RoadRobot project

- An experience using STEP in Construction -

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ABSTRACT

Up to now, the construction industry has not achieved a very high degree of automation. This lack has resulted in a demand for very flexible and automated heavy-duty machines, as well as integration concepts for automated construction sites. The utilisation of Information Technology (IT) in outdoor applications, specially in the building industry and automated construction, should receive more attention concerning the utilisation of standards in the modelling process, towards system's integration. A STEP (ISO10303) based platform (SIP toolkit), for integration of applications under standard information modelling, was developed by the UNINOVA institute, helping to reach standardised Computer Integrated Manufacturing (CIM) environments. This paper devotes special attention to the results and experience acquired during the implementation of SIP in several R&D industrial projects. The focus is put on the European Project named RoadRobot - Operator Assisted Mobile Road Robot For Heavy Duty Civil Engineering Applications.

1. INTRODUCTION

The application of a computer integrated environment, to an outdoor building site including design, planning, production and control, can be seen as the last stage of IT integration into construction industry.

Up to now, only little research work has been undertaken into the development of overall control architectures for building sites, whereas the development of such control architectures for other industrial sectors has advanced significantly during the last number of years. The question is now, whether the results of the past developments can be transferred to the demands of building industry. The evaluation and improvement of architectures and modules coming from other industrial areas [Camarinha-Matos.92] seem to be necessary.

For that reason, to learn from existing architectures and modules from other industrial areas, according the special requirements of the building industry, can help to find new ways towards fully or partly automated and integrated construction processes.

The general aim of any project with these purposes can be achieved following the next steps: (1) to define the needs correlated to the demands of the project, (2) to select the adequate software packages[1] to be used (commercially available, or to be developed), (3) to develop and implement a modular and flexible control architecture, and (4) to integrate the selected tools, using preferentially a standard way. The results found will enable the overall achievement of a global CIM environment for the construction industry.

Several questions have been made concerning strategies for this implementation. A possible approach, in order to go from the scenario found in the company, to the integrated scenario, can be to integrate the existent tools in the system using a specific data protocol. The use of standards in the modelling process should be used. In this way a high number of required interfaces are avoided, and a unique data exchange format would be used.

A STEP (ISO10303) based platform for integration of applications (SIP toolkit), created by UNINOVA in the ambit of the European project for the furniture industry - CIMTOFI, was developed. SIP is a set of tools that helps the integration of applications using a unique format. The main objective when using SIP, is to develop an environment which meets the production requirements, introducing the CIM concept in the industry in a realistic step by step way. The goals will be reached by adapting existing applications selected in the market, integrating product models, processes and resources in a global and standard information system. In this way, "islands of applications" are linked using logical "bridges".

Several managerial and engineering applications were integrated in industrial environments, including the construction one, using SIP. SIP is being used in several Portuguese and European projects for different industrial companies, and demonstrations are available showing the encouraging results.

2. INTEGRATION OF IT INTO THE CONSTRUCTION INDUSTRY

The integration of IT into the building industry has not receiving a high degree of research and development work. No special interest was paid to one major area of the building industry, namely the outdoor construction of dams, roads, airfields and other large projects, with the help of heavy-duty machines.

In the spite of the fact that the work in outdoor building sites is often very harmful and dangerous for human workers, the number of workers is relatively high in relation to modern industrial manufacturing processes in other areas. Depending on the type of application in building industry, normally one to four or more workers are necessary to control safely a heavy-duty building machine. Compared with other industrial manufacturing processes, the degree of automation is thus very slow.

[1] We also use the term "tool" and "application" with the same meaning.

Quality aspects of work are mainly controlled by more or less skilled workers in manual supervision processes. Only a few machines have the possibility of automated quality control of the specific process. Time and material planning are normally done manually at the construction site.

Regarding the state-of-the-art in integration of new technologies into building industry, the results are very poor. Most established developments concentrate on the Computer-Aided Design (CAD), drafting and scheduling of works, and the automation of certain pre-fabrication processes [H.J.Helpenstein.91, U.Rembold.86].

Future developments have to focus at the integration of IT into the building industry [D.Bradly.91]. Besides the low-level automation of overall planning and control systems, the task-level programming of complete building sites, has to be achieved. The main interest of future works lies in the development and elaboration of a generic architecture for standardised integrated out-door building site. Also, further work will concentrate on the automation of specific heavy-duty machines [A.Ulrich.91, G.Leidinger.91], in order to obtain a manpower reduced building site, with computer integrated time scheduling and material planning possibilities.

