A FRAMEWORK FOR ‘CPD AND 5D BIM’ PROCESS REUSE

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ABSTRACT

This paper tries to establish a framework for process reuse in ‘collaborative product development’ (CPD) with 5D BIM. 5D integrates 3D models with non-geometrical metadata, costs, and schedules that can be developed in three main ways (part-recipe, task-part or embedded link). For continuous process improvement (CPI), we identified barriers and enablers and proposed explicit and implicit process reuse support options via workflow systems, process repositories with new process querying.

Keywords: process reuse, 5D BIM, collaborative product development, workflows, BPM, CPI

1 INTRODUCTION

Processes that were actually executed and delivered results, meeting or exceeding expectations, call for reuse. These *best practices* either save time or money, deliver a higher quality of products and services, or improve customer satisfaction. In this paper, we focus on two types of process reuse.

The first type of process reuse addresses the collaborative product development (CPD) best practices, which involve inter-disciplinary AEC professionals. We are interested in process reuse as a way of business process management (BPM) that embraces BIM practices and technologies.

The second type of process reuse relates to a 5D BIM that consistently integrates geometry (3D) with non-geometrical metadata, costs (4D) and schedules (5D). A 5D BIM improves transparency and stakeholders’ communication and reduces costs, risk and production times.

The CPD of a 5D BIM can be divided into three workflow categories, depending on the product-process model mapping: (1) *Part-Recipe*, (2) *Task-Part* and (3) *Embedded* link (Figure 1).

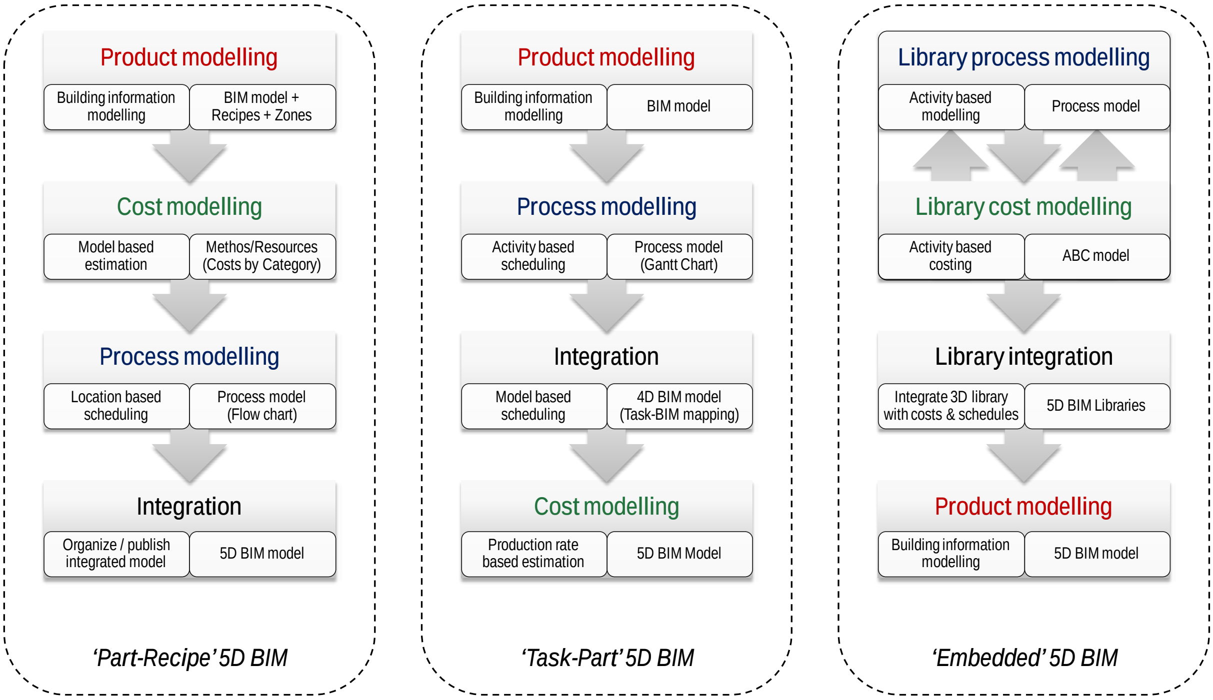


Figure 1: Three ways to develop a 5D BIM: (1) Part-Recipe, (2) Task-Part and (3) Embedded link

1.1 Part-Recipe 5D BIM

In the Part-Recipe 5D BIM, the process starts with product modelling whereby part libraries are used to model a building along with a set of reference architectural drawings or models. A construction recipe is assigned to each building part. A recipe is stored in a relational database that is linked to the method records, where each method is further linked to a unique set of resources (labour, material, equipment, and sub-contracting). Each resource has defined costs and/or a production rate per unit.

Cost modelling is based on an integrated model-based quantity take-off that enables automatic calculation of quantities, which are multiplied by the unit values for the required resources. Scheduling includes the development of a work breakdown structure that is linked to zones, enabling location-based scheduling (see Figure 3). The state-of-the-art representative of the above approach is offered by Vico Software. A conceptual model of 'Part-Recipe' CPD processes is shown in Figure 2, below.

