CE CONCURRENT ENGINEERING: Research and Applications

Integrating Concurrent Engineering Concepts in a Steelwork Construction Project

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Abstract: The aim of this paper is to present a methodology for integrating Concurrent Engineering (CE) concepts in a steelwork construction project. Differences between construction sector and manufacturing sector are first reviewed through the description of the specificities of the construction sector in terms of organisations and main features projects.

The second part presents an integrated product and process model currently developed by the authors (ProMICE project). CE concepts are introduced according to a two axes methodology, a first axis describing the "working method" and a second providing a way of representing "CE knowledge" through the description of CE specificity. This axis also defines a way of "translating" those concepts into the generic representation of the model.

One objective of the ProMICE project is to identify changes needed by this transition from the traditional approach towards CE approach, then to represent them, in the domain of steelwork construction.

Key Words: integration, product and process modelling, UML, concurrent engineering, steelwork construction.

1. Introduction

The construction industry is notoriously fragmented with a typical project involving up to six or more different professional disciplines. This has led to numerous problems including, *inter alia*, an adversarial culture; the fragmentation of design and construction data (with data generated at one stage not being automatically available for re-use "downstream") and the lack of true life-cycle analysis of projects (including costing, safety assessment, maintenance, etc.) [1]. It is now recognised that the adoption of new business processes based on Concurrent Engineering principles will provide a means of overcoming these problems, and improving the competitiveness of the industry.

Previous studies have focused on modelling either the product or the process, without adequate consideration of the implications of one on the other [2]. Indeed many research projects (some based on European initiatives) have been devoted to the description of the product to be designed or achieved with the aim of providing an "automated way" of designing, archiving and exchanging data [3].

The inadequate infrastructure that exists for seamless project team communication has its roots in the structure of the construction industry. The use of disparate computer-aided engineering (CAE) systems by most disciplines is one of the enduring legacies of this problem and makes information exchange between project team members difficult and, in some cases, impossible. The integration of product and process modelling will help to overcome this problem by enabling construction project teams to collaborate on the basis of a shared project model.

One of the aims of the work done within the ProMICE project is to provide an integrated product and process model for life cycle design and construction of steelwork structures, enabling the introduction of Concurrent Engineering concepts. The ProMICE model is still under development. However, first results provided by the analysis of the first two stages seem to be very promising in terms of contribution to the initial objectives of the project.

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2. Analogy between Manufacturing and Construction: Specificities, Organisation

2.1 Specificities of the Construction Sector

Specificity of the construction sector can be described through several points, which are:

- *construction features:* one-of-a-kind nature of products, mainly site production, temporary combination of parts, regulatory interventions
- *problems for developing new methods, or for taking new measures,* given the lack of repetition of projects, the environmental uncertainty and the difficulty of data collection on site

The peculiarities of this sector have usually been addressed, either by eliminating unique solutions, so favouring standard solutions, or by overcoming the problems of site production, using prefabrication and pre-assembly, or else by the formation of partnerships for production in a mutual effort to overcome the problems of temporary multi-organizations, and corresponding temporary links.

The construction sector is also very complex, since it encompasses both the building in itself, as well as the different products used during the construction, such as steel, concrete, prefabricated elements (beams, pre-stressed slabs, . . .), and various components (doors, windows, cladding and covering elements, furniture, HVAC components, . . .). According to the kind of construction product we refer to, the type of fabrication will be different:

- *whole building:* **project type**
- *components* (of whatever kind): **batch processing**
- *concrete* (and other basic materials): **continuous flow production**

It is also possible to observe a close correlation between the complexity, measured by the number of different subsets the product is made of, the time factor, and the typology of fabrication: project type manufacturing often takes months to be completed, usually with a complexity bigger than for batch processing. This diversity in the manufacturing processes of the products to be used also contributes to create additional constraints that have to be taken into account during the construction process.

2.2 Organisation of the Operations

Construction [4] requires the application of a diverse palette of resources to realize a finished facility (building or bridge). The organisation and application of these resources can be viewed in terms of the level at which decisions are being made; that is, there is a construction hierarchy that is dictated by the way in which construction is organized. At the company level, decisions related to which projects to bid and the recruitment of personnel are of interest. At the project level, decisions regarding how long it will take to complete a facility and the selection and movement of resources such as machines and workers must be considered. Ultimately, however, the project must be constructed. Physical items such as concrete, glass, steel and a broad spectrum of materials must be erected, placed and installed to achieve the completed facility. This is the production level in construction. This is where planning and design, analysis and control measures come together to realize the end item—the facility.

Four levels or hierarchy can be identified, as follows:

- *organizational:* legal and business structure of a firm, the functional areas of management and the interaction between head office and field agents performing these management functions
- *project:* the vocabulary of this level is dominated by terms relating to the breakdown of the project for the purpose of time and cost control (e.g., project activity and project cost control). Also, the concept of resources is defined and related to the activity as either an added descriptive attribute of the activity or for resource scheduling purposes.
- *operation (and process):* technology and details of how construction is performed. It focuses on work at the field level. Usually a construction operation is so complex that it encompasses several distinct processes, each having its own technology and work task sequences. However, for simple situations involving a single process, the terms are synonymous.
- *task:* identification and assignment of elemental portions of work to field agents

2.3 Manufacturing Industry vs. Construction

Although constructed facilities themselves are typically unique, the methods used to construct them are often repetitive or cyclic in nature, as in the case of steelwork construction, either for industrial buildings (with a layout of repetitive portal frames), or for residential ones (with assemblies of columns, or beams as needed for steelwork floors).

