Proceedings of the 12th Manufacturing Science and Engineering Conference
MSEC2017
June 04 – June 08, 2017, Los Angeles, California, USA

MSEC2017-2889

BUSINESS PROCESS MODEL LIFE-CYCLE MANAGEMENT IN CLOUD MANUFACTURING

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ABSTRACT

To facilitate the vision of service-oriented manufacturing (SOM), Cloud manufacturing (CMfg) will need to support business process model life cycle management. In this paper, we propose a business process catalog to support that role. Such a catalog can facilitate adaptation of business process models. We validate life-cycle management requirements for such a catalog and propose capabilities the catalog must have to address these requirements. We analyze related work in academia and industry as a basis for synthesizing a meta-model and a conceptual architecture for the catalog. We conclude that contextual information for business process models is a critical part of such a catalog and where the CMfg community can contribute new and valuable results.

KEYWORDS

Business Process Model, Life Cycle Management, Cloud Manufacturing, Catalog, Standards

1 INTRODUCTION

Cloud manufacturing (CMfg) is facilitating the vision where cloud-based services will replace resident software applications and provide a foundation for the next great revolution in manufacturing [1,2]. Realizing that revolution, then, will require manufacturers to access and assemble these services to solve specific business problems. This assembly capability requires a level of service connectivity that currently does not exist. In our belief, this can be achieved by utilizing business process models.

Literature offers various business process definitions [3–7]. Common to all of them is the notion of the business process as a set of activities conducted together in order to create output using one or more types of inputs. Business process model act as a blueprint of the business process, documenting its activities and execution constraints between them [8].

Currently, manufactures use business processes as the foundations for accessing, integrating, and orchestrating the right applications. In this paper, we assume the same for the cloud services. This means that the new solutions will need to provide for business process evolution and adaptation management, and enable convergence of proprietary business processes to shared ones.

Presently, business process evolution and adaptation is largely a manual and inefficient procedure. CMfg will not deliver on its vision unless the procedure is made efficient and repeatable. We propose, partially at least, to automate this procedure using the Business Process Cataloging and Classification System (BPCCS). Previously, we identified requirements for BPCCS to address the business-process-model evolution-management problem [9]. Among those, Business Process Model Life Cycle Management (BPM LCM) requirements are most challenging. The next logical question, which we address here, is - What type of system capabilities and architecture are needed to support effective BPM LCM?

We continue by reviewing literature of relevant CMfg research. Next, we validate BPM LCM functional requirements on two manufacturing use cases. Then, we devise a conceptual entity representation in support of the required BPM LCM functions. Finally, we describe our conceptual approach for BPCCS by synthesizing key capabilities and proposing a meta-model and conceptual architecture for the BPCCS. We conclude with a discussion of the paper findings and next steps.

2 LITERATURE REVIEW

The recent published research in Cloud Manufacturing points at an initial but growing interest to enable business process model life cycle management (BPM LCM).

Tao et al, indicate importance of BPM LCM for Cloud Manufacturing and refer to the similar issues as Business mode and business management [2]. This area of research investigates technologies for the dynamic construction, management, and execution of enterprise business flows in CMfg environment. Within the manufacturing service management (MSM) area of hybrid cloud manufacturing platforms, a main challenge is the complexity resulting from the dynamic changing resource and service access rules. This implies the need for BPM LCM that can adapt to such dynamic changes at both service- and business-process levels.

Schulte and colleagues discuss a number of Cloud Manufacturing aspects that require BPM LCM [10]. They state that the increasing dynamics and complexities of manufacturing processes require new solutions to business process management. They show that during manufacturing-process enactment there may be a need to change process models or instances. Consequently, they point at the need for (1) a knowledge base to support decisions that are made in every stage of business process lifecycle as well as (2) semantic models for manufacturing assets and services.