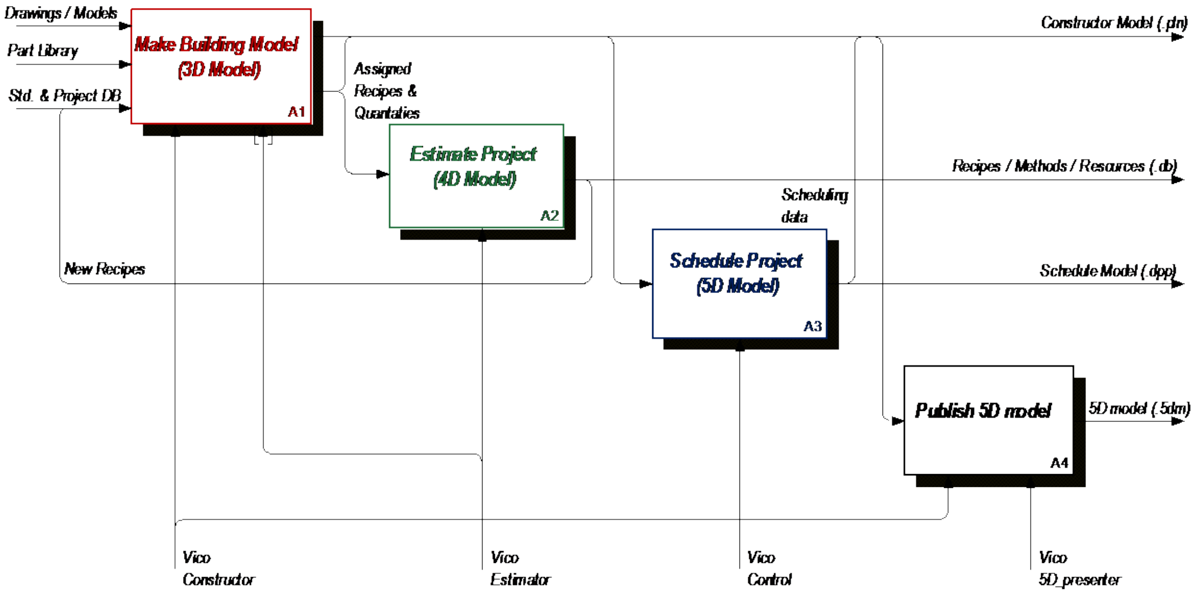


Figure 2: A conceptual process model of 'Part-Recipe' 5D BIM (adapted from Cerovsek, 2008)

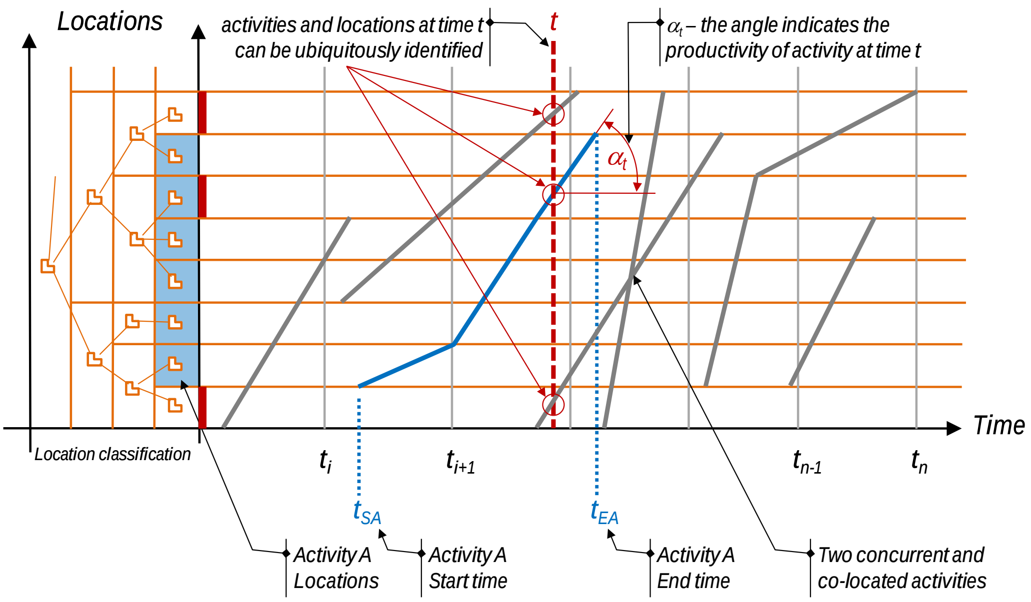


Figure 3: The flow-chart as a source for process reuse that includes both times and locations that are hierarchically broken-down. For example, for "*Activity A*" (blue), start and end times for the entire activity (t_{SA} *and* t_{EA}) and for particular locations can be read, whereas the angle of the activity line represents "*productivity*". The flowchart also enables easy identification of concurrent and co-located activities. Note that each activity has own workflow and consumption of resources that can be reused

1.2 Task-Part 5D BIM

In this case, a process model may be developed concurrently with or even before the building model is developed. In the first phase of process modelling, the hierarchical work breakdown structure (WBS) with classifications of tasks (without task durations) is determined.

Once the BIM model and WBS (which can be reused) are in place, we can assign building parts to the tasks. Next, we take the advantage of a model-based scheduling whereby task durations are calculated based on the production rates and actual quantities that are automatically calculated from the model. Additionally, erection order and sequencing may be defined, buildings parts may be filtered and quantities may be exported for detailed cost estimation. The most prominent example of Task-Part model-based scheduling is provided by Tekla, which uses an Open BIM approach to do building detailing and process modelling in one single application.