In manufacturing, the cornerstone of mass production is the repetitiveness of the work to be performed. This is based on the standardization of the product to be created. Standardization and modularization are historically well-known concepts for construction materials (e.g., brick and block sizes). The concept of standardization (of the shapes) to achieve repetition has been less successfully applied to the design of construction processes, since it largely depends on the architectural designer, the architect, most of the time fond of his prerogatives.

However, recently, successes on large projects have proved that design of process to achieve repetitiveness is the basis for cost-effective construction, which also leads to high quality.

We must also notice the fact that industrial manufacturing is more and more moving towards a customization of the products (automotive industry, aerospace, or other mass production), with the same consequences on the type and the methods of fabrication as already seen for the construction sector.

3. Some Key Features of Concurrent Engineering

Concurrency and simultaneity are the major force of Concurrent Engineering. Concurrency and simultaneity in Concurrent Engineering can be achieved through seven enabling principles, which are:

3.1 Parallel Work-Group

Parallel work-groups are one of the key elements of the concurrency described [5–7]. Paralleling describes a "time overlap" of one or more activities in the A-set, tasks, etc. CE is structured around multi-functional teams that bring specialized knowledge necessary for the project.

- *Multidisciplinary Project Team:* The multidisciplinary setup—called design and construction team (DCT)—is composed of several distinct project sub-units specializing in a variety of areas: Property Planners, Clients or Owners; Structural Engineers, HVAC Engineers and analysts; Architectural designers; Consultants & Regulators, Contractors & Partners; Cost Estimators; Materials Suppliers, Procurement teams; Fabricators, Assemblers and Erectors; Facility Operators. A building's construction process is not a Concurrent Engineering process unless it involves all parties that are responsible for its fabrication, assembly and erection, regardless of who they report to administratively. Subcontracting companies must be included as participants in the CE teams, at least until the construction specifications have been determined, validated, and are somewhat firmed up.
- *Inclusion of Outside Contractors or Trade Partners:* The effective inclusion of outside contractors or (consultant) partners in the cooperative construction is frequently one of the under emphasized issues related to the implementation of a CE process. In today's environment because of the growth in the complexity of investments goods and services (buildings, bridges, etc.) and the increased reliance on ready-to-assemble pre-built building parts and trouble-free procurement methods to construct them, partnership has become an increasingly important issue. Building and civil engineering industries often rely on outside contractors or partners to supply materials, services and products in various specialized forms and shapes.

3.2 Parallel Product Decomposition

Smith and Browne [8] and Los and Storer [9] describe decomposition as a fundamental approach to handling complexity in architectural design, engineering and construction of a building. Property decomposition means viewing the property construction process as a part of the whole and then overlapping (aggregating) the decomposed A-sets to recreate or reconstruct the whole set (IDC-set) from its parts (A-sets). In other words:

$$\begin{gathered}\text{Property Construction} \Leftrightarrow \\ [\text{Decomposing (parts-from-the-whole)} \\ \oplus \text{Reconstructing (whole-from-the-parts)}]\end{gathered}$$

The term "whole" also includes multiple characteristics of life-cycle concerns (e.g., X-ability). Although not all life-cycle activities are independent, many sets can be decomposed safely. For example, it is not necessary to delay the start of an activity if the information required for that activity is not dependent on the rest. Due to an increased global pressure to construct a building or a facility as early as possible, parallel processing in CE is becoming a necessity [10]. The two steps process shown in equation is in line with the way a contracting company builds a property. Usually, the design team produces the detailed design of a building from top-to-bottom, but when the construction starts, the structure is fabricated or erected from bottom-up. There are, however, many ways a building, a facility, a construction process or work information can be decomposed and overlaid in parallel [11]. If a property, construction process or a work information activity does not affect other parameters (such as safety or regulatory codes), it can be performed locally. If it does, it can be performed in a distributed fashion. Local or distributed processing, to a large extent, depends on how a property's structure is originally broken up or decomposed [5]. Do the decomposed parts exhibit independent or semi-independent characteristics? Decomposition allows the scheduling of activities to proceed in parallel. In a construction process, usually a high degree of dependencies exist, as such it becomes even more important that such decomposition of construction properties is done in the right way.

The two (decomposition + concurrency) allow one to identify activities that can be overlapped or performed simultaneously. It also allows one to formulate strategies leading to their separation, e.g., indexing, alternate decomposition, teaming, or restructuring. Meaning they are coupled and cannot be separated explicitly either in a series or in a parallel mode. Interdependent (or coupled) activities take more design time and many iterations (of information transfer back and forth) before they finally converge. The aim of CE is simultaneous, immediate interaction. In practice, however, mutually independent group of activities seldom exist. Strategically, decomposing the interdependent activities into a series of dependent, semi-independent and independent activities can reduce the size of the working groups and the number of iterations that is required to obtain a reasonable solution.

3.3 Concurrent Resource Scheduling

Facilitating the transfer of work information among work-groups is an essential organizational task of any construction company. Concurrent resource scheduling involves scheduling the distributed activities so that they can be performed in parallel. Paralleling is simple for activities exhibiting independent or semi-independent characteristics, however, it is not so simple for dependent activities set. There are many cases when activities are dependent (not yet coupled) but need to be scheduled in parallel with other activities. A simple case is that of an overlap. Even though an activity is dependent on another, there is no need for one to wait until the other task ends. If an activity precedes and generates the needed information for a later activity, the next task can start as soon as the needed information is made available. There is no need to wait for the completion of the former task. If the two activities are independent, they can be scheduled in any order necessary. The other options that address these issues more precisely are: optimal scheduling (minimizing time, resource, cost, etc.), backward scheduling (meeting target time), and team-based project management. Sanborn Manufacturing Company employed a backward scheduling to set up major milestones consisting of hard and fast dates and worked back from those dates as a planning mechanism [12].