Qanbari and colleagues point at the need for dynamic composition of services for CMfg [11]. Manufacturing services and resources, such as devices and sensors, may be composed into the product "bill of manufacturing services" (BOMS). BOMS may be seen as cloud-manufacturing virtual products, which can be dynamically configured, deployed and coordinated on multi-production lines. The result will be actual "as-built" assets, which implies the need for BPM LCM to address varied aspects of service interactions within BOMS.

Adamson and coauthors review state-of-art in CMfg [12]. They point to the need for intelligent, globally and locally distributed monitoring and control systems that would include high-level collaborative manufacturing tasks down to shop-floor control, and from selection and composition of services to run-time services management. This would be essential for handling volatile and dynamic manufacturing scenarios, unpredicted changes and new products, and to minimize the need for human intervention. As such, these systems need to be intelligent, agile and flexible, which could be enabled by an effective BPM LCM solution.

In conclusion, while the need for BPM LCM has emerged in the published CMfg research, very limited development has been done to meet the need so far. Our research is intended to fill the gap in enabling BPM LCM within a BPCCS solution.

3 CMFG REQUIREMENTS FOR BPM LCM

Previously, we identified functional BPM LCM requirements for a visionary CMfg scenario – an enterprise seeking to reduce costs and increase agility by using third party cloud providers of manufacturing and software services [9]. Such an enterprise constantly evolves its business processes. What used to be a business process involving only integrations between internal applications becomes a process partially integrating with third party software services. In such an environment, the ability to analyze, categorize, and evolve business processes according to their usage context (such as geo-location and industry) and in a traceable manner becomes essential. The BPCCS is envisioned to meet these needs.

In the visionary scenario, the BPCCS provides BPM LCM functions to help keep track of the BPM evolution in the CMfg

TABLE 1 – POTENTIAL CMFG SCENARIOS AND THEIR REQUIRED BUSINESS PROCESS MODEL LIFE CYCLE MANAGEMENT FUNCTIONS

Scenario:	Business process model (BPM) LCM function:					
	Classify/ Catalog/Retrieve BPM (FR-C)	Manage life cycle of classification scheme (FR-L)	Version BPM (FR-V)	Map BPM versions (FR-M)	Analyze BPM (FR-A)	Match BPMs (FR-H)
End-to-end product procurement scenario - Business process model discovery & reuse	- Manage multiple classifications of BPMs – e.g., ISO 10314 classification, ebXML's Porter classification, OAGi functional classification	APQC PCF continuous industry-specific adaptation and refinement	Update 'close' BPs for new requirements (e.g., from in-process testing to 3rd party testing)	Enable traceability among BP versions (e.g., to allow cross-industry reference BP model, such as using APQC PCF)	Analyze BP models for a particular requirement, based on its usage context specification (e.g., determine which BPMs reference ProcessInspectionOrder business object document)	Identify BP models with usage context close to the specified usage (e.g., match in-process testing BPM that is close to 3rd party testing BPM requirements)
Inspection Order scenario - Business process specification for business document content profile definition	- 'Canonical' BP classification: generalized '5WH' classification based on Zachman's classification framework)	OAGIS functional classification scheme, regularly updated with additional classification (which matches evolution of the OAGIS standard)	[Same as above]	[Same as above]	[Same as above]	[Same as above]

era. (Table 1 names the functions and labels them using prefix 'FR-'.) In the scenario, BPCCS supports similar processes for qualifying materials of different types of products (e.g., Animal Feed vs. Dairy) by generalizing them into a reference BPM (FR-L) with the BPCCS helping to do the mappings from the product-specific to the reference model (FR-M). Context classification schemes in BPCCS help catalog these BPMs (FR-C); in a food production scenario, say, a product classification scheme may be used to classify the BPM for Animal Feeds vs. the BPM for Dairy Product. When looking into outsourcing the parts of a BP, the BPCCS can provide the reference BPM along with its context information to help discover cloud services (FR-C). Once services are discovered by way of matching their descriptions with the required context information (FR-H) and procured, the original BPM is modified (FR-V). The new BPM can be cataloged using the same classification as the original BPM (FR-C). The original BPM is kept for reference for the traceability purpose (FR-M). The modified BPM is used to drive the specific integration requirements after analysis of the BPM for specific message definition, authentication, and security requirements (FR-A). The modified BPM shares the context with the original one while adding these additional context properties (FR-C). We analyzed two potential CMfg under investigation to validate these BPM LCM requirements.

