Theme:

Title: **Defining the Matrix of Communication Processes in the AEC/FM Industry: Current Developments and Gap Analysis**

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Abstract: *A formal approach for the analysis of AEC/FM related processes has been undertaken in the frames of the EU ICCI cluster project (IST-2001-33022). The approach is based on a modified application of the Generic Process Protocol (GPP) proposed in a research project funded by the UK Engineering and Physical Sciences Research Council, coupled with a dedicated usage of the UML technique. GPP is applied on high-level, for the definition of a multi-dimensional matrix capturing the classification of roles, activities and communication, together with their inter-relationships, whereas UML diagramming is used for detailed representation of sub-processes. The original GPP matrix is modified in accordance with two objectives: (1) to prepare the matrix in a suitable form for database management as well as Web-based presentation and processing, and (2) to improve the capabilities for information capture so that various analyses can be easily performed and reported.*

In this paper, first the suggested modelling approach is outlined, and then already available results of an ongoing study of current developments are presented and discussed. The reported study synthesises the performed examination of the ICCI member projects OSMOS, ISTforCE, eConstruct, DIVERCITY, eLEGAL and GLOBEMAN and of several other large efforts and literature sources. At the end, future directions for work are extrapolated and some general conclusions regarding further development efforts are drawn.

Keywords: *Process modelling, generic process matrix, user requirements, user scenarios, IFC, ICCI.*

Introduction

The idea of establishing a generalised *conceptual information model* that can capture project data within building construction has been well documented over many years and is progressing towards a degree of fruition through the Industry Foundation Classes model of the International Alliance for Interoperability.

More recently, there has been a growth of interest in the idea of developing a counterpart *generalised process model* (see e.g. Howard, 1996; Björk, 1999; Wilson et al., 2001). In some cases this has been in support of proposed new, non confrontational methods of working within the industry whilst in others it has been seen as a useful basis for identifying gaps in the coverage of conceptual information models and for creating road maps to fill them. Both of these are legitimate objectives.

Within the European ISTforCE project (IST-1999-11508), preliminary work was carried out on the development of a *reference process matrix*, primarily to support the development of a road map for the IFC model (Wix and Liebich, 2000). Using existing and new findings, it demonstrated that such a matrix could be completed at high level. However, the performed study also showed that there are already a lot of process models existing for the construction industry but that they are totally independent and thus incompatible to each other.

To develop the process matrix further, it was essential to establish a coherent overall methodology for collecting, analysing and synthesising e-Business user scenarios and user requirements. For this, a close examination of process models that are easily accessible and well documented was needed, followed by their incorporation into a consistent framework. A snapshot of the current state of the work on this task, undertaken in the frames of the ICCI project (IST-2001-33022), is presented in this paper.

ICCI is a 'cluster' project that aims to improve the harmonisation and coherency of European RTD projects through co-operative peer review of approaches to common problems and needs leading to identification of best solutions. Project partners are drawn from six major prior projects: OSMOS, eConstruct, ISTforCE, DIVERCITY, eLEGAL, GLOBEMEN. Other projects are being added to the cluster. There has been an evident specification of process that has informed the development of the technical work that is the main focus of each of these projects.

ICCI takes account of the directions that technical development, standardisation and commercialisation might take in the short to medium term (1 – 5 years). The intention is to eliminate unnecessary overlap in work, to achieve improved focus, to re-use and refine results, and to expedite progress towards fully functioning solutions. It is through this intention that it provides the necessary infrastructure for continuing work on development of the reference process matrix.

The ICCI Approach

A process model sets out to describe a sequence of activities having a logical dependency that determines which is the predecessor and which is the successor. Various types of dependencies can exist between activities. These may be:

- *functional*, whereby one activity must complete before another can start,
- *temporal*, whereby one activity is time dependent upon another,
- *data related*, whereby one activity requires that certain data are available from another.

These may all be seen as 'views' of the process.