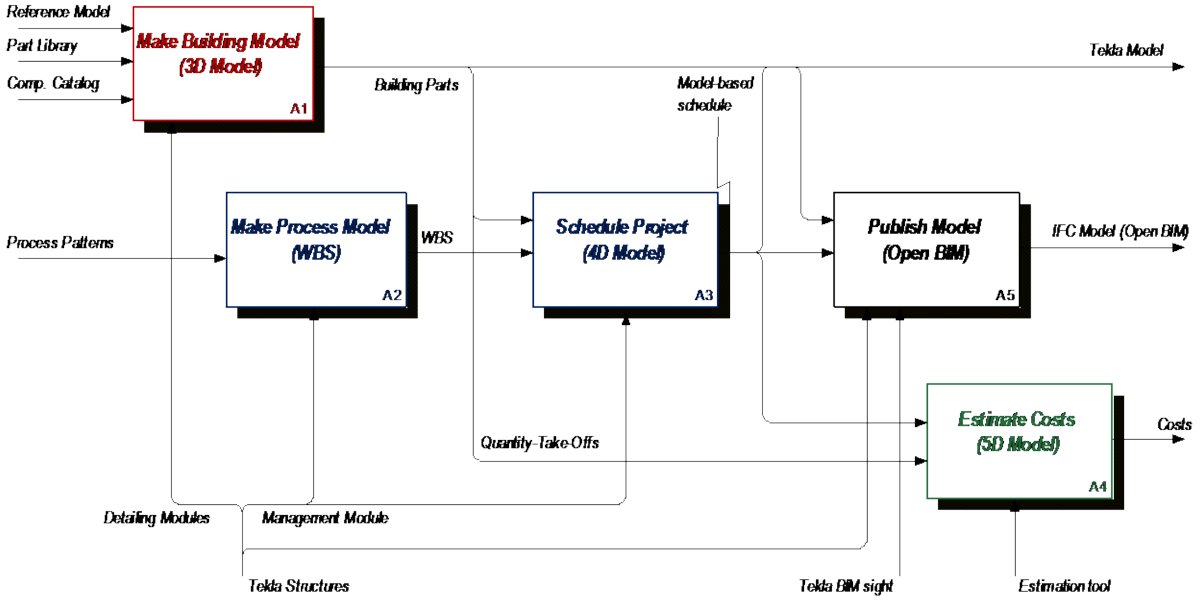


Figure 4: A conceptual process model of a Task-Part approach to modelling of 5D BIM

1.3 Embedded 5D BIM

Embedded 5D BIM is based on the 5D Part Library. Each part already contains parameterised information on the costs and time required for construction. As a building is modelled, a 5D model is automatically created that contains information about geometry, costs and scheduling. These libraries could be connected with web services. The result of a 'collaborative product development' (CPD) process from Fig.2 is a 5D model that includes processes.

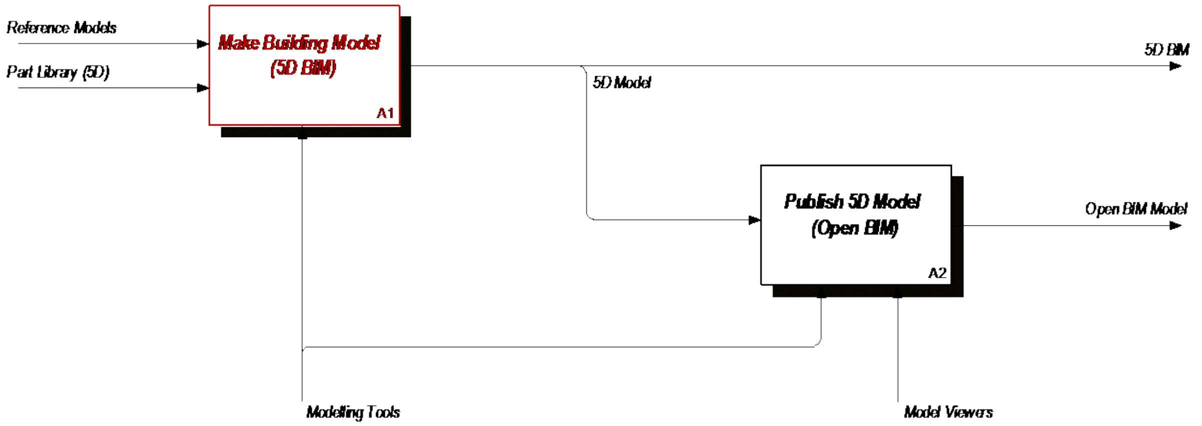


Figure 5: A conceptual process model of an envisioned Embedded 5D BIM based on a 5D Part Library modelling that enables automatic modelling of costs and schedules

2 REVIEW AND DEFINITIONS FOR PROCESS REUSE

In this section, a review is given of time dependencies and first order logic descriptions for explicit and implicit reuse. In particular, we formally observe '*when and how*' issues related to process reuse. In contrast to the intuitive, ad-hoc reuse of parts' non-process data, the ad-hoc reuse of parts of actual CPD and 5D model processes is not so straightforward. The problem is with media, whereby processes are executed and modelled, and *important workflows, actors, and tools* that lead to results may not be recorded. Table 1 gives standpoints that describe characteristics affecting reuse in CPD business process management (BPM). From the process perspective, we can divide any knowledge into: (1) *how*, or process-knowledge and (2) *what*, or process result-knowledge (Cerovsek et al. 2006).

2.1 Related work

The reuse of processes has been widely studied in many professional fields. Development efforts are justified by specific application requirements, which include a configuration of relevant standpoints, characters and capacities (Cerovsek 2011b). Although different methods may be used for process reuse (Maurizio 2000), any development of a process reuse system must study at least the following *three essential issues*:

- barriers and enablers to process reuse,
- process-reuse repositories, and
- process similarity measures.

Barriers and enablers to process reuse. The barriers that prevent process reuse may be grouped into seven categories (Goderis et al. 2005): availability, rigidity, intellectual property rights, interoperability, difficult process discovery, highly limited process knowledge acquisition, and lack of ranking for fragments of processes. Furthermore, researchers identified special problems for process reuse in overly-restrictive procedures, incomprehensible processes (Henninger 1998), differences in process modelling techniques (Greco et al. 2008), or different use of roles. The enablers for process reuse are the classification of processes (Biplav 2009), the use of controlled vocabularies, semantics with ontologies (Philippe 2006), and the advanced use of specialised workflow information search engines (Qihong 2009). Technical components of software architectures that enable process reuse include the following functions: assess, cast, display, navigate, retrieve, adapt, and specify business processes (Zlatkin and Kaschek 2005; Fiorini et al. 2001).