In the first case, we looked at the end-to-end product procurement scenario with the goal to support business process model discovery and reuse. The scenario starts with the customer issuing purchase order and ends with the customer receiving the goods along with shipment notification and as-built inspection information. The component BPMs of the scenario are classified using a reference classification framework APQC PCF, which is continuously updated for specific industry needs (FR-L) [13]. Multiple context classification schemes are managed in BPCCS to help catalog these BPMs, including ISO 10314 classification, ebXML-adopted Porter classification, and OAGIS functional classification (FR-C) [14–16]. When outsourcing the parts of a BPM for the end-to-end product procurement scenario, the BPCCS provides the reference BPM along with its context information (using the OAGIS classification) to help discover cloud services (FR-C). Once services are discovered (e.g., to match in-process testing BPM that is close to 3rd party testing requirements) (FR-H) and procured, the original BPM is modified (e.g., to update the BPM for the new 3rd party testing context) (FR-V). The original BPM is kept for reference for the traceability purpose, where the APQC PCF is employed to allow cross-industry reference (FR-M). In addition, to find appropriate BPM, BPCCS supports analysis for other requirements, based on the BPM usage context specification, such as required use of the ProcessInspectionOrder business object document (FR-A).

In the second case, we analyzed the inspection order scenario with the goal to support business process specification for business document content profiling. The scenario focuses on the inspection order part of a more complex scenario, such as the above end-to-end product procurement scenario. The component BPMs of the scenario have been classified using the OAGIS functional classification scheme, which is regularly updated with additional classes, matching evolution of the OAGIS standard itself) (FR-L) [15]. Both proprietary classifications of BPMs, as well as the 'canonical' classification developed by generalizing Zachman's classification framework, are used to catalog and retrieve the BPMs (FR-C) [17]. Since the scenario was treated as a part of the previous scenario, we confirmed that the remaining functional requirements hold for this scenario as well (FR-V, M, A, H).

In conclusion, we found the proposed functional requirements for the BPM LCM to be valid, based on the two potential CMfg use cases we analyzed for BPCCS support.

4 REQUIREMENTS ANALYSIS

Previous section introduced and validated functional requirements to manage BPM LCM. Based on the requirements, we now devise a conceptual representation for key entities in support of the required BPM LCM functions. Figure 1, shows two parts to our approach: *Classification Schemes* (shown on the right) and *Catalog* (shown on the left).

4.1 BPCCS Classification Schemes

The *Classification Schemes* allow the BPCCS users to classify their process models (and their parts) using multiple contextual dimensions. They may be used to characterize a process model stored in a *Catalog* by defining a context for intended use of the model.

A number of contextual dimensions have been proposed previously for inclusion into systems similar to BPCCS. Those dimensions include industry, product, business process, role, and function, among others [18]. Besides being used to define context for the process use, dimensions can also be used to search and browse a BPCCS *Catalog*. Namely, by using particular contextual dimensions and providing appropriate values for them, a BPCCS user can search a BPCCS *Catalog* in order to find process model(s) that fit a specific context.

In addition, it should be possible to find a process or activity model with the needed (or similar) semantics by providing context in which that model will be used and to which it is applicable.