Frequently a building is radically redesigned to achieve parallelism. Paralleling of activities provides the management team with opportunities to reorganize and control the resources applied during CE. These resources fall into three main categories: teams [e.g., people, machines (cranes, ladders, etc.), facilities (materials, outside firms, etc.)]; tasks (activities or projects they work on, knowledge of the projects, information they need to work with) and time. The trio provides a basis for defining a work breakdown structure, series of interrelated work tasks initially set in motion by the planning track. New tasks are added or created by the subsequent tracks when put into motion. The latest series of tasks are mostly due to construction specifications, cost management, and procurement and supply tracks.

3.4 Concurrent Processing

Managing time is the fulcrum of Concurrent Engineering. Some companies rely on milestones. Others use strategic routing and queuing as another way to manage time. Concurrent Processing means optimal routing and queuing of activities both from the work-group distribution and information buildup standpoint. This is essential to guide the architectural design of the property and its fabrication, assembly and erection processes toward a safety, quality-build end. Concurrent Processing is never easy, particularly in industrial settings where solvable technical problems are prevailed upon by cultural considerations. Resistance to change is quite predominant. This is seen, for example, in the automotive industry, and more generally, in companies where the age profile of the technical staff is high. The three most important concepts associated with Concurrent Processing are: creation of "variable-driven" product/process models, route management and queue management.

In concurrent processing, activities are staggered (performed simultaneously or overlapped) rather than carried out sequentially. Keeping track of those complex dependencies that vary with time is a critical task in concurrent processing. Appropriate synchronization efforts between different CE teams have to be made.

3.5 Minimize Interfaces

This entails reducing all types of interfaces required for the "Product Realization Process" to a bare minimum. These include the interface relationship between project definition and architectural design, construction specification and cost management, architectural design and structural engineering, cost management and procurement, fabrication, assembly and erection interface, procurement and supply design, etc. Such interfaces can be very long indeed and tend to depend upon the size of the industry, and the construction facility and process complexity. Partitioned design and construction can be facilitated by introducing adequate interface management. The main focus is on identifying various sources of interfaces and determining whether they are actually needed or not.

3.6 Transparent Communication

This provides virtual communication between the individual activities that are partitioned (decomposed), and between the team members. Transparent communication involves identification and definition of mission-critical data. All members of the CE teams need to have the same common understanding of the frequently used terms and their meanings. It may require definition of "data dictionary and semantics" as a structured approach to resolving conflicts and for consensus building. The elements that contribute to transparent communications are (a) global access (b) Universal Product Representation (STEP) (c) Electronic Data Interchange (EDI) (d) Technical memory.

3.7 Quick Processing

Quick Processing means performing individual activities as fast as possible using productivity tools or design aids. It also amounts to speeding up the preparation time in building up the information content before and after an execution of an activity. This emphasizes the mandate for shortening the pre- and post-processing time and the time it takes for completing the decomposed activities themselves.

4. The ProMICE Integrated Product and Process Model

4.1 The ProMICE Project

ProMICE (Product and Process Models Integration for

Concurrent Engineering in Construction) is a collaborative research project between the Department of Civil and Building Engineering at Loughborough University, UK and the Ecole Supérieure d'Ingénieurs de Chambéry, Université de Savoie, France. It is funded jointly by the British Council and the French Government [13].

4.2 Objectives of the Project

The aim of the project is to compare and link British and French approaches to product and process modelling with a view to developing a generic integrated model based on CE principles. The specific objectives of the project include:

- review and comparison of the use of product and process models in the construction industry in Britain and in France
- development of a generic integrated product and process model for design and construction, based on concurrent engineering principles. The generic model will embody the best features of French and British practice, and as far as possible will be developed as a conceptual model, independent of implementation constraints.
- investigation of the requirements for computer-aided design (CAD) and information technology (IT) systems—including virtual reality (VR)—to support the generic product and process model. These requirements will form the basis for a software architecture for the implementation of the model.

The concurrent engineering (CE) framework within which the integration of the product and process models is being undertaken is innovative and incorporates the best features of CE implementation in the manufacturing industry.

4.3 Work Programme

To achieve the goals defined for the project, the work has been split into five tasks, which are:

- identify available models: for data and processes (UK and France)
- identify available representation methods
- agree on common methods, for data and processes
- elaborate a synthesis of the models to produce the generic integrated product and process model
- identify CAD and IT requirements and formulate a software or logical architecture for the generic model

4.4 Applicability

It is intended that the integrated product and process model will facilitate improvements in the construction process, particularly with respect to: collaborative design, project co-ordination, reduction in project duration, reduction in costs, reduction in claims and disputes, and improvements in product quality. The generic model will be applicable to different European countries, many of which have similarly fragmented construction industries. The project also contributes to the ongoing international work on product and process improvements in construction, and will inform about the development of appropriate international standards, such as the standards being developed within the ISO TC 184/SC 4 "Industrial Data": ISO 10303 STEP (STandard for the Exchange of Product model data) and ISO 15531 MANDATE (MANufacturing DATa Exchange) [14,15]. This project will also inform about the IAI (International Alliance for Interoperability), in charge of the development of the IFCs (Industry Foundation Classes).