Process-reuse repositories. The availability of processes is the first and the most important prerequisite that enables process reuse. Each repository may be described by six generic properties that determine the efficiency and effectiveness of process reuse: volume, ownership and access, format, metadata, structure, and dynamism. An important goal of any repository for process reuse is to assure the availability, relevancy and adaptability that match specific methods. In software development, where reuse systems are more developed, a typical process reuse is often based on case studies (Funk and Crnkovic 1999), process customisation (Henninger 1998) supported by process schema and process adoption rules with process review. An important enabler is to observe processes from different levels of abstractions (Cerovsek et al. 2006; Xiaorong 2007). In scientific research, an effective enabling approach for reuse is a graph-matching algorithm for the discovery of similar workflows; processes can be used in a segmented manner or as wholes. Therefore, IR should be made possible on different parts and/or granularities. The repository should not force the use of overly restricted processes, but it should ensure traceability.

Process similarity measures. If we want to reuse, compare, or improve processes, we must be able to find and group similar processes. Therefore, we need process similarity measures. These measures may be adopted from information retrieval (IR) of texts (Jae-Yoon 2008), linguistic analysis, graph-theory structural analysis, or other hybrid approaches. For example, the similarity between process workflows can be categorised based on language or structure (Wombacher 2006) or through iterative combined similarities of process names (Juntao 2009), and sometimes it is easier to use dissimilarities (Dijkman et al. 2008; Remco 2007). The same similarity measures are used for grouping (clustering) of processes, e.g., k-means clustering (Greco et al. 2008), hierarchical clustering (Jae-Yoon 2008), or structural clustering.

2.2 Process reuse timeline

The use of similarity measures in process reuse requires some formal definitions. Processes may be modelled before, during or after actual processes. Furthermore, modelled processes may target and refer to processes at different times (see Fig 2). Time dependencies between modelled and actual processes are essential for reuse. Note that processes may be created by modelling or/and by doing.

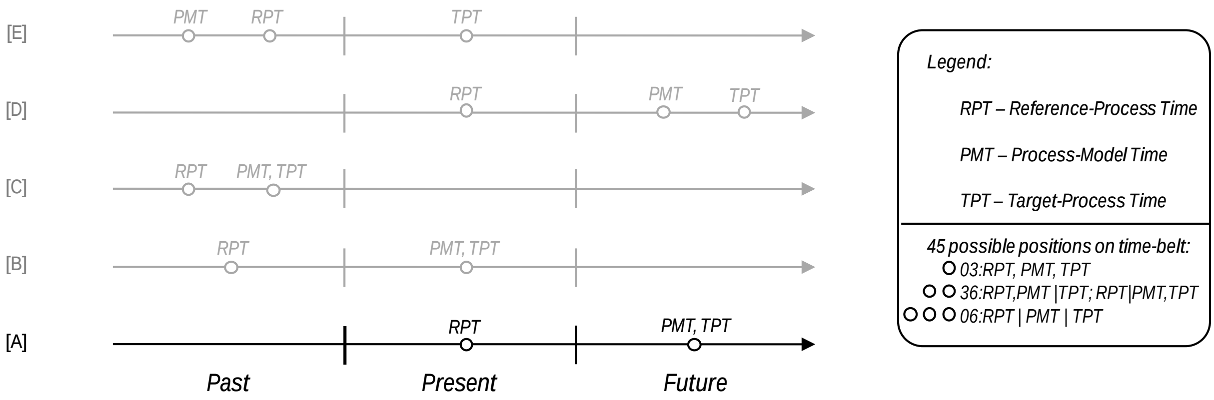


Figure 6: The 'process reuse time-belt' illustrating variations of time-based dependencies among: '*process-model time*' (PMT), '*reference-process time*' (RPT), and '*target-process time*' (TPT). Description of examples: [A] '*to-be*'; and [B] '*as-is*' process models, as known from the BPR; [C] '*as-it-was'* process model; [D] '*transition*'; and [E] '*adapted*' process model. The models [A-D] are only a few chosen from 45 possible variations of the PMT, RPT, and TPT positions (Cerovsek 2011b)

2.3 Explicit and implicit process reuse

Any executed reference process can be explicitly reused (adapted) in target processes if they are compatible. Such compatibility can be measured with a distance. Mathematically, the distance *d* is a measure that satisfies the distance criteria (i.e., positive, symmetric, triangle inequality). The distance may be Euclidian, angle based, p-norm (e.g., block distance, Chebsyhev), or IR specific (e.g., Levinstein - edit distance, Jaro-Winkler, or Hammin). We can conclude that if the distance between two process models exists, than processes can be explicitly reused to reuse or to find a process:

$$\forall x \forall y \exists d\ (\mathrm{Process}(x) \wedge \mathrm{Process}(y) \wedge \mathrm{Distance}(x,y,d)) \leftrightarrow \mathrm{ExplicitReuse}\ (x,y) \qquad \textbf{(1)}$$

The implicit process reuse enables the retrieval and re-use of processes, even though processes cannot be explicitly compared, where searchable features linked to unsearchable items make unsearchable items searchable, possibly through common controlled vocabularies *CCV* for metadata *m*.

$$\exists m\ (\mathrm{Metadata}(m) \wedge ((\mathrm{Has\_Metadata}(x,m) \wedge \mathrm{Has\_Metadata}(y,m))) \rightarrow \mathrm{Linked}(x,y,\mathrm{CCV}(m)) \qquad \textbf{(2)}$$

$$\forall x \forall y \forall z\ (\exists a\ (\mathrm{Related}(x,y,a)) \wedge \exists b\ (\mathrm{Related}(y,z,b))) \leftrightarrow \mathrm{Related}(x,z,y) \qquad \textbf{(3)}$$

where a and b can be any type of common parameters, features or objects. The logical propositions define two processes to be related if they have common features, metadata, or events. The above definition also implies ternary relationships, if we combine several items into one item. Note: the above definitions are recursive and very powerful as one can contain any type of relation.