4.2 BPCCS Catalog

Analyzing processes only by classifying them by contextual dimensions can be useful at higher levels of abstraction and in the early stages of process analysis. Moving to lower levels of abstraction, towards the implementation level, requires a more detailed description of the business process. This description is provided by the business process model, which captures different perspectives of process including flow, data, roles, and events. Such business process models are stored within a BPCCS *Catalog*. Both reference models and specific models are

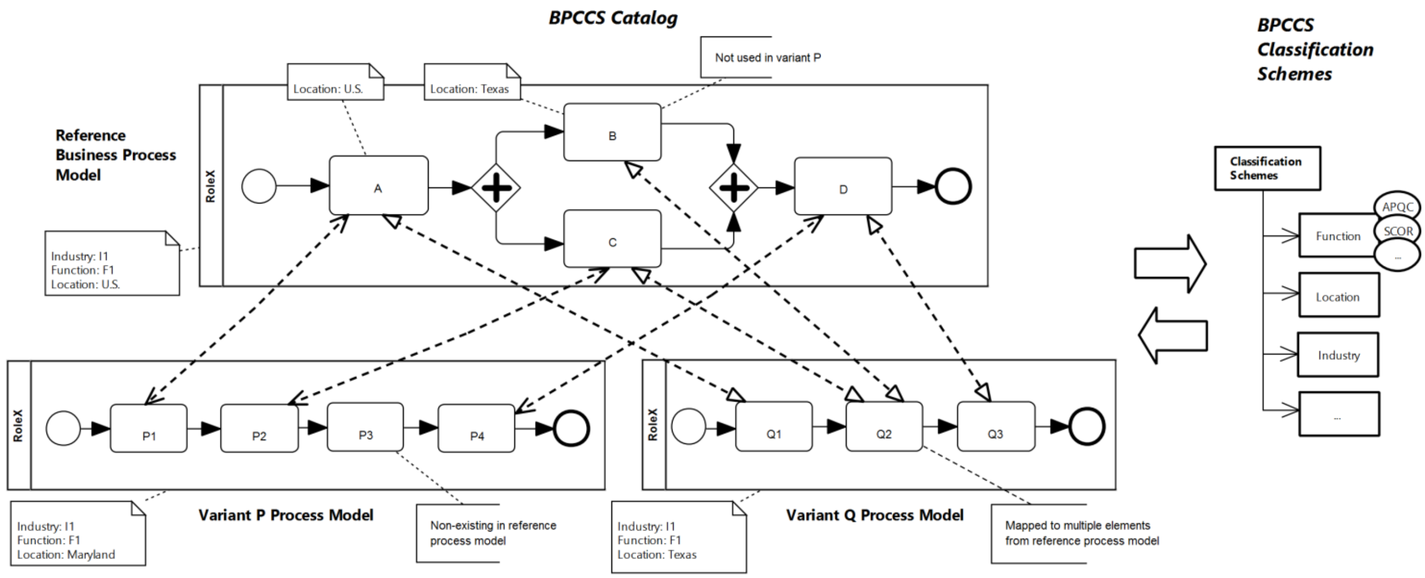

FIGURE 2. OVERVIEW OF APPROACH

stored and described by the context in which they are applicable, using *Classification Schemes'* context dimensions. In that sense, specific process models are regarded as variants of the reference process model. Variants are needed because the context of the specific model can differ from the context of the original reference model.

As illustrated in Figure 1, a BPCCS reference process model, defined for a particular context dimensions, can be used to semantically align process models originating from different sources, i.e., different process variants. In Figure 1, processes P and Q are aligned by mapping their elements to the reference model elements (illustrated by dashed associations with open and closed arrowheads). Basically, reference model elements are used as shared vocabulary to which elements of specific process models are mapped and thus semantically aligned.

5 SOLUTION APPROACH

Here, we present essential aspects of our proposed solution, starting by synthesizing needed BPCCS capabilities, followed by discussing possibility of adopting some of existing solutions. Ultimately, we propose a BPCCS metamodel and BPCCS functional architecture, in support of the capabilities.