4.5 Areas of Potential Concurrency during the Life-Cycle Phases of a Construction Project

The different life-cycle phases of a construction project can be detailed into eight "tracks" [16], which are: inception and project definition, outline design, structural engineering and analysis, property specifications, cost management, procurement and supply, fabrication, assembly and erection, and finally facility management. The track "facility management" is an ongoing coordination track that runs for the full construction life cycle, also providing normal project management functions, tasks sequencing, cooperation and central support to the other tracks. These eight tracks are not unique to a particular construction facility (such as buildings, bridges, roads, factories, etc.). Individual tasks breakdown, their identifying names and time overlaps may differ from project to project. Figure 1 represents possible areas of concurrency during these phases. As we will see, the focus of the ProMICE project has been put on the design stages of a construction project.

4.6 Modelling Approach

Following a preliminary review of modelling languages able to represent both product and process information, the project team decided to use the Unified Modelling Language (UML) [17], as it offered the potential for achieving the ProMICE objectives [2].

UML is not a modelling method in itself, rather a modelling notation, or more, a graphical modelling language used to describe, most of the time, software development processes. Constitutive elements of the language are modelling elements and diagrams: UML defines nine diagrams, four of them bringing a "static view" (Class, Object, Component, Deployment diagrams) and five a "dynamic view" (Use Case, Sequence, Collaboration, Statechart, Activity diagrams).

It is important to notice that a diagram is not a model, but only a partial graphical representation of some elements of the model: a diagram is a projection onto the model, as a kind of perspective on the model. Several diagrams are necessary to illustrate the entire model.

One of the problems we met when we started the represen-

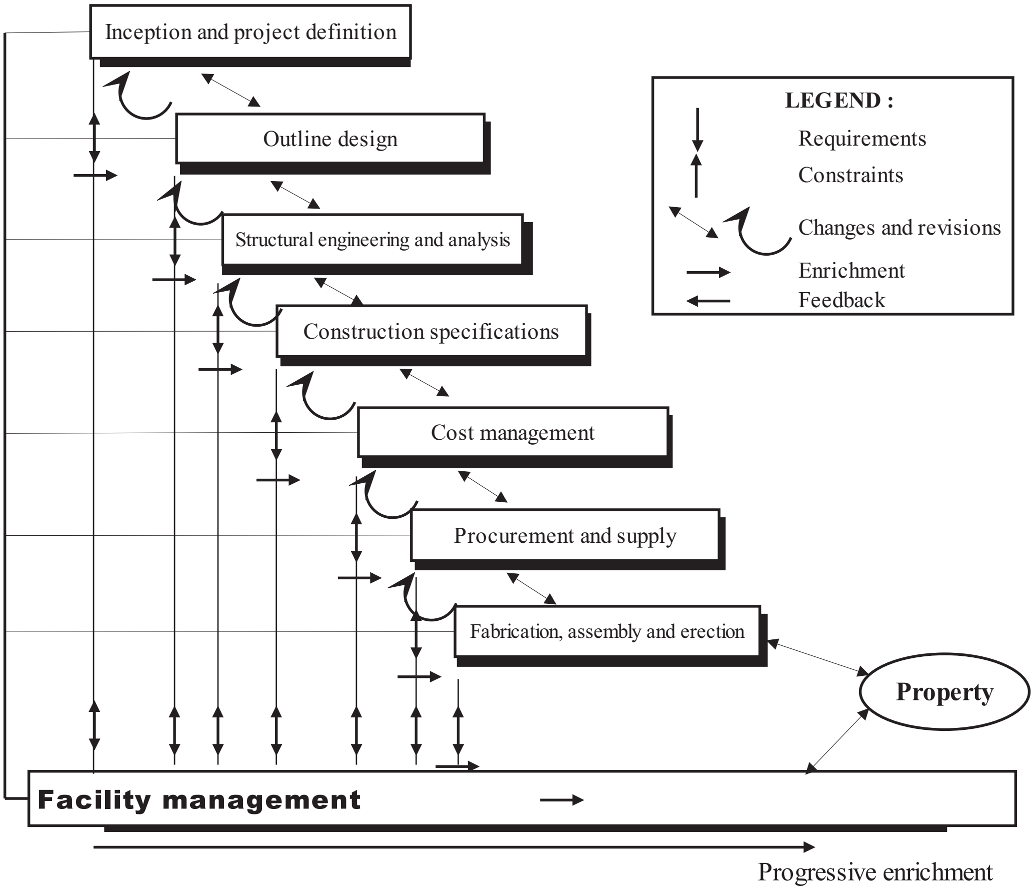

Figure 1. Areas of potential concurrency.

tation of the model with UML was the determination of the types of UML diagrams to be developed and their sequence, since the subject of our development is different enough from the common usage of the language, notably the nature of the system to be described. The system we need to represent (and of which we want to know, the behaviour through the knowledge of elements and diagrams) is made of the design team (architect, engineers, project manager) involved in a building construction project.

For the ProMICE project, we decided to focus our work on the design stage of a construction project, without considering the full life cycle of the building, since this stage can be considered as belonging to the "decisional core" of the construction process. It is a critical stage where inappropriate decisions can have big consequences on subsequent stages, this can be prevented if problems are identified during the early stages of the project.

