustainable Building Council Consultant, BREEAM Assessor, DGNB Certification Expert and Auditor, EUREM European Energy Manager, LEED Accredited Professional and EU GreenBuilding Endorser. Although the company has successfully implemented BIM tools and processes in their daily work the project teams are faced with the problems described above who need to tackle challenges involved in managing the information represented in the building models. This often leads to inefficiencies and information loss within the specific design discipline and even more in exchange with other design disciplines included in a project.

The energy performance depends on parameters such as building materials, room topology and occupancy, building envelope, mechanical equipment, etc. These parameters are connected to each other and are highly dependent from other design disciplines, e.g. architecture and the respective architectural model. This leads to the problem that the design information of a certain parameter is influenced and managed by multiple parties, such as the architect or the heating, ventilation and air conditioning (HVAC) energy designer. Furthermore, the impact of changes among these parties is either not traced or is manually supported, such as with architectural plans on paper or with incomplete digital models.

In the attempt to effectively solve some of this challenges CES has tried several different information exchange platforms that are available on the market. However, most of those platforms are limited to simplified document management based on versioning. This means that the expected benefits of applying BIM are often missing. The available platforms still do not support effective tracing of the decisions and related impact on the project design. The aforementioned challenges of software and process heterogeneity of different project disciplines and teams present an additional barrier.

Although the described problem focuses on the energy aspects due the specific experience of CES, the same problem definition can be translated to other disciplines as well. By linking this project and operational level barriers to the policy level, it is anticipated that the changes and a paradigm shift happening in development and financing of construction projects, as described in the previous chapters, will facilitate the introduction of a goal oriented design approach which is also more transparently integrated.

In order to achieve this, the management of such a project requires a method and a platform which supports an enhanced and more transparent process management on horizontal levels – i.e. through different project stages - and vertically addressing different stakeholders, project participants and team members. The key for this change is the seamless integration and interconnection of supporting systems into design and then construction and operation processes to assess the project goals in all project phases. The integration and interconnection of these systems and processes have to manage and make the transfer of knowledge-based decisions open to the project stakeholders and participants, such as the architects or the planners of HVAC systems by creating a common data environment [14]. Often different stakeholders and project participants have different levels of technical understanding, which is another reason for introducing a clear and domain oriented methodology as well as terminology, based on the principles of "open BIM", where the information exchange between different disciplines is executed "by means of an uniform open interface and common data structure" [15]. As argued in the beginning of this paper, it is expected that energy related KPI and design performance will gain importance in the overall construction project development where information flow and transparency, as well as goal oriented workflows, will be the key factors to develop construction projects under pre-defined target criteria of energy efficiency and sustainability in a wider sense. As discussed by Rezgui et al. [8], BIM governance is "the process of establishing a project information management policy across lifecycle and supply chain underpinned by a building information model, taking into account stakeholders' rights and responsibilities over project data and information". Building on this definition, the solution proposed in this paper brings a novel approach that focuses on the content related targets and not on the specific predefined task flow. In this way, the dynamic nature of the building design process, which is characterized by frequent changes, can be effectively addressed. This distinguishes the ACM approach from other existing approaches.

3 Actions taken

The current case is addressed in the context of the "BIM Saves Energy" research project, which aims to manage building projects with sustainable processes where the evolution of KPIs related to energy demand and consumption can be optimized throughout the building project and the impact of decisions taken in this regard can be traced between the parties involved.

In order to seamlessly approach the management of energy-related business cases with different stakeholders, we consider the importance of the partners' shared knowledge (such as architectural models or thermal properties) as a key factor. With this objective, the ACM paradigm is proposed to solve the identified problems in BIM projects. As discussed in [6,11], ACM is a methodology designed to manage knowledge work with ad hoc situations that cannot be modelled with predefined workflows. It proposes that the involved business users (aka knowledge workers) adapt the case execution to the situation relevant for each individual business case (e.g. a building project). In other words, ACM supports businesses by letting them focus on content rather than task flows where business processes are difficult or even impossible to model in advance or are susceptible to frequent and rapid changes.