5.1 Conceptual Design: Capability Synthesis

In this section we specify capabilities that BPCCS should provide in order to support business process model life cycle management (BPM LCM). The conceptual approach in the previous section has informed review of prior work [19–23] and subsequent synthesis of required capabilities. Here, we describe the synthesized capabilities first, followed by an analysis of their dependencies that provide the basis for a layered, architectural view of these capabilities:

- *Multi-perspective variability* should provide mechanism(s) for recording variability across multiple perspectives of a process model (informational, organizational, etc.).
- *Process model merging* should enable creation of reference process models as a composition of different process variants. For example, a reference process model from Figure 1 can be created by merging variants P and Q into a union model that subsumes both variants.
- *Specific process model derivation* should allow derivation of a process model from a merged reference model. Every process model used as input to the merging process should be possible to derive from the resulting reference model.
- *Soundness check support* should provide mechanisms for checking soundness of process models, especially derived ones, and for preventing creation/derivation of syntactically or semantically incorrect models.
- *Semantics support* should provide means to determine if parts of various processes are semantically equivalent, based on the context of their usage and their relations with other parts of the process.
- *Context support* should allow storing contextual information about a process model and its parts. This is realized by utilizing context dimensions of the BPCCS Classification Schemes from the previous section. A context defined by specific contextual dimensions supports a semantic-equivalence evaluation between process activities.
- *Context handling support* should support storing different contextual information as well as to (1) distinguish different relations existing between values of context dimensions and (2) determine how they should be treated and used. For example, when someone searches for artefacts applicable in the context of the U.S., the context handling needs to determine whether artefacts associated with a subcategory

of the “U.S.” – such as “Maryland” - should be retrieved as well or only those exclusively associated with the category “U.S.” should be retrieved.

- *Mapping support* should allow for various simple and complex mappings between process elements. Such mappings are needed to illustrate their semantic relations, based both on their contextual dimensions and on their relations with other process elements.
- *Evolution support* should provide various mechanisms to evolve the reference process model. These mechanisms are used primarily when one or more parts of specific process models cannot be semantically aligned to the reference process model.

Figure 2 shows dependencies between particular capabilities illustrating that realization of some capabilities is a prerequisite for realization of others. For example, *Context support* is a prerequisite for *Semantics support*, since contextual description of a particular process activity is a basis to determine its semantics and to reason about it. Obviously, the set of foundational capabilities primarily includes *Context support* capability, followed by *Semantics support* and *Context handling support* capabilities. They are regarded as foundational in the sense that they are prerequisites for realization of other capabilities.

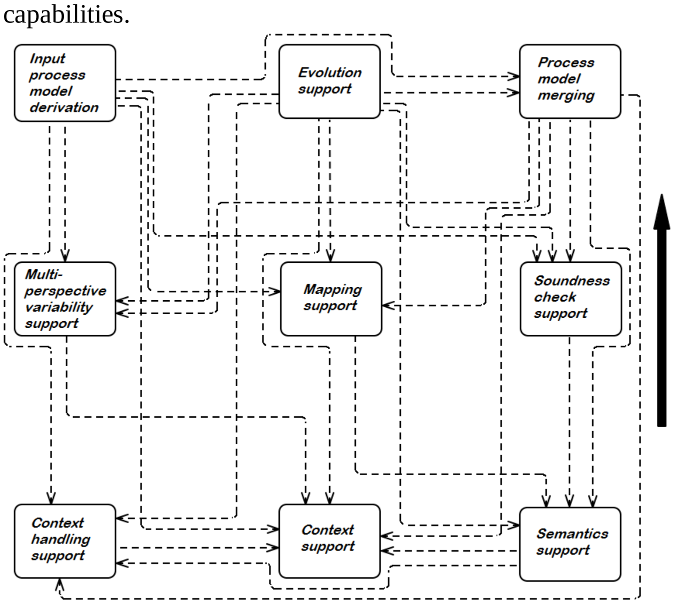

FIGURE 3. CAPABILITIES AND THEIR DEPENDENCIES – LAYERED VIEW

5.2 Conceptual Design: Adoption of Existing Solutions

In our view, precise definitions of context and its semantics, which can be achieved by the implementing *Context support*, *Context handling support* and *Semantics support* capabilities, is crucial for BPM LCM. Therefore, we focused on these capabilities first and identified candidate solutions for these capabilities as well as gaps in the existing approaches to support them. We analyzed results in four related areas: Modeling BP Variability; BP Catalog Approaches; Modeling BP Context; and Industry Approaches.