Compared to software development, the specificity of the use we make of the language lies in the way of defining the specifications of the system: specifications of a building project are known at the beginning, since they have been defined by the project owner.

Activities of the actors involved in the project are defined through activity diagrams and sequence diagrams. These sequence diagrams provide a powerful representation of the sequencing of the different activities, through the description of "working scenario" of the actors involved, thus enabling a detection of possible "strategic crossings" that could be improved using CE features. Figure 2 shows an example of a sequence diagram.

Case diagrams can be used to provide a high level view on the (main) actors involved in the "system" considered. A rough representation of the outline design stage is shown in Figure 3.

The names of all the actions have not been represented on the diagram, for readability reasons. However, in the final version of the project, all the diagrams will be provided with their glossary. It is interesting to represent at the same time activity diagrams, since they provide a complementary view, emphasizing the flows of control among the actors and their activities. Figure 4 shows an example of an activity diagram related to the outline design stage.

4.7 Current State of the Model

To date, the development of UML diagrams (activity, sequence, use case, collaboration, deployment and state) is ongoing, mainly focused on the design stage and the related actors and tasks of the construction project. In order to facilitate the description of a construction project, not the same ac-

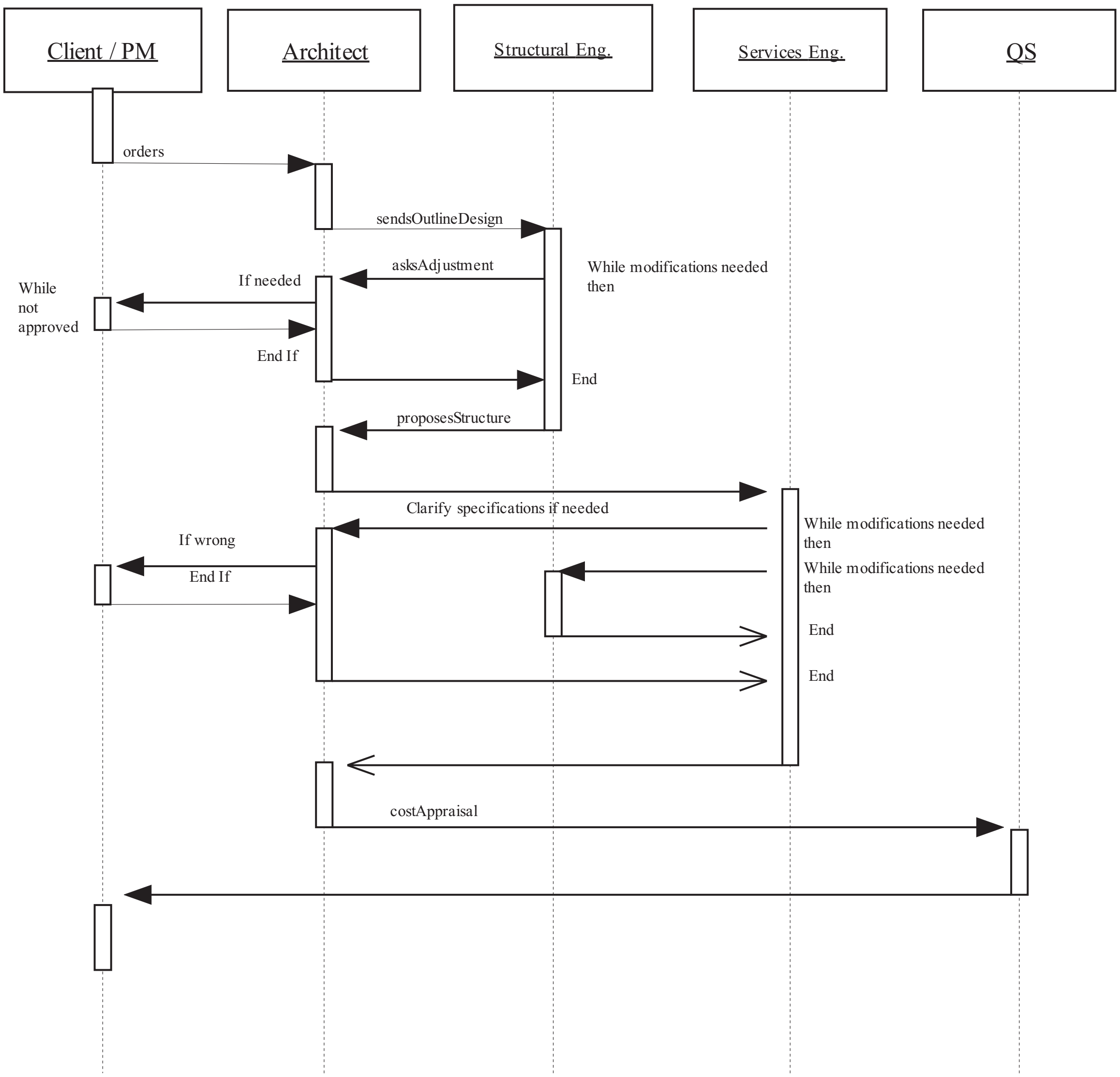

Figure 2. Sequence diagram: design stage—traditional approach.