$$\forall x \forall z\ (\neg \mathrm{Similarity}(x,z)) \wedge \exists y\ ((\mathrm{Are\_Related}(x,z,y)) \wedge (\mathrm{Similarity}(x,y))) \rightarrow \mathrm{ImplicitSimilarity}(x,z) \qquad \textbf{(4)}$$

The solution is an implicit transitive similarity that could allow end-users to search processes for reuse implicitly, although there is no direct relation between target and reference processes. Therefore, it is important to know the content that may enable reuse in the context of CPD with 5D models. Detailed description of the issues addressed in section 2 is available in (Cerovsek 2011b)

3 THE ROLE, REQUIREMENTS AND PROTOTYPE FOR PROCESS REUSE

This section provides an overview of the requirements for process reuse with a short description of prototype implementation, which illustrates basic concepts. The main goal of the developments is to develop an approach that will allow for easier transfer, adoption and adaptations of business processes.

For the development of any process-improvement facility, it is important to understand the dynamics of business process management (BPM). The main goal for BPM is continuous process improvement (CPI) to assure that instead of seeking a radical breakthrough, process optimisation proceeds via continuous, incremental improvements as illustrated on Figure 7 below. We are addressing CPI through process reuse in CPD and 5D BIM modelling approaches.

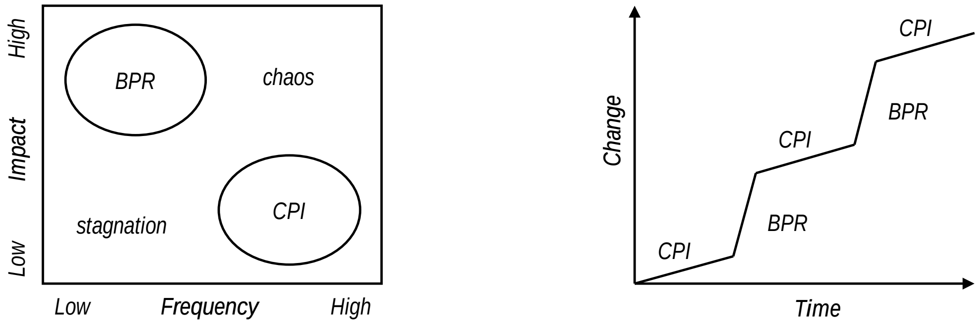


Figure 7: The role of continuous process improvement (CPI) and business process reengineering (BPR) as important driving forces for process reuse (image source: courtesy of van der Aalst)

3.1 General requirements for process reuse

The requirements for process reuse are:

- Enable reuse of CPD and assure continuous process improvement (CPI).
- Capture activities' collaborative process development, integration and interoperability.
- Make processes retrievable implicitly and explicitly through advanced information retrieval.
- Be non-redundant in process reuse and enable process retrieval through retrieval.
- Assure consistency of process descriptors with the use of controlled vocabularies.

If we observe BIM models in reference to the physical buildings, both can be divided into "as designed" and "as-built" processes, which are covered in the process timeline, described in section 2.2. However, CPI in CPD with 5D BIM would require remodelling of both process and product models. Depending on the interface synchronicity, we can make a time-wise division of the display of and process use into: synchronous and asynchronous process reuse.

- Make possible the reuse at different granularities (see Figure 8)
- Do not force the use of overly restricted processes because they do not allow improvements
- Enable better discovery, indexing, searching, retrieval, and reuse of process and product data

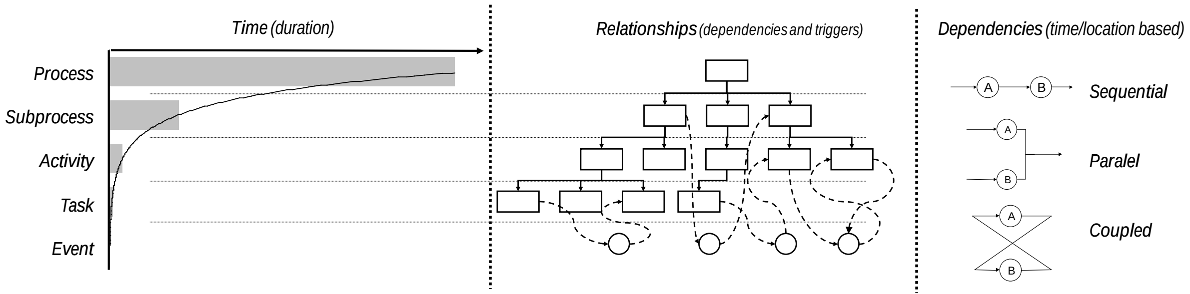


Figure 8: Structural dependencies between processes that should be taken into account for reuse

3.2 Scenario with elements of software architecture

The prototype was developed as a part of an ongoing effort to develop an adaptive system (Cerovsek 2011a). The approach is used as a high-level functional architecture that allows for further developments that combine CPD and BIM related to the selection of technological solutions.