TABLE2 indicates work in the four areas to address the capability: we place ‘+’, if the group has been addressing the capability, or ‘-‘, otherwise; also, ‘+/-’ indicates that group partially addresses the capability.

TABLE 2. CANDIDATE APPROACHES TO FOUNDATIONAL CAPABILITIES

	Modeling BP Variability	Modeling BP Context	BP Catalog Approaches	Industry Approaches
Context support	+/-	+(*)	+/-	+(**)
Context handling support	+/-	+(*)	+/-	+(**)
Semantic support	-	-	+/-	-

(*) not supported within a single approach
(**) not defined for business processes

Approaches for modeling business process variability [24–26] propose various mechanisms to represent and manage variants of process models. Although these approaches recognize the role of context in process variability domain – that different variants of business process are caused by their usage in different contexts - they do not focus on context formulation or they use its simplified representation.

An obvious group of approaches that is relevant for the foundational capabilities are those for modeling business process context. Their main focus is on the context formalization, which varies (1) from a fixed set of context variables over a set of context categories without defining finer-grained context variables (such as [27,28]) (2) to various context metamodels that allow dynamic identification of context categories and variables (such as [29,30]). We argue that the latter is the appropriate way of representing contextual information, since the context model should be dynamic and adaptable instead of being static and fixed.

There were many research efforts conducted for the purpose of developing catalogs, repositories and libraries of business processes [31–33]. Certain approaches rely on using various ontologies and semantic technologies [34,35], thus being potentially interesting candidates to build upon. Our analysis showed that context and semantics have not been effectively addressed in any of these approaches.

Another relevant group of approaches are the ones proposed by SDOs and industry consortiums. It includes different proposals for context handling and/or context-based document configuration by change operations [18,36–38]. Although these approaches are focused on managing message definitions, they can be adopted to the process model management. A relevant industry-based approach is the *ebXML Registry Information Model (ebRIM)* [39]. It specifies types of content and associated metadata that facilitate organization of content for ease of discovery. By the same token, ebRIM can be a starting point for building a metamodel to support the foundational capabilities in

BPCCS. Our analysis shows that additional association types and association properties will be needed for representing the process' context information.

5.3 Conceptual Design: Meta model

Our proposed BPCCS meta-model, primarily building on the work conducted in ebRIM specification [40], is given in Figure 3 using UML Class diagram notation. Our analysis of related work showed that effective support for foundational capabilities is still an unsolved problem. That is why we scoped BPCCS metamodel, shown in Figure 3, only to the elements that are relevant for contextualization of objects stored in BPCCS. (To improve readibility and conciseness, attributes of the shown elements and their descriptions are omitted.)

Key elements of the BPCCS metamodel are *CatalogObject*, representing an object that is registered in BPCCS, and *Association*, which is used to define different relations between catalog objects. Type of catalog object (e.g., Business Process, Activity, Event, Role/Participant, BOD, XMLSchema, etc.) is represented by *CatalogObjectType*. Similarly, type of association is represented by *AssociationType*.

As mentioned earlier, BPCCS allows its users to classify their process models (and their parts) using multiple contextual dimensions. These dimensions are represented in BPCCS metamodel by *ContextDimension* element. Multiple context dimensions can be grouped by their purpose – for example, to describe location, both geographical location and organization unit can be used - and organized into aspects, represented by *ContextAspect* element.

Currently, we are exploring Zachman's framework [17] and its 5W1H maxim as a convenient way to organize context dimensions into context aspects. For example, geographical-location and organization-unit context dimensions will belong to the *Where?* context aspect and industry context dimension will belong to the *What?* context aspect.