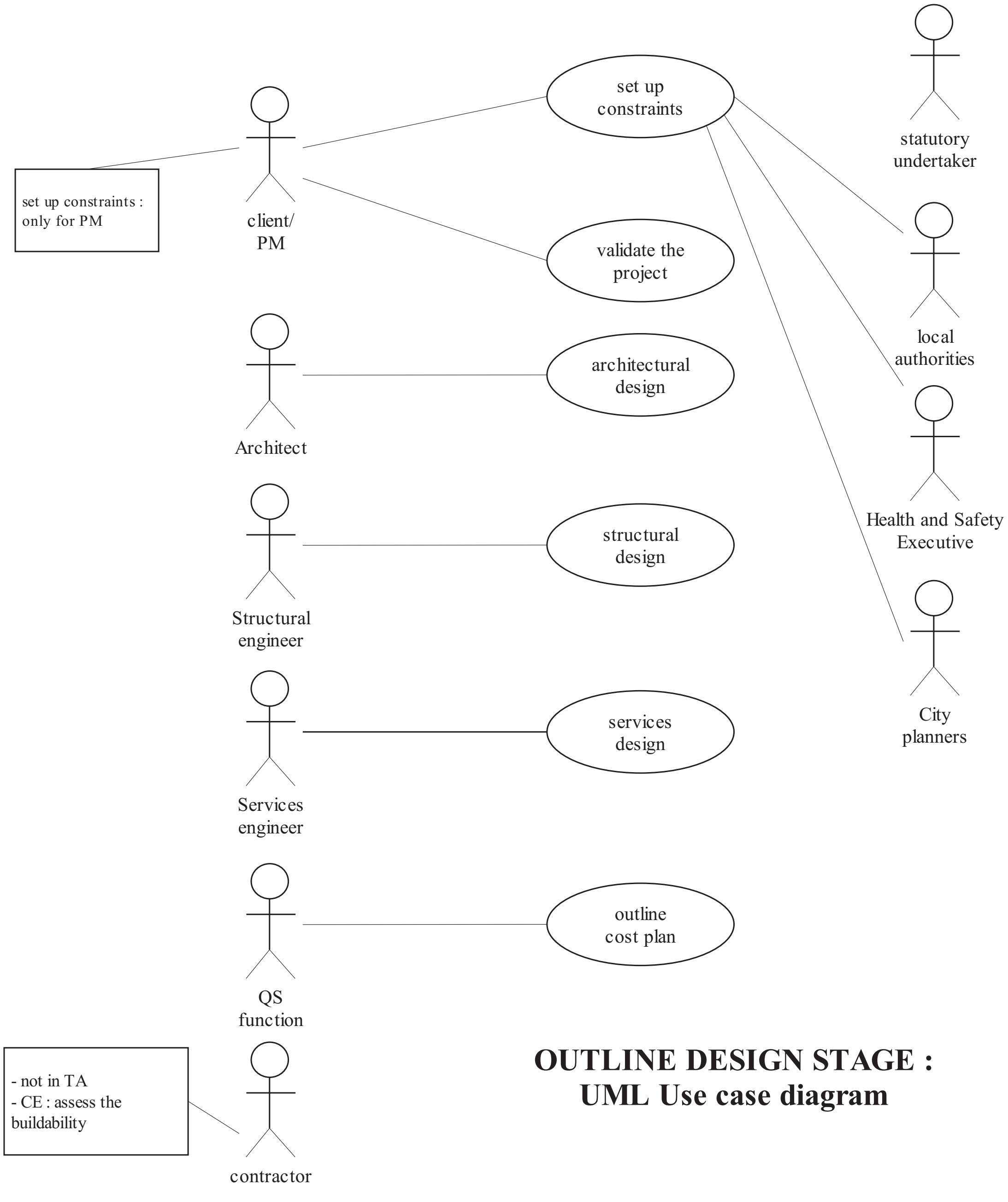

Figure 3. Use case diagram: outline design stage.