In ICCI, the view that is of interest is that in which activities are *data related*. In particular, this view is concerned with the impact that data exchange between the different participants in a building construction project has on the completion of the overall process. The approach that is adopted for the development of this process model view has two parts:

- a statement of key activities throughout a project placed in a broad sequence as a reference identification of the major functional processes;
- specification of activities to further elaborate functional processes.

In summary, ICCI proposes a framework within which sets of reference processes can be identified and from which those that are relevant to individual projects can be derived (thus defining project processes). The framework and reference processes are an extension of the process matrix described in (Wix and Liebich, 2000).

The core of the framework is the process matrix that has the primary axes of actor and activity. It is further separated according to the project stages set out in the Generic Process Protocol (GPP) proposed recently in the UK (Kagiouglou et al., 1998)[1]. Each reference process in the matrix represents an identifiable activity that can be further elaborated within or as part of an UML activity diagram (Booch et al., 1999). Thus, from modelling point of view, an adaptation of the GPP method, enhanced by UML elements is suggested.

Identifying Components in the Process Matrix

Actors

Communication on a project occurs between the actors that are participating. Predominantly, actors are identified by discipline in most current models. Within the reference process matrix, it is considered that communication occurs between actors fulfilling roles. That is, the same actual actor may fulfil multiple roles; communication at the role level is the aspect of interest.

However, it is not considered possible to account for all of the possible roles that could exist in a construction project within the process matrix. Therefore, a subset of the possible roles has been defined, based on major functional characteristics. To illustrate the principle, some of these roles are provided in Table 1 below.

1 Development of the GPP was undertaken as a research project funded by the UK Engineering and Physical Sciences Research Council (EPSRC). It was a direct response to the publication of the *Latham Report* (Latham, 1994) that identified fragmentation and confrontational relationships as being the greatest barriers to improving quality and productivity in the construction industry.

Table 1: Actor Roles Definition

Actor	Description
Client	All activities of the respective actor that commissions and ultimately pays for the project, together with the activities of the building owner and operator who may be different to the commissioning organisation.
Project Manager	All activities concerned with management of the project. Whilst there may be a single designated Project Manager, it is likely that several actors may undertake project management roles at various levels and for various purposes.
Building Designer	All activities that relate to the functional and aesthetic design of a project. This can include the traditional architectural role, landscape design, interior design as well as the design detailing role that may be undertaken by actors that otherwise fulfil a more traditional contractual role.
Building Services Designer	The design of all active systems in a project that provide environmental conditioning. It is a wide designation that includes all mechanical, electrical and public health services together with specialist activities such as lighting, acoustics, building automation etc.
Cost Manager	All actors that play a role in managing cost. In the UK, the quantity surveyor is a discipline that specialises in this area but this designation is geographically limited. Additionally, other actors may have specific roles to play in cost management. For instance, services and structural designers may need to determine the extent of work done by a specialist contractor to facilitate payment.
Contractor	The lead role in construction works. It includes management of sub-contract activities and is exclusively concerned with the translation of the design into a physical reality.
Sub-Contractor	All specialised construction activities that are undertaken in support of the contractor. There are many actors in a project who will fulfil this role. Sub-contractors will typically execute a set of particular design requirements (mechanical, electrical, public health, piling, steelwork etc.)
Supplier	All actors that supply goods and materials to the project. A supplier may also act as a contractor, sub-contractor or sub-sub-contractor in a specialist role.
Statutory Body	All organisations that provide primary services to a project (water, electricity, gas etc.) or that play a role in determining satisfactory design, construction and operation of the project (fire services, building regulations, health and safety etc.). This encompasses the idea of organisations that supply primary services in a deregulated environment.
…	…

Major Project Stages

The matrix is divided horizontally according to the 4 major stages of the project identified in the GPP: (1) *Pre-project*, (2) *Pre-construction*, (3) *Construction*, and (4) *Post-completion*. These stages are then divided into ten phases as shown in Table 2 below.