In order to define range of values that can be used for particular context dimension, different taxonomies or controlled vocabularies can be used. They are represented by the *ClassificationScheme* element, their custodian by the *Organization* element, and their values by the *ClassificationNode* element. Furthermore, different types of nodes within a classification scheme are represented by the *ClassificationNodeType* element. Besides classification schemes, stored catalog objects of a particular type can also be used as values for a context dimension. This is illustrated by the association between *ContextDimension* and *CatalogObjectType* in Figure 3.

Finally, the context of a particular catalog object is defined implicitly, as the set of all associations that the object has. Included are classification nodes of appropriate schemes and other catalog objects of appropriate types that can be used for particular context dimensions.

5.4 Conceptual Design: Functional Architecture

The proposed BPCCS metamodel allows dynamic and adaptable definitions of contextual information. This is possible because the metamodel provides the possibility of defining (1) context dimensions and aspects that suit particular situation, as well as (2) appropriate catalog object types and association

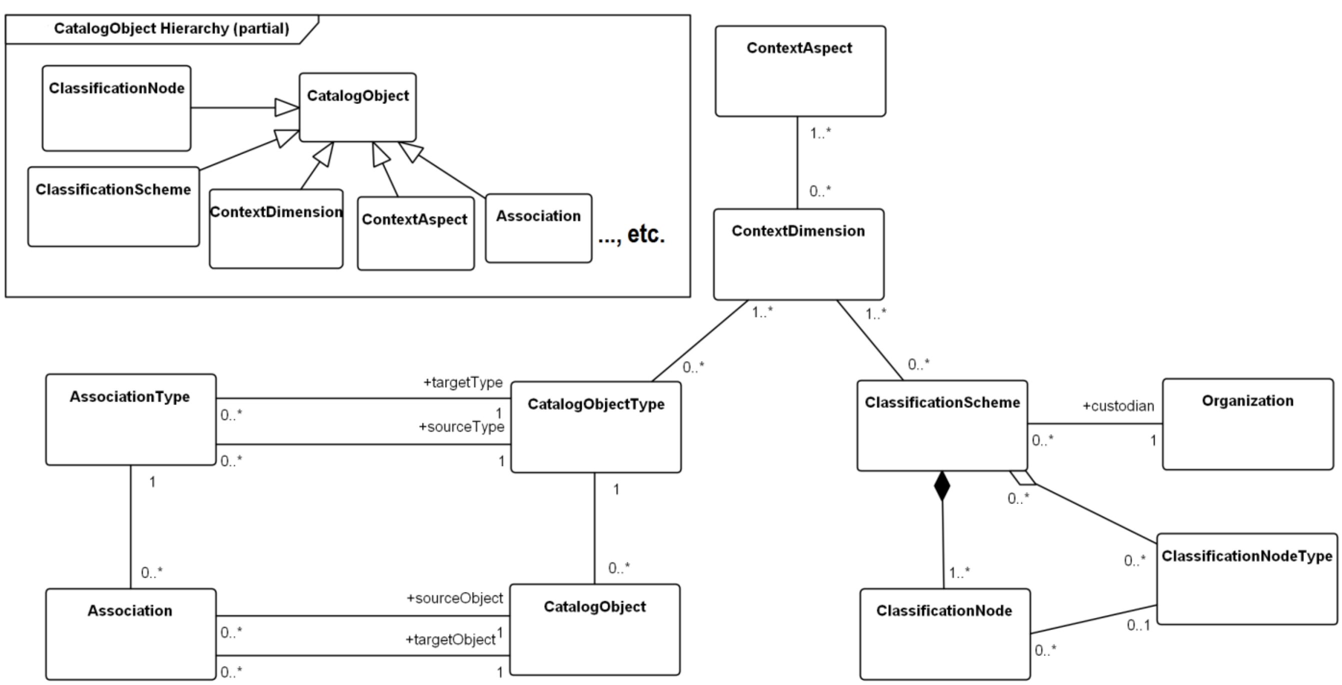

FIGURE 4. BPCCS METAMODEL

types. We found this crucial characteristic necessary to effectively support foundational capabilities, especially to build the basis for semantic support. That basis involves context reasoning using ontologies and semantic technologies, which we regard as one of key BPCCS functionalities. This is illustrated in Figure 4, which shows BPCCS conceptual architecture using FMC block diagram notation [41].