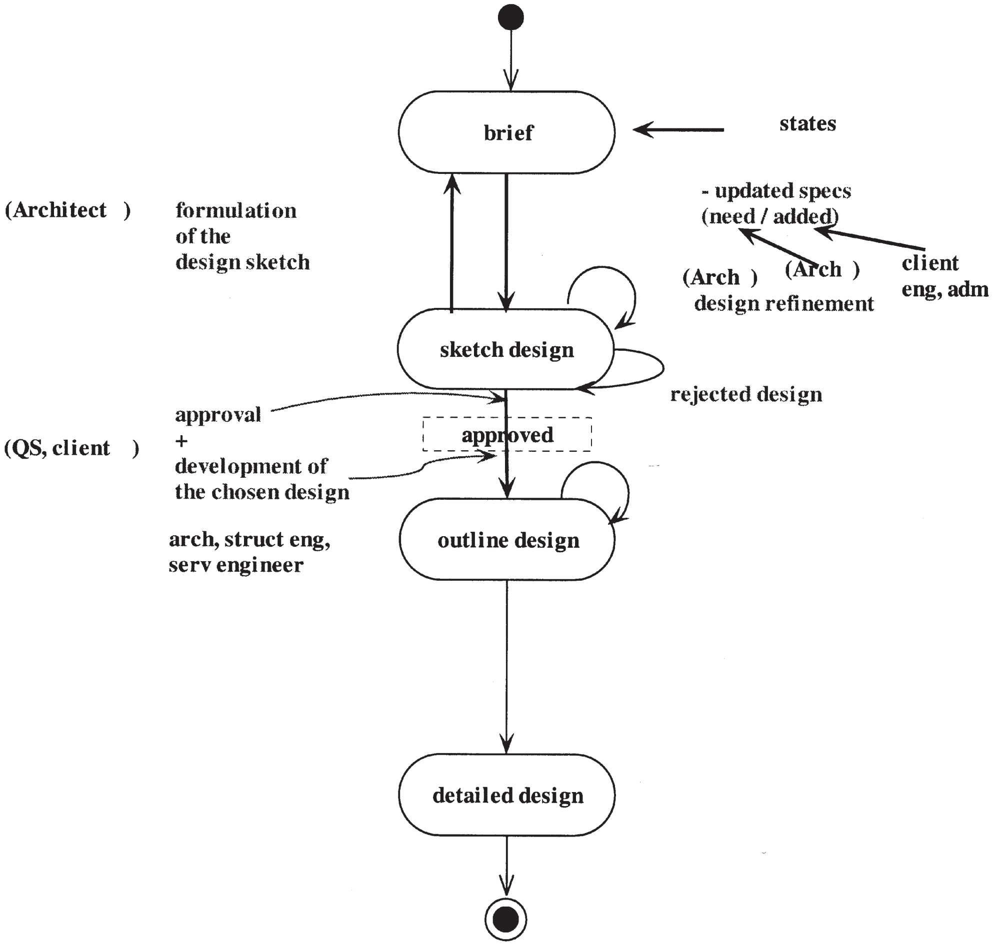

Figure 4. Activity diagram: design stage.

cording to the nature of the bid or the country, we decided, for a first stage, to separately represent the two models (in France and in the UK). It has then been possible to find a common representation of the project, valid for both countries, on which we are now introducing CE concepts. The validation is made on a steelwork building project.

5. Introduction of CE Concepts into the ProMICE Model

5.1 Methodology

Concurrent Engineering features are introduced in the model according to a three-stage methodology we developed for this project.

The aim of this methodology is twofold: first, we have to define the *way of working,* that is to define the set of procedures necessary to introduce concurrent engineering concepts into the model; another feature of this methodology is to provide a *way of representing "CE knowledge,"* that is how to describe CE specificity in order to introduce the related concepts in the model. In a second stage, it is thus necessary to "translate" those concepts into the generic representation provided by the model resulting from the integration.

5.2 Stages of the Work

The three stages of the method followed in the ProMICE project are:

- *Stage 1:* description of the current situation (traditional approach) in terms of the actors involved in the construction process and in terms of the information flows
- *Stage 2:* description of a CE way of working (using the same tools as in Stage 1)
- *Stage 3:* define changes to facilitate the transition from the current situation to a CE way of working.

STAGE 1: CURRENT SITUATION, TRADITIONAL APPROACH

This stage used decisional tools, such as behavioural graphs and templates to be completed for each actor at each stage of the design-construction process, nonetheless restricted, for the analysis, to the design stage. The first template was used to define the functions included in the design process at every stage from inception to scheme design (Table 1). The actors' involvement and responsibilities at every stage are then shown on another set of templates using four levels of involvement (None, Low, Medium and High) and three classes of responsibilities (None, Partial and Total), an example of this is shown in Table 2. At this stage, it is important to mention that all the diagrams represented already result from a synthesis of the structure of a construction project between the two countries involved in the work.

STAGE 2: CONCURRENT ENGINEERING APPROACH

The same working procedure is then applied to the CE approach of the same construction project. The same decisional tools are used: matrix representation and forms (same as for traditional approach). The result of the matrix analysis is also available on a table showing the actors and the stage of their intervention.

STAGE 3: TRANSITION FROM TRADITIONAL TO CE APPROACH

This stage is not yet fully developed. Work is ongoing. The

Table 1. Definition of functions in the design process.

	Stages			
Functions	**Inception**	**Feasibility**	**Outline Proposal**	**Scheme Design**
Project initiation	Examine the present circumstances and consider the need to build. Set up project team.	Conduct user studies, and provide further information. Consider feasibility report and develop brief.	Receive and appraise designs and reports. Approves costs and makes decision to proceed.	Approve full design and costs. Authorise formal approval for statutory consent.
Management	Liaise with client and obtain background information, budgets, requirements and time tables about the site.	Survey and site study and locality. Consult statutory authorities. Prepare feasibility report, site meetings.	Co-ordinate the development of the outline proposal and amend brief. Report to client.	Co-ordinate design and prepare full scheme and report to client. Apply for planning consents.
Architectural design	Discuss terms of appointment: Service provided Basis of fees.	Carry out site studies. Attend meeting, assist in preparation of the report. Obtain outline-planning consent.	Carry out outline proposals and contribute to meetings and preparation of report.	Prepare full scheme design and pass drawings to QS. Prepare draft report.
Structural design	Discuss terms of appointment: Service provided Basis of fees.	Carry out studies on site. Obtain additional information. Contribute to meetings and assist in feasibility study.	Contribute to meetings and carry out further studies. Prepare outline design proposals.	Assist QS in finalise cost plan, and contribute to scheme design and report.
Services design	Discuss terms of appointment: Service provided Basis of fees.	Carry out studies on site. Obtain additional information. Contribute to meetings and assist in feasibility study.	Contribute to meetings and carry out further studies. Prepare outline design proposals.	Assist QS in finalise cost plan, and contribute to scheme design and report.
Costing	Discuss terms of appointment: Service provided Basis of fees.	Obtain additional information. Attend meetings and assist with feasibility studies, building cost & tenders.	Contribute to meetings and carry out further studies. Prepare outline cost proposals and plan.	Develop and finalise cost plan. Contribute to report.
Production	Discuss site operations and running of site.	Assist in preparation of feasibility report, and attend meetings and liaise with client.	Contribute to the preparation of the report and advise on buildability.	Assist in building schedules and advise on buildability.
Operation	Discuss terms of appointment: Service provided Basis of fees.	Carry out studies on site. Obtain additional information. Contribute to meetings and assist in feasibility study.	Contribute to meetings and carry out further studies. Prepare outline design proposals.	Liaise with client, QS and engineers to help with the preparation of the final report.
Decommissioning and demolition	Consider life cycle and duration of building and occupants.	Obtain additional information. Contribute to meetings and assist in feasibility study.	Obtain further information. Contribute to meetings and assist in feasibility study.	Liaise with client, QS and engineers to help with the preparation of the final report.