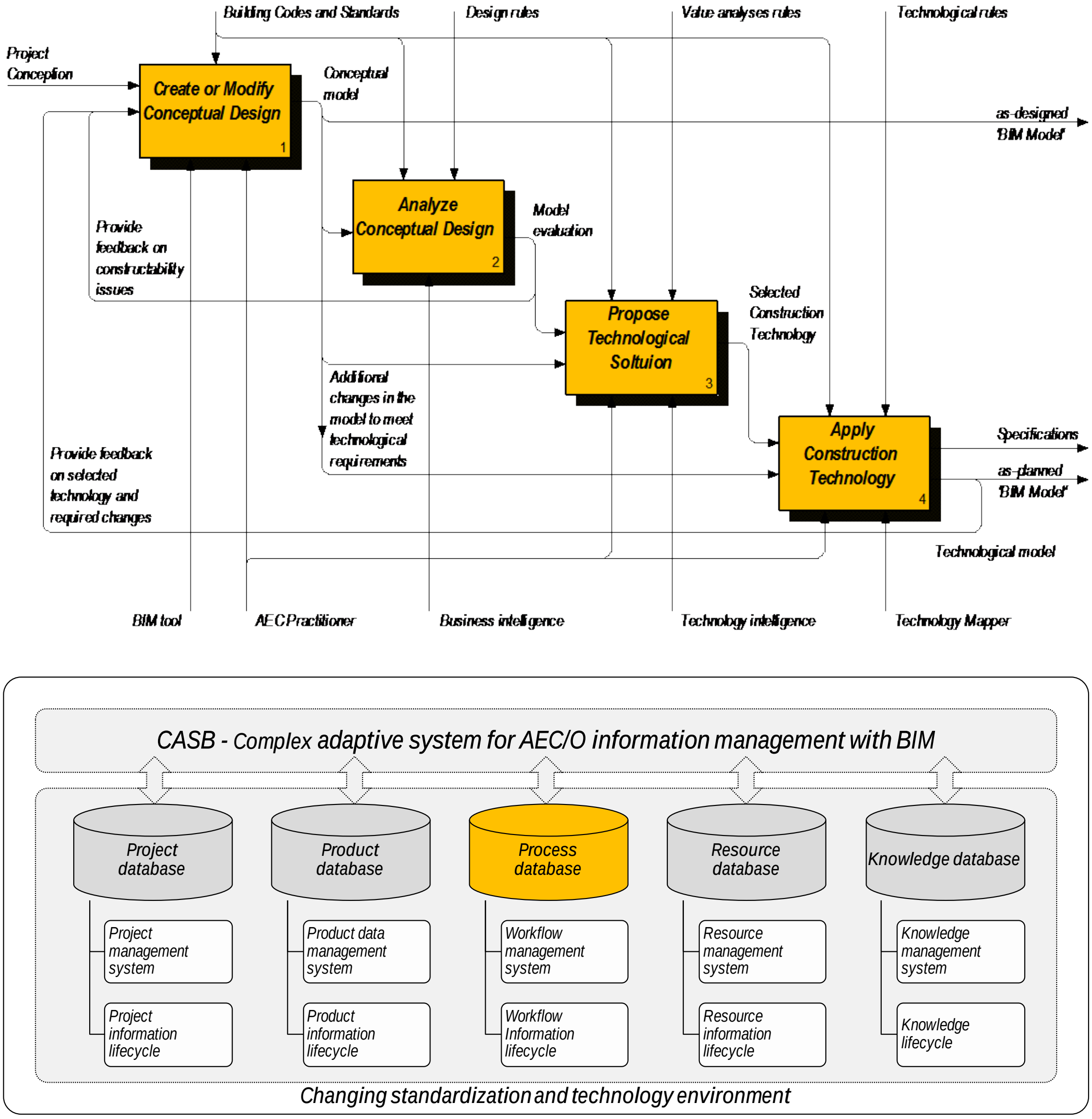


Figure 9: Early conceptual design with Complex Adaptive System with BIM (Cerovsek 2011a)

To illustrate the concept, we provide a detailed description of the above conceptual process, which itself can be the input to the process reuse. There are four main activities in the process:

1. Create a Conceptual Design. The source (reference) model is a conceptual design created by an architect. The inputs to the activity are client requirements and project conception.

Example of the activity result: A 3D Architectural Concept of a multi-story building.

2. Analyse a Conceptual Design. The geometry of a building is analysed to support the selection of a structural system that balances loads with superstructure, lateral system, foundations and soil characteristics. The process shall support the iterative nature of the design in which new information is modelled or additional inputs are identified to allow for consistent decision-making.

Example of the activity result: Generic geometric entities are mapped into building component concepts.

3. Propose a Technological solution. Once the model contains enough information the construction, technology intelligence helps an end-user to select the most appropriate construction technology. The construction technology of the decision matrix enables them to select the best technology.

Example of the activity result: A decision matrix for the technology selection with alternatives.

4. Apply Construction Technology. The application of the selected construction technology uses the conceptual model as input. The tool – called a Technology Mapper – maps a conceptual model to the technology model. A basic geometrical entity is mapped to a concrete technological solution.

Example of the activity result: Selection of the technology would adjust geometrical representation.

The overall process should enable semi-automatic conversion of a SketchUp model into the technological model through the concept of process reuse. The Model evaluator, Technology Intelligence and Technology Mapper are mechanisms implemented as Ruby Scripts that would support designers in their decision-making. Each Ruby Script mechanism can be developed independently and can work independently, whereas each construction company can provide different mappers for technologies (i.e., Pre-Cast Mapper, Steel Facade Panel Mapper).

3.3 Prototype

A complete description of the prototype is outside the scope of this paper. Thus, only basic information on the approach is provided, and more details will be presented in a separate report. The initial prototype was developed for educational purposes and includes integrated web application based process modelling systems and freely available 3D modelling tools, such as SketchUp. All interfaces are developed in a way that enables a completely open exchange of design information.

The implementation of the system is support by the workflow management system. The implementation of the prototype covers only a small portion of the system presented on Figure 9. The goal was to demonstrate an open approach to collaborative processes and product modelling with cost modelling. As shown in Figure 10, the envisioned system should be supported with a workflow management system and open, loosely coupled product and process modelling systems.