3.1 Business Architecture Approach

In ACM, the business behavior is commonly described with business rules, such as "To specify the window properties, the thermal transmittance value must be defined". The ACM platform has to support the evaluation of such behavioral rules in order to assist the user in deciding on next actions in compliance with these rules. The business applications are maintained by the definition of new rules which have an immediate impact on the case execution. These rules shall be formalized as domain constraints in natural business language [8] to ensure compliance and to help the business user to make decisions. Such behavioral rules are evaluated at runtime by monitoring events in the ACM platform. This avoids the definition of rules using programming languages by IT departments which are not understood by business users.

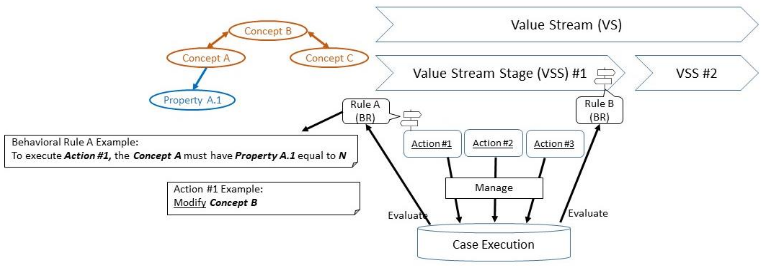

Fig. 1. ACM Methodology

In order to meet the BIM project management needs discussed above we present in this paper an ACM platform that combines the business architecture methodology introduced by Open Group [7] with the business rules concept proposed by Ross [9]. This way the definition of domain-specific requirements from the business perspective will empower business users and allow them to react to specific needs without much IT involvement. Figure 1 introduces value streams (VSs), value stream stages (VSSs) and business rules (BRs). VSs are an atomic end-to-end flow of activities triggered by a certain business event (e.g. a request for constructing a new building) and deliver after completion a value to the involved parties (e.g. an architecture model for the new building). A VS is decomposed into VSSs, each representing individual goals of the VS which are in principle independent from each other but BRs can establish dependencies between them (e.g. the goal "Commit architectural model" depends on "Upload new architectural model"). Further, BRs constrain actions which can be taken by business users either (i) as entrance rules or (ii) as completion rules. The former refer to prerequisites enabling actions (see Rule A constraining Action #1) and the latter evaluate the accomplishment of a VSS (Rule B in Figure 1).

Business Architecture	Synonym	Definition
Value Stream (VS)	Case	Business case with value for customer
Value Stream Stage	Goal	Value Stream decomposed into (sub-)goals to be accomplished
Business Ontology (BO)	Ontology	Domain specific information model with concepts and relations
Action	Task	An action related to the fulfillment of goals
Business Rule (BR)	Rule	Behavioral constraints defined on actions
Business Application		The VSs, goals, actions and rules for a specific domain
Business User (BU)	Knowledge Worker	Person executing a VS and taking decisions within a BA
Business domain analyst	Knowledge Worker	Person defining the BA entities for a specific domain template

Table 1. Business architecture terminology

A glossary of the business terms is summarized in Table 1. A business application (BA) is described throughout its VSs, VSSs, BRs and actions. In order to automate the management of the BA, it is formalized using a business ontology which includes all the business Concepts and Properties involved in the BA (Concept A, B and C and Property A.1 in Figure 1) and it is shared by all the BA partners. This ontology avoids ambiguities or confusing terms and at the same time allows describing the BA in natural language with the help of a grammar. This grammar contains (a) expressions such as mandatory terms (i.e.: must/exists) and conjunctions and disjunctions (and/or), and (b) allows navigating between related Concepts and Properties (e.g.: Concept A has Property A.1). This enables business domain analysts to express a wide range of business rules and actions using a formalized natural business language.

For the project described in this paper, we use the ACM platform Papyrus Converse from ISIS Papyrus [4] with its support for a conversational user interface to implement the proposed methodology. This type of user interface allows business users to intuitively communicate with the system in order to reach a certain goal, guided by the behavioral business rules. The platform provides also a business composer to define all the business entities, that is, value streams, goals and actions, and rules based on a domain-specific business ontology, as depicted in Figure 2. The definition and administration of the business ontology by business domain analysts can be addressed with ontology editors (item 4 in Figure 2) together with data mappings to underlying information systems. These data mappings depend on the business domain but business data structures are rather stable during the business lifecycle so they can be developed at early stages of the domain development. The action enactment is performed by business users through a user interface based on the rule analysis for business compliance. Rule analysis can be performed by a number of event processing engines, as it has already been addressed by our previous work [12, 13].