Table 2. Actors' involvement and responsibility, feasibility stage.

Functions	Actor	Client	Project Manager	Architect	Structural Engineer	Services Engineer	Quantity Surveyor	Contractor	Facilities Manager
Project initiation	*inv*	High	Low	None	None	None	None	None	None
	resp	Total	Partial	None	None	None	None	None	None
Management	*inv*	Medium	High	None	None	None	None	None	None
	resp	Partial	Total	None	None	None	None	None	None
Architectural design	*inv*	Low	Low	Medium	None	None	None	None	None
	resp	Partial	Partial	Partial	None	None	None	None	None
Structural design	*inv*	Low	Low	None	Medium	None	None	None	None
	resp	Partial	Partial	None	Partial	None	None	None	None
Services design	*inv*	Low	Low	None	None	Medium	None	None	None
	resp	Partial	Partial	None	None	Partial	None	None	None
Costing	*inv*	Low	Low	None	None	None	Medium	None	None
	resp	Partial	Partial	None	None	None	Partial	None	None
Production	*inv*	Low	Low	None	None	None	None	Medium	None
	resp	Partial	Partial	None	None	None	None	Partial	None
Operation	*inv*	Low	Low	None	None	None	None	None	Medium
	resp	Partial	Partial	None	None	None	None	None	Partial
Decommissioning and demolition	*inv*	None	None	None	None	None	None	None	None
	resp	None	None	None	None	None	None	None	None

aim of this stage is to make clear the main points targeted by a transition process from a traditional approach of a construction project towards a CE one.

A comparison between the two sets of diagrams and corresponding glossaries (traditional and CE), added to the actor/stage matrices and the related forms will enable an identification of some crucial points of the design process: differences between the ways the actors work, gaps or overlaps of the function(s) assumed by the actors, leading to misunderstandings or lacks of communication. It is hoped that the results from this stage will highlight all these problems associated with the design process.

6. Expected Results

Among the different results expected from the ProMICE project, we will separate the results coming from the first two stages of the methodology, from the results of Stage 3. Results from Stages 1 and 2 enable a more direct (or immediate) validation on a real test case such as a steelwork building: a comparison between two ways of working seems at a first glance easier to do. Results from Stage 3 will need further developments in order to really validate the set of rules developed: in that sense, it may appear as a more long term action. Of course all these results are not yet available, since the project is currently under development.

6.1 Results Expected from Stages 1 and 2

The analysis of the results of the first two stages enables a comparison between traditional and CE approaches of the design-construction process, but also a comparison between UK and French ways of working.

- *comparison between traditional and CE approaches*
  The differences between the two approaches clearly appear on the matrices and the forms, but also on the UML diagrams—even if not fully developed as they are today. The differences seem to lie in the important number of "messages" exchanged among the actors in the traditional structuring of a construction project. Besides, those messages are essentially sequential, thus contributing to increase the problems met when something occurs at the end of the exchange process.
- *comparison between UK and French project procedures*
  The model built up within the framework of the project resulting from a synthesis of the working procedures of the two countries, problems may appear when the model is applied to a French construction bid. To develop the example, we tried to take the most similar type of construction project (in France and UK), that is the *design and build* project. Some other types of projects proved to be more or less incompatible among the two countries.

6.2 Results Expected from Stage 3

Once completed, the third stage will enable the elaboration of a set of rules, both for the actors (defining their role) and for the information flows (defining the type of information management to be dealt with by the actors).

This set of rules can be seen as a "guideline," providing the way of moving from a traditional project organisation towards a CE one. Of course, these rules will need several (industrial) validations, to refine the values of the different parameters.

6.3 Industrial Validation of the Final Model

One of the objectives of the ProMICE project is to identify the changes needed by this transition from traditional towards CE approach, then to represent those changes, notably in the domain of steelwork construction and to write guidelines to help users. The objective is also to provide an industrial validation of the final model. This validation will be made on a steelwork building, chosen since this type of construction provides a better "traceability" of the work done by the different teams involved in the project. It also enables us to rely on several results (in terms of communication and information exchanges) of the Eureka EU130 CIMSteel Project on which one of the ProMICE partners has worked for many years.

7. Conclusions

At the heart of any good outline design, construction and procurement process, there lies a set of underlying principles for satisfying the interests of the clients, the contracting body, and the company.

This paper focuses on the presentation of these principles, in a context of Concurrent Engineering, allowing the construction project teams helps formulate significant outline design and construction process strategies.

The introduction of these CE concepts has then been presented through the work achieved within the framework of the ProMICE project, both in terms of the methodology carried out in the project and in terms of ongoing work.

The final stage of the work will be to represent and validate the changes needed for the transition from the traditional process to Concurrent Engineering using the case of a steel frame building.

This will enable the project team to make use of methodologies in communication and information exchange already carried out and used within the Eureka CIMSteel Project.

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