Between each two phases an intermediate phase review (*stage gate*) is introduced as a separate co-ordination and management process, recognising the need for work to be carried out during a stage or phase of the project development following which a review is undertaken. Gates are identified as being either 'hard' or 'soft'. A 'hard' gate requires the completion of all activities within the phase or stage. Project development is halted until this is achieved. A 'soft' gate allows non-completion to be identified and carried over until the next gate is reached. Project development is not halted but the respective phase is only 'conditionally approved'.

In ICCI, slight modifications to the phases and stages identified in GPP are proposed to take into account broader European practices and the usage and disposal stages of a facility.

Table 2: GPP Project Phases

Phase	Description
Pre-project phases	
0	Demonstrating the need
1	Conception of need
2	Outline feasibility
3	Substantive feasibility study and outline financial authority
Pre-construction phases	
4	Outline conceptual design
5	Full conceptual design
6	Co-ordinated design, procurement and full financial authority
Construction phases	
7	Production information
8	Construction
Post completion phase	
9	Operation and maintenance

Activities

At each stage, a number of activities are identified. These are sorted into different major groups.

Within the matrices, activities are not related to each other in terms of time or sequence. This is not their purpose; other process modelling methods are more appropriate for this and are intended to be used for more detailed analysis. Thus, an activity in the matrix describes the fulfilment of a particular requirement but not the actions that are undergone in achieving its fulfilment. It is proposed that, over time, sets of actions will be provided in the form of *Activity Diagrams*. ICCI suggests a notation to be used for this purpose and provides examples.

Information Sender and Receiver

The matrix uses a simplified approach to identifying potential senders and receivers of information for each identified task. A potential sender of information is identified in the matrix by the letter ‘o’ whilst a potential receiver of information is identified by the letter ‘x’. Identification of communication is restricted to initial sender and final receiver(s) and is not concerned with intermediate communications between actions that are undergone in the fulfilment of an activity. Such communications will be apparent in the Activity Diagrams.

Representation Classification

Each activity in the matrix is considered to communicate using a particular representational form. This could be a geometric representation (incorporating ideas of 3D models and 2D drawings), cost (cost records, cost plans etc.), schedule (design, construction, maintenance etc.) and others. Both a primary and a secondary classification are assigned to the activity to assist in understanding the appropriate form of communication.

Diagramming Method Selection

An activity within the process matrix may be further elaborated to define the actions that are undertaken. It is anticipated that this close description of an activity will be the subject of a detailed activity diagram.

There are many approaches that can be adopted for that purpose. Each of them may offer particular benefits according to the view required. Here, we are concerned with the view in which activities are data related in terms of the data exchange between the different actors. Thus, the IDEF0 notation (NIST, 1993) which has been used by the majority of formal process models that have been developed for building construction was not found appropriate for the further elaboration of process matrices. IDEF0 provides a focus on an individual process. In building construction terms, this is a view that relates to a particular role or discipline (e.g. structural engineering, building services etc.). It is not the most effective way to easily identify communication between multiple processes and/or multiple roles.

UML (Booch et al., 1999) is used to specify, visualise and document the artefacts of an object-oriented system under development. It comprises a number of separate but integrated approaches that reflect the requirements of different stages in the development process. Amongst these are several diagramming methods that deal with process including activity, sequence and collaboration diagrams and use cases. However, sequence and collaboration diagrams reflect messaging between objects at a very detailed, technical level. Use cases deal with detailed functional process components and the identification of objects that serve the processes. Hence, all these methods would not deal well with a broadly defined process, such as ‘Design system’, but would adequately handle a narrow process definition, such as ‘Calculate authority of control valve’. Besides, they are also not designed to deal with aspects of communication between different systems. Therefore, the principal diagramming notation of interest are the UML ‘Activity Diagrams’.