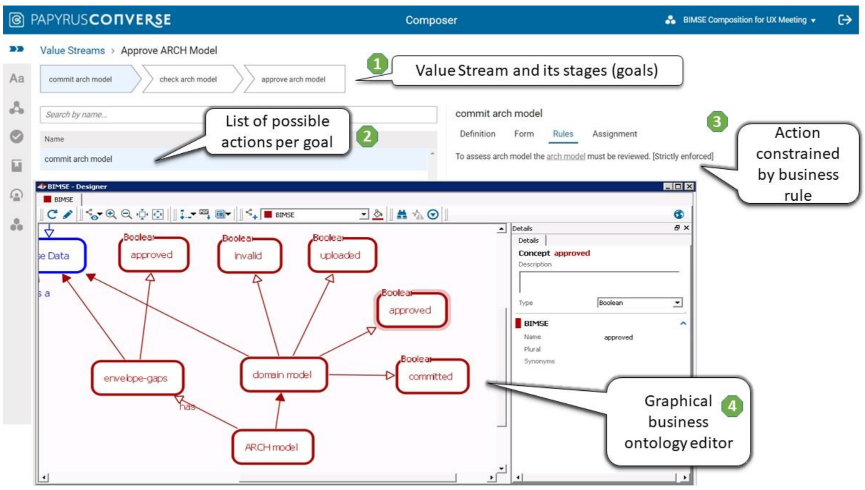

Fig 2. Papyrus Converse Composer and Ontology Editor of the Papyrus ACM Platform

3.2 Modelling the BIM project

In order to address the management of a BIM-based project, we apply the methodology described in the previous subsections. The digitalization of the BIM value streams encompasses the various management levels of the project and enables the interaction between the project participants. These management levels are depicted in Figure 3. In level 1 of this figure, where the different partners responsible for certain building trades define their own domain models, either to meet specific goals for each participant (e.g.: check the quality of building envelope) or goals that involve other partners (e.g.: adding physical parameters to the building elements). With a set of domain models, a complete building model, so called coordination model, is created in level 2 and additional goals can be defined (e.g.: there is no overlapping between pipes and electrical panels). And finally, in level 3, the results of already achieved goals are compared with initially defined KPIs in order to make decisions for next iterations (e.g.: request an improvement in building materials to reduce heating energy demand).

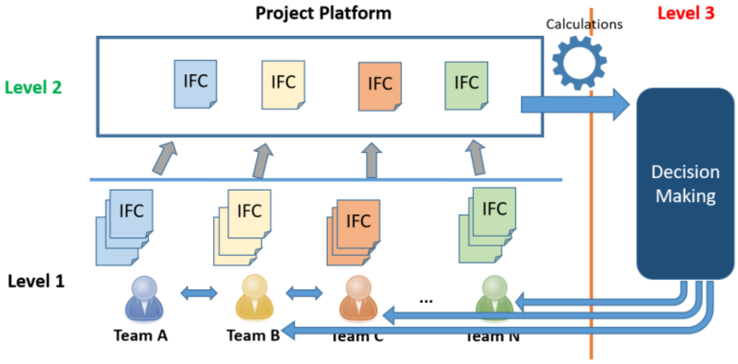

Fig 3. Building project management. Source: FFG project No: 861710 (BIMSavesEnergy)

In this paper, we focus on the value streams related to the use cases of consumption and demand of energy. These use cases cover the calculation of the building energy demand together with the evaluation of the impact of the summer overheating. The thermal behavior of a building depends on factors such as the location of the building, its structure, the room topology or the building materials, while summer overheating is a special case which corresponds to the dynamic behavior of the materials in response to higher temperature in summer and is aimed to completely avoid or reduce the size of mechanical cooling facilities. The related calculations depend on a proper definition of the architecture model (e.g.: without building gaps) and of the building material properties (e.g.: thermal transmittance), which are considered separate use cases but their evaluation is required by the former ones in order to avoid unnecessary, computation-intensive energy calculations. In attempt to address the issue of repetitive actions (if the architectural model does not have the certain model quality, it has to be recreated specifically for the thermal calculations), the architectural model quality checks were introduced: checks for gaps, overlaps and building materials. It is planned to link the architectural and building physics model with the help of material numbers and, in case of the successful checks, use the architectural model as a basis, enrich it with the necessary parameters and proceed to the thermal calculations. We exemplify the use case related to define an architecture model in the value stream *Approve Architectural Model*, depicted in Figure 4. This value stream is composed of three goals, *Commit Model*, *Check Model* and *Approve Model* ((1) in Figure 4).