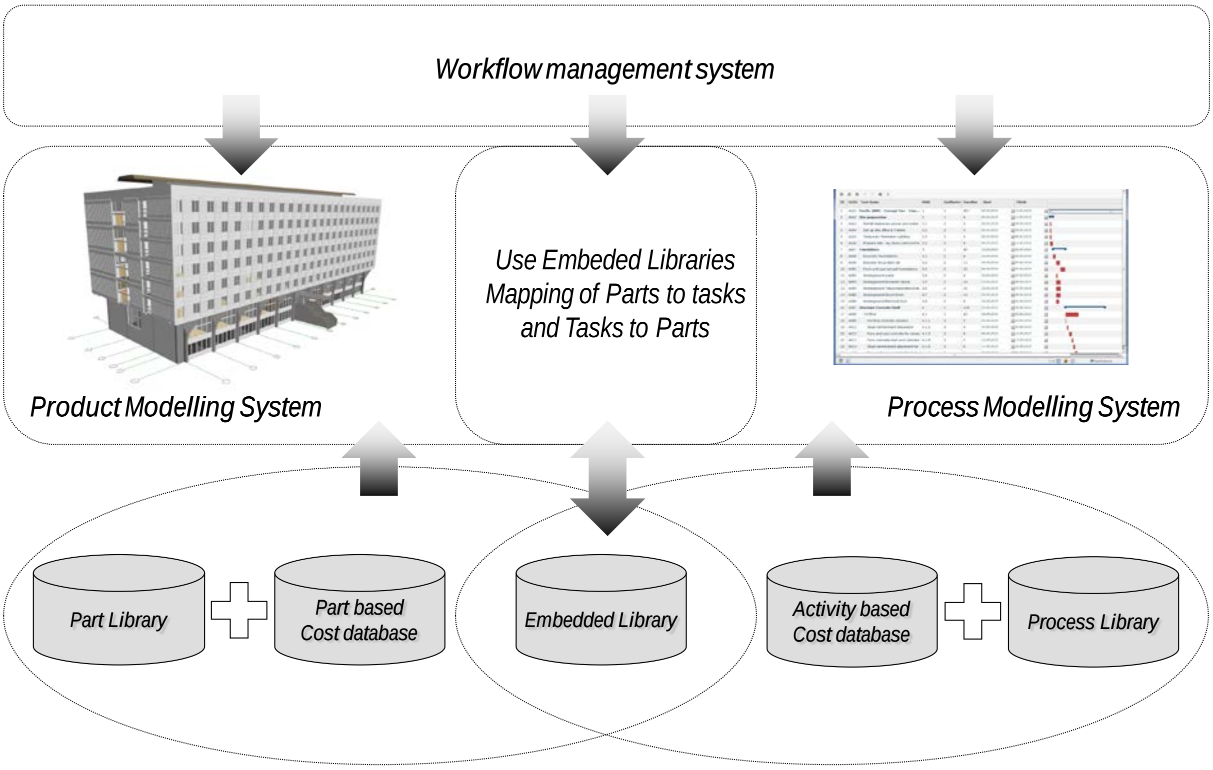
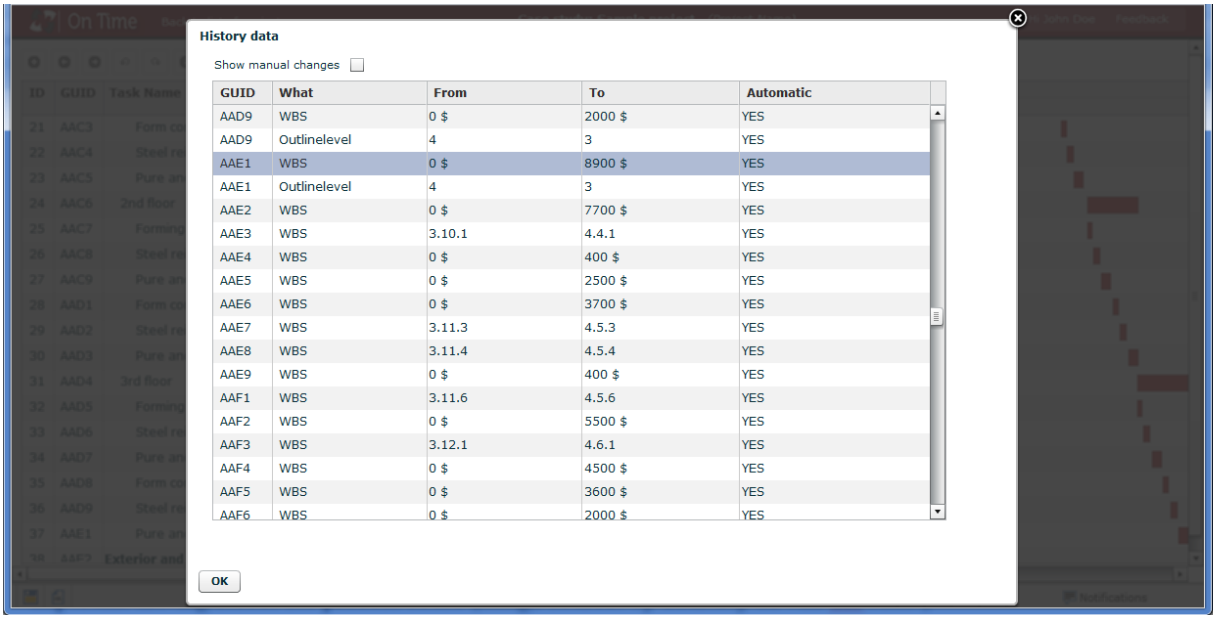


Figure 10: Prototype of a 5D modelling system: workflow management systems support the process reuse, whereby process and product modelling with cost modelling is used separately and mapping of tasks to costs and costs to tasks can be used to develop an embedded 5D part library for future projects