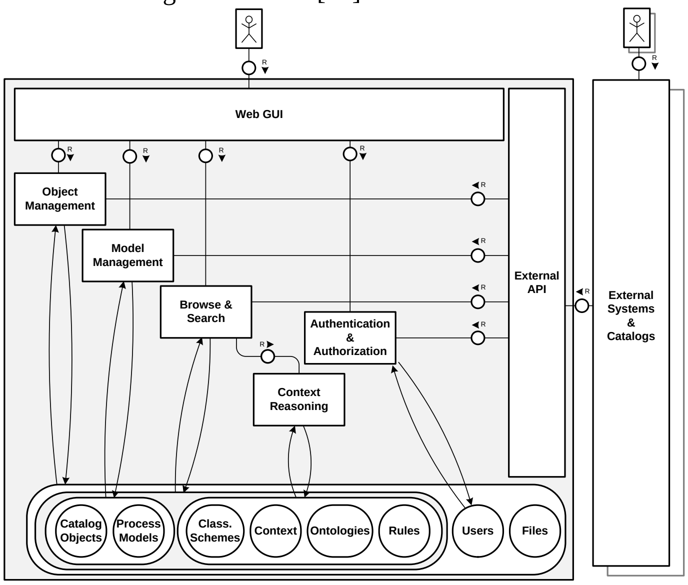

FIGURE 5. BPCCS CONCEPTUAL ARCHITECTURE

All BPCCS functionalities shall be provided through a Web user interface, as well as an external API that allows its integration with external systems and catalogs. *Object Management* includes a wide set of features related to catalog objects. Example features include adding, updating, removing, classifying, and mapping, among others. *Model Management* includes features related to stored process models. Example features include adding, updating, or removing the process model; introspecting a model in order to identify additional catalog objects; and, exporting the model, among others. *Browse & Search* supports (1) finding process model(s) that fit a specific context, (2) browsing the content of BPCCS by navigating appropriate classification scheme along particular context dimension, and (3) searching BPCCS by defining more complex context-related conditions. It relies on *Context Reasoning* that provides semantic support by reasoning over ontological representation of business process context and controlled vocabularies using appropriate reasoning rules. Finally, *Authentication & Authorization* identifies BPCCS users and grants them appropriate access rights.

7 CONCLUSIONS

The focus of our interest in this paper is to achieve business process model life cycle management (BPM LCM) requirements. While the research area has not been extensively researched by the community yet, we believe that enabling BPM LCM represents a key ingredient to the success of Cloud Manufacturing.

We were interested to identify capabilities and conceptual design needed to support these BPM LCM requirements (1) when it is essential to enable non-standard business processes and (2) where modeling of these business processes brings many different considerations and interpretations that need to be resolved and aligned.

We have synthesized the necessary capabilities and proposed a conceptual design for Business Process Cataloging and Classification System (BPCCS) to provide answer to the research question. Further, we analyzed relevant state of the art to find that a key issue involves enabling treatment of contextual information for business process models. We have identified a promising direction to architect and conceptualize a tool that is oriented towards providing a context-based BPM LCM. Following this direction, in our future work we will focus on business-process context formulation and semantics definition. We plan to adopt semantic technologies and develop a context reasoning approach for efficient BPM LCM management. We are using varied manufacturing BPM use cases in order to validate our context-based approach.

ACKNOWLEDGMENTS

Any mention of commercial products is for information only; it does not imply recommendation or endorsement by NIST.

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