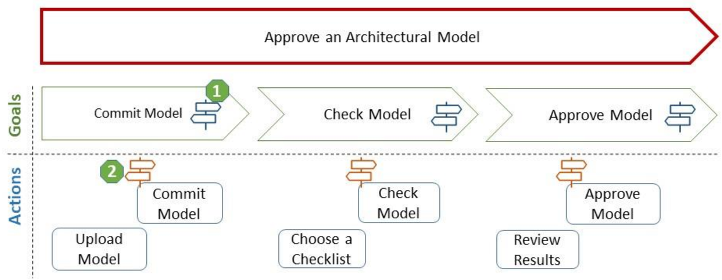

Fig 4. Creation of Business Application from action and rules

The same named goal completion actions are marked with a rule icon ((2) in Figure 4) and guarantee the fulfillment of these goals. The execution of these actions depends on the accomplishment of behavioral rules (indicated by the rule icons), such as "*To commit a model, the model has to be uploaded"*. Other actions involved in the VS are shown at the bottom of Figure 4, such as *Upload Model* or *Choose a Checklist*.

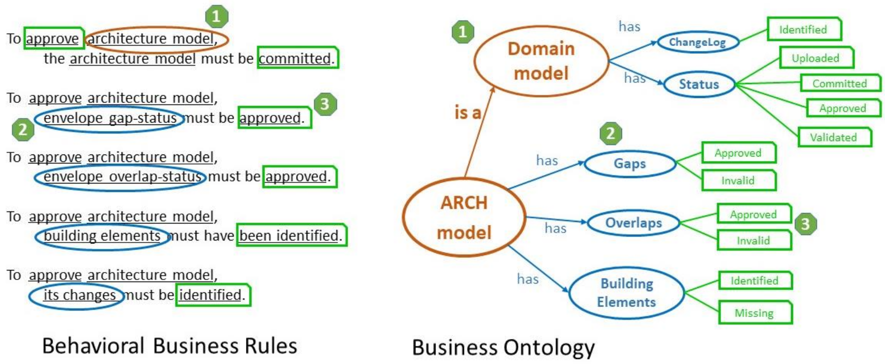

Fig 5. Defining behavioral rules using ontology

To formalize actions and rules, we first design the underlying ontology that allows users to describe each action and rule with precise concepts in business terminology. In Figure 5, we depict this formalization for the value stream *Approve an Architectural Model*. On the left side, behavior rules are shown which constrain the action "Approve architecture model". On the right side are shown the related items from the business ontology. The rules are composed of an action name and a constraint. The action has a predicate composed of a verb and an *object*, such as "Commit *Model"*. The *object* has to be one concept or property in the ontology (e.g.: *Model*, *Gaps*, etc.). The constraint describes the business state required to perform the action and is formalized with the concepts, its properties or property values (e.g.: Status *Approved*, Gaps *Invalid*, etc.). The wording to compose these constraints will depend on the relationship between the involved entities, such as "must have" for constraints on concepts and their properties.

4 Results achieved

Although the formalization of the business application for the four value streams required the definition of more than 100 entities in the ontology (including concepts and properties), 30 actions and 70 rules, the definition of actions and rules could be easily accomplished by using natural language patterns contained in the grammar along with the ontology entities as was described in the previous section. The rules are composed by business users with a rule editor indicating the action in scope (1), as shown in Figure 6. This supports business users in their daily work by providing an intuitive, non-technical application. In addition, the life cycle of the content is fully traced throughout the project, providing all relevant information for taking decisions with regard to energy saving.

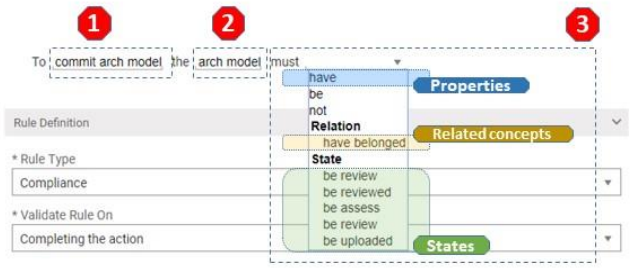

Fig. 6. Rule definition with Papyrus Converse Composer

The concept on which an action is performed ((2) in Figure 6) is constrained by a formalized natural language that suggests verbs such as *have* ((3) in Figure 6) for the concept's properties, *belonged* for describing its relationship with other concepts (or the proper wording for the relationship), or *be* for its states. A rule can be combined with other rules using "and/or" or be negated with "not" although for the reasons of comprehensibility, each action rule should be as simple (atomic) as possible. With this procedure, the expected behavior of the building management is shared by all the partners in a catalog understandable by business users (architects, BIM managers, etc.).