History data

Show manual changes

GUID	What	From	To	Automatic
AAD9	WBS	0 $	2000 $	YES
AAD9	Outlinelevel	4	3	YES
AAE1	WBS	0 $	8900 $	YES
AAE1	Outlinelevel	4	3	YES
AAE2	WBS	0 $	7700 $	YES
AAE3	WBS	3.10.1	4.4.1	YES
AAE4	WBS	0 $	400 $	YES
AAE5	WBS	0 $	2500 $	YES
AAE6	WBS	0 $	3700 $	YES
AAE7	WBS	3.11.3	4.5.3	YES
AAE8	WBS	3.11.4	4.5.4	YES
AAE9	WBS	0 $	400 $	YES
AAF1	WBS	3.11.6	4.5.6	YES
AAF2	WBS	0 $	5500 $	YES
AAF3	WBS	3.12.1	4.6.1	YES
AAF4	WBS	0 $	4500 $	YES
AAF5	WBS	0 $	3600 $	YES
AAF6	WBS	0 $	2000 $	YES

Figure 9: An audit trail capturing the development of process model

Whereas collaborative product modelling (BIM model servers) are well established based on the concept of long transactions, an important drawback of existing process systems that do not enable the reuse of process modelling processes was addressed in the early prototype via the implementation of a web-based process and activity-based cost modelling system with an audit trail that enables the reuse of process modelling activities by utilising process mining as described in (Cerovsek et al. 2006).

4 DISCUSSION AND CONCLUSIONS

Process reuse has many unexploited potentials, especially in the field of business process management. The process can be used to describe or prescribe the way processes are carried out. Process reuse is particularly important for the CPI. The key to process reuse is to allow capturing of the business process. After that, process mining can make use of more processes in decision-making. The presented approach could also be used for BPR related to BIM adoption at large and for specific tasks.

The development of any model is a collaborative task, and although process reuse is very promising, it depends on the availability of sufficient amounts of process data in standard representations (e.g., BPEL could be the best candidate). The quantity of process data will drive the development of specialised crawlers and parsers and of indexing for process reuse. Therefore, establishing process repositories and business intelligence is essential.

4.1 Conclusions and future work

The main barriers to process reuse are availability, rigidity, intellectual property rights, interoperability, difficult process discovery, highly limited process knowledge acquisition, and lack of ranking for fragments of processes. Furthermore, researchers identified special problems for process reuse in overly restrictive procedures and incomprehensible processes.

The work in the future will focus on:

- Development of repositories with representations using different modelling techniques.
- The use of workflow engines and existing workflows on top of engineering applications.
- The advanced use of process mining techniques for process discovery and optimisation.
- Implementation of process retrieval based on implicit querying of project information.
- Development of an approach for constant process improvement based on process reuse.

ACKNOWLEDGEMENT

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REFERENCES

BIPLAV, S. 2009. Organizing Documented Processes. *In:* DEBDOOT, M. (ed.) *IEEE International Conference on Services Computing.*

__________, T. 2011a. A review and outlook for a 'Building Information Model' (BIM) : a multi-standpoint framework for technological development. Advanced engineering informatics, 2011(25)2, pg. 224-244, doi: 10.1016/j.aei.2010.06.003.

__________, T. 2011b. Process reuse in product development with 5D models: Concepts, similarity measures and querying techniques. *In:* PUTNIK, G.D., Cruz-Cunha M.M. (ed.) *VinOrg'11.* Ofir, Portugal: CCSI, Springer Verlag, 2011.

__________, T. & KATRANUSCHKOV, P. 2006. Active process reuse model for collaboration. *ITcon - Journal of Information Technology in Construction,* 11**,** 467-488.

DIJKMAN, R. M., DUMAS, M. & OUYANG, C. 2008. Semantics and analysis of business process models in BPMN. *Information and Software Technology,* 50**,** 1281-1294.

FIORINI, S., DO PRADO LEITE, J. & PEREIRA DE LUCENA, C. 2001. Process Reuse Architecture. *Advanced Information Systems Engineering.*

GODERIS, A., SATTLER, U., LORD, P. & GOBLE, C. 2005. Seven Bottlenecks to Workflow Reuse and Repurposing.

GRECO, G., GUZZO, A. & PONTIERI, L. 2008. Mining taxonomies of process models. *Data & Knowledge Engineering,* 67**,** 74-102.

HENNINGER, S. 1998. An Environment for Reusing Software Processes. *Software Reuse, International Conference on.*

JAE-YOON, J. Hierarchical Business Process Clustering. *In:* JOONSOO, B. & LING, L., eds., 2008. 613-616.

JUNTAO, G. 2009. On Measuring Semantic Similarity of Business Process Models. *In:* LI, Z. (ed.) *Interoperability for Enterprise Software and Applications China, 2009.*

MAURIZIO, M. 2000. Diversity in Reuse Processes. *In:* COLIN, T. & MICHEL, E. (eds.).

FUNK, P.J. & CRNKOVIC, I. 1999. Reuse, Validation and Verification of System Development Processes. *Proceedings to the First International Workshop on the Requirements Engineering Process, Florence, Italy, IEEE Computer Society,September 1999*

PHILIPPE, R. 2008. An Ontology-Based Support for Asset Design and Reuse. *In:* CORINE, C. (ed.) *International Conference on Computer Science.*

QIHONG, S. 2009. WISE: A Workflow Information Search Engine. *In:* PENG, S. & YI, C. (eds.) *International Conference on Data Engineering.*

REMCO, D. 2007. A Classification of Differences between Similar BusinessProcesses. *Enterprise Distributed Object Computing Conference, IEEE International.*

WOMBACHER, A. 2006. Evaluation of Technical Measures for Workflow Similarity Based on a Pilot Study. *On the Move to Meaningful Internet Systems 2006: CoopIS, DOA, GADA, and ODBASE.*

XIAORONG, X. 2007. Improving the Reuse of ScientificWorkflows and Their By-products. *In:* GREGORY, M. (ed.) *Web Services, IEEE International Conference on.*

ZLATKIN, S. & KASCHEK, R. 2005. Towards Amplifying Business Process Reuse. *Perspectives in Conceptual Modeling.*