UML activity diagrams enable the easy identification of communication between activities undertaken by different roles within a process. This notation has a strong focus on the activity and on the key outputs that trigger another activity. It uses a ‘swimlane’ approach to distinguish between activities undertaken by each role and therefore specifically identifies the occurrence of a data exchange requirement whenever a data output crosses a swimlane boundary. Thus, UML activity diagramming is seen as the most adequate notation for the capture of inter-process communication between the actors in a construction project[1].

Preparing for the Process Matrix: User Requirements and User Scenarios Capture

To enable specifying the details of the process matrix and to populate it with relevant data reflecting actual construction practice, at first user requirements and scenarios/use cases need to be adequately captured and mapped to project phases, activity zones and actors. For that purpose, a broad study was performed encompassing analysis of all member projects of the ICCI cluster, peer reviewing of 23 ongoing or recently finished IAI projects, 8 past and current European and national projects and a number of literature sources (Katranuschkov et al., 2002).

A *unified form template* was developed for collecting user scenarios from the ICCI member projects (see Table 3). This template was defined on the basis of experience from several other projects, such as OSMOS, ISTforCE, a number of IAI projects etc. It focuses – in narrative style – on the most essential data that had to be collected and analysed from the ICCI viewpoint. The content is intentionally kept as concise as possible, to limit the effort required for completion and to concentrate on the harmonised representation of a set of basic issues. Furthermore, it was requested that only *major scenarios* covered by the respective project are provided, specifically focussing on scenarios where multiple roles are involved. Not in scope were processes such as system and database administration and management, software maintenance, use cases for error management, fallback scenarios and other similar technical issues. However, where the member projects are dealing with supporting processes, such as legal issues (eLEGAL), software service providers (ISTforCE, OSMOS), supply chain management (eConstruct) etc., these processes were explicitly requested to be included as well.

Altogether, 24 user scenarios comprising 77 tasks (use cases) have been collected and analysed. In summary, the OSMOS scenarios address important collaboration processes in the virtual project organisation with applicability spanning over the whole life cycle of a project. The eConstruct scenarios deal with different e-Commerce issues to support the collaboration between building designers and suppliers. The ISTforCE scenarios deal with the efficient support of the designer’s e-workplace through the provision of various rental services offered by application software providers, as well as with the use of essential tools for co-operative work. The focused processes are all from the design phases of a project. The DIVERCITY scenarios present usage examples of the developed Virtual Environment (dynamic 3-D representation of the built environment) as a means to help solving practical construction problems. The scenarios address problems from the design phase, the client brief and the construction planning phase. The scenarios from eLEGAL deal with different contractual aspects related to the Virtual Enterprise in building construction, and GLOBEMEN focuses on some major aspects of product model based distributed engineering.

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1 Details of the rationale for diagramming method selection and a review of strengths and weaknesses of several examined candidate methods are provided in (Katranuschkov et al., 2002).

Table 3: User Scenario Template

Scenario Name

[Short indicative name of the scenario]

References

Author	[Your name]
Date	[The data when you completed the form: dd/mm/yyyy]
Project Source	[The project the scenario is taken from]
Reference # [1]	[Ref. No. in the Form P_n - see footnote]

Overview

[Summary of the scenario as described in the source project - 3 lines to 1/2 page]

Actors and Roles [2]

Actor	***Role*** [3]	***Purpose***
[Synthetic actor name]	[Role of the actor]	[Brief description of the role's purpose]

ICT Tools and Systems [4]

Name	***Type*** [5]	***Description***
[Tool name/acronym]	[Type of Tool or System]	[Brief description of the tool's features]

Tasks

Task # [Seq. number of the task] *[Repeat this table for all tasks in the scenario]*