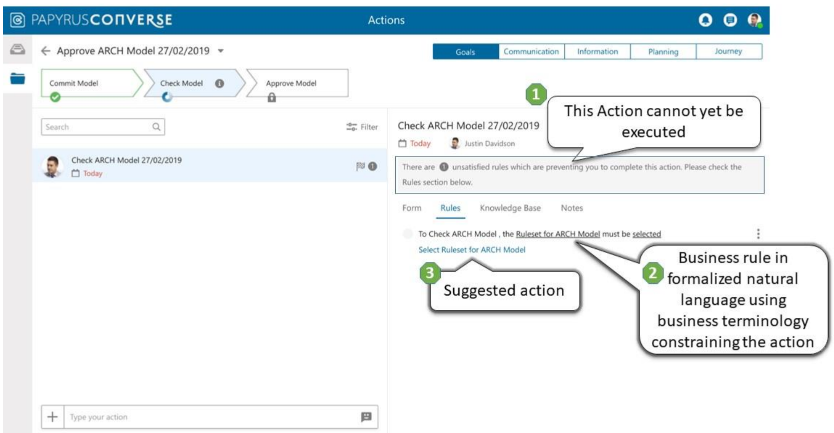

Fig 7. Papyrus Converse Player for case execution by business users

The definition of business actions, constrained by formalized behavioral rules based on an ontology enables the evaluation of these rules in order to support the business user to take precise decisions in the conversational user interface. Furthermore, it avoids the need for implementations of business logic for action flow control in an IT layer. The ACM platform supports decisions with the explicit explanation case requirements as shown in Figure 7. In this figure, the next expected action for the current user is "Check Model". However, as it is described ((1) in Figure 7), this action is not possible because the model checking requires adding some checklist. This dependency ((2) in

Figure 7) is described together with the suggested action ((3) in Figure 7) to fulfill this dependency. In this way, the business user can freely define new actions which are eventually required in a particular situation to fulfill the goal without a strict flow. The case implementation is defined from the business instead of the IT perspective.

5 Lessons learned

One of the first steps in the presented approach is the formalization of the business information model with a business ontology that describes all entities for the definition of goals, actions and rules. In our project, business users from the construction industry with many years of experience in their field were asked to define these ontology entities on their own. We realized that it requires several iterations to review the value streams with all stakeholders at CES (and their departments) as well as AIT in order to identify the involved entities in an unambiguous way. But it was recognized as an essential benefit to achieve a common terminology and to agree on “the way we work”.

The formalization has required a structured approach which was supported by the business domain analyst using the Papyrus Converse Composer for the definition of actions and rules described in section 3. One key element in this iterative process is the modelling tool used, which must support intuitive editing and reviewing of concepts and relationships. To this end, we have worked with a graphical editor to facilitate the management of relationships. As the ontology becomes more complex, the possibility to work with business-specific subdomain definitions provides a valuable mechanism to avoid errors and redundancies. This initial effort was not taken into account in the management, resulting in delays in the initial phase of the project and in the implementation of cases. Despite the initial definition effort mentioned above, we found that the effort decreases rapidly as soon as the ontology becomes more complete, as new rules can be formulated by reusing existing concepts and relations as well as by adding new items to meet new business requirements. The execution of energy efficiency tracking requires a flexible integration layer so that different tools from different vendors as well as open source projects like Solibri and EnergyPlus can be easily integrated to establish an agnostic base implementation. The iterations of architecture model changes and frequent material adaptations until defined energy KPIs are met can be seamlessly executed and verified and are a proof for the ease of usage by the involved parties and their domain specific users. These encouraging results allow us to apply this methodology and solution to new projects with a wider range of construction industry companies. The initial results also show significant potential to apply the similar approach outside the specific energy domain.

Acknowledgment

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