Task Name	**[Indicative task name on 1 line]**	
Task Description	[Brief description of the task]	
Applications Used	[Name(s) of the tool(s) used (from field "Name" in table "ICT Tools")]	
Communication	**Sender(s)**	**Receiver(s)**
Actors	[Sender ("Actor" in tbl. "Actors")]	[Receiver ("Actor" in tbl. "Actors")]
Form	[The communication form(s)/paradigm(s) used, e.g. "Client/Server", RPC etc.]	
Method	[Standard comm. method used (HTTP, FTP, …), non-standard, or proprietary]	
Information Used [6]	**Input**	**Output**
Content	[Major data set(s) used for input]	[Major data set(s) provided as output]
Type [7]	[Type of the input data]	[Type of the output data]
Data model [8]	[Reference data model(s) used]	[Reference data model(s) used]
Data format [9]	[Fmt. of the exchanged/shared data]	[Format of the exchanged/shared data]

Comments

[any comments that might be appropriate in addition]

1 Ref. # should be in the form P_n where 'P' is a name (or shortcut) for the project and 'n' is a one-digit number. Ref. numbers are used for: (1) book-keeping, (2) to enable referencing one scenario from within another.

2 Add all actors relevant for this scenario as described in the source project. Alternatively, all actors for all scenarios may be input in the first scenario, and then omitted from subsequent scenarios.

3 Use role definitions from IAI/IFC where possible, i.e. Supplier, Manufacturer, Contractor, Subcontractor, Architect, Structural Engineer, Cost Engineer, Client, Building Owner, Building Operator, Mechanical Engineer, Electrical Engineer, Project Manager, Facilities Manager, Civil Engineer, Commissioning Engineer, Engineer, Consultant, Construction Manager, Field Construction Manager, Reseller, Service Provider. If none of these roles is appropriate, write 'Special Role' and define this shortly in parenthesis, for example 'Special Role (Regulator)'. The next field 'Purpose' may be omitted if an IAI role is specified.

4 Add all ICT tools relevant for this scenario as described in the source project. Alternatively, all tools for all scenarios may be input in the first scenario, and then omitted from subsequent scenarios.

5 Specify the type of the tool or system using one of the following categories: (1) Tools - *End-User*, *System*, *Workflow*, *CSCW*, *AI*, *Communication*, *e-Commerce*, *Browser;* (2) Systems - *Basic*, *Enterprise Resource Planning* (*ERP*), *Product Data Management* (*PDM*), *Electronic Document Management* (*EDMS*), *Database Management* (*DBMS*), *Communication* (*CMS*), *EDI*, *Knowledge Management System* (*KMS*). If none of these categories is appropriate, write '*Other Type'* and name this briefly in parenthesis.

6 Specify only the major data used in the task. If more than one data set needs to be described, put these descriptions on separate lines in each of the following four table rows, i.e. one line per dataset.

7 Specify type of the data used, such as '*model based'*, '*document*', '*database query*', '*message*'.

8 Specify the reference model for the respective dataset: a standardised model, such as '*IFC*', '*STEP AP 225*', '*XML Schema*' etc., '*non-standard'*, or '*proprietary'*.

9 Specify a standard format used for data exchange or sharing, such as '*SPF*', '*XML*', '*HTML*' etc., '*non-standard'*, or '*proprietary'*.

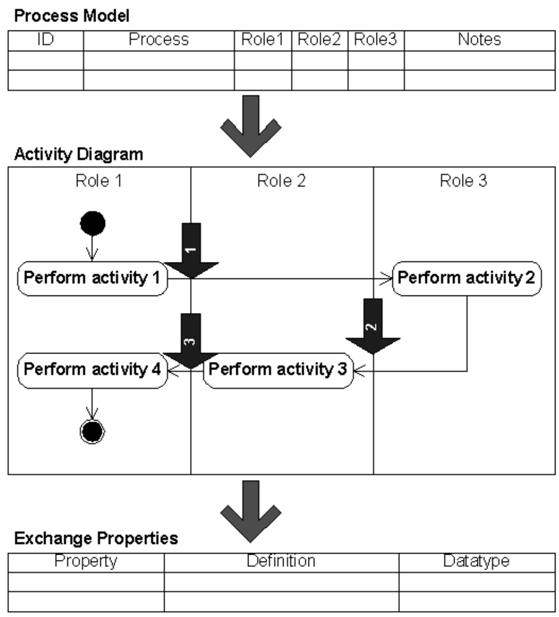
These scenarios, as well as requirements and use cases from 22 IAI industry related projects, were synthesised and then mapped to the GPP phases and the pre-defined actor roles. From the resulting harmonised table (see Katranuschkov et al., 2002), a first iteration on the process matrix and initial gap analysis w.r.t. ICT support could be performed. The results showed that multi-player collaboration and communication processes are strongly supported primarily in the design phases of the project life cycle (21 scenarios reference phase 4, 27 reference phase 5, and 30 reference phase 6). The construction and maintenance phases are only beginning to be addressed in latest efforts (12 and 14 scenarios respectively), whereas pre-project phases are hardly considered (altogether 10 explicit references plus a few potential use cases). In spite of their recognised importance, stage gate activities are hardly dealt with (only 4 scenarios from DIVERCITY and the IAI ES-2 project). Another identified gap was the low involvement of the clients, and – surprisingly – the relatively little attention paid to structural engineering, foundation design and sub-contracting issues in the overall project process. Further analyses from other viewpoints (e.g. related to roles, activity zones, communication methods applied, data models and data exchange paradigms) are currently in progress and are expected to reveal more detailed business needs.

Development Support from the Process Matrix

A process matrix and supporting activity diagrams provide potentially valuable tools to the industry in moving forward to more effective use of ICT tools and collaborative working. The following are scenarios that are already identified. Others are expected to become apparent over time.

1. *Project Process Model*: A reference process model is intended to identify a range of possible processes that might be used on projects. It might not identify everything; equally, it might offer alternative approaches for a particular function. It can act as a 'shopping list' for the development of a project-based process model that can then be further elaborated to provide the project schedule.
2. *Road Maps*: An initial motivation for the process matrix was to provide an understanding of elements of the conceptual information model not yet developed and to guide the prioritisation for their development. It is also providing a basis for understanding activities where ICT tool support is not yet available or where such support could be reformulated to enable collaborative working. Furthermore, it also enables a clear distinction to be made between activities that need to be supported through project data and those that can be supported through more direct business transactions.
3. *Conceptual Information Model Development*: A reference process matrix can be used to support the development of the conceptual data model through the following sequence:
   - develop the process matrix;
   - for each line in the process matrix, develop an activity diagram;
   - for an identified exchange in the activity diagram, develop a table of exchange properties;
   - *from this, the conceptual information model that defines the exchange structure can be created*.

The figure on the right illustrates the suggested approach.



Conclusions

There are many process models that have been defined for the building construction industry. Some of these are implied through narrative text descriptions whilst others are explicit diagrams, normally in the

IDEF0 notation. Whilst the narrative models frequently express the process in detail, many of the explicit models do not break down to levels of functional detail.

Virtually all existing process models focus inwards. That is, they deal only with the specifics of the process with which they are concerned. There is little evidence of processes that focus outwards and that attempt to use developments of and integrate with other existing models.

The facility to focus outwards is not well supported by popular diagramming notations such as IDEF0 and UML activity diagrams. However, UML activity diagrams do support the concepts of interdisciplinary communication that is a fundamental requirement of building construction work. GPP on the other hand does provide support for integration of process models by formalising stages and activity zones.

Within ICCI, the attempt is made to rationalise many existing models and bring them into a coherent framework that is of broad benefit to the building construction industry. It combines aspects of the GPP with identification of specific process that may be subject to UML activity diagramming. Through this approach, a degree of integration can be achieved that enables definition of a reference process model for the industry.

From this work, it can be concluded that:

- models in projects (and specifically in EU supported projects) should be developed consistently using the same methodology,
- they should fit into a larger reference process model,
- the reference process model should be defined within a process matrix supported by GPP and UML activity diagramming,
- anything already in a matrix should be either reused or expanded within new or additive models.

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