3. ROADROBOT PROJECT[2]

The purpose of the European ESPRIT 6660 RoadRobot - Operator assisted Mobile Road Robot for Heavy Duty Civil Engineering Applications [J.P.Pimentão.94] - project is the definition of a flexible control architecture suitable for outdoor heavy-duty construction applications, towards an automated construction site involving mobile equipment, concerning the building industry requirements. To test the functionality of the integrated system, a road paver and an excavator working on the field are used. The RoadRobot consortium is composed by a group of seven European partners coming from different areas of expertise, ranging from research centres, to developer of heavy-duty machines, up to manufacturing companies.

RoadRobot's information models have been described in EXPRESS (STEP's language for modelling) in order to create a proposal for a new Application Protocol (AP) for the road construction industry. In this way, the results achieved with RoadRobot project can be shared by any road construction company interested in the use standards.

Recognising the low level of IT in building industry, the focus point of interest was to develop information technology for the specific requirements of this sector. Therefore, the knowledge and experience brought in by the building industry, the manufacturers of heavy-duty building machines, companies with special IT expertise, and the R&D institutes, was very important. The results of this project will be demonstrated in May 1996, under real conditions.

3.1 ARCHITECTURE OF ROADROBOT

At the beginning of the project, we lacked most knowledge on the road construction domain and, in our ingenuity, we believed that we might be able to find the tools (or at least most of them) needed for the information processing. In fact, we later found that

[2] For more details see URL:
http://www.uninova.pt/CRI/GR_SSNC/RESEARCH/roadrobot.html

besides the project development tool, no much software was used in this domain and we had to develop most of it ourselves (the most IT aware companies used spreadsheets for some of the planning and scheduling tasks). After several meetings with road construction companies, a four layer system was devised for the RoadRobot project: (1) Site, (2) Cell, (3) Machine and (4) Tool (Figure 1) [J.P.Pimentão.93]. Let us follow the information flow that occurs in the RoadRobot, in order to present the architecture.

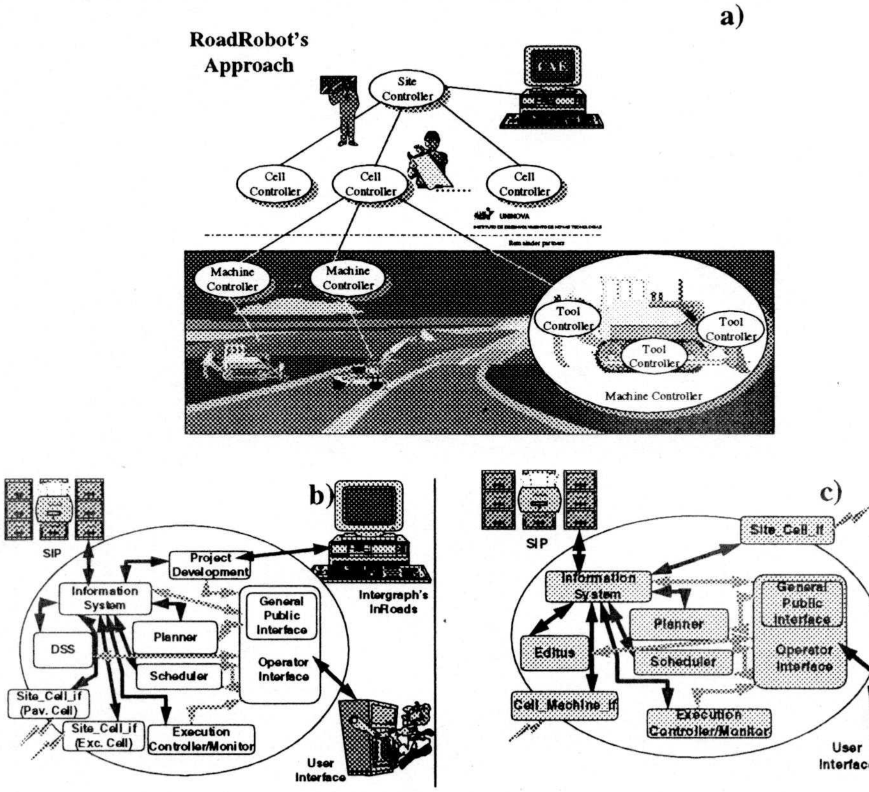

Figure 1 - RoadRobot's Architecture(a). Focus on the Site(b) and Cell(c) Controllers.

It all starts with loading into the RoadRobot Information System (IS) the information produced by a CAE system (in this case the InRoads package from Intergraph), using a tool that we called "Project Development". After that, the information is decomposed and processed in order to produce the tasks. Task decomposition is performed in a semi-automatic way with the aid of a Decision Support System (DSS). The DSS looks at the geometrical and geological information, regarding the road construction, and, based on a set of rules supplied by the experts (e.g. on a two lane road produce a task per lane), and on equipment restrictions (such as excavator arm length), produce the tasks.

Each task is then assigned to a given construction cell-type. Cell types are based on the characteristics of the set of equipment that composes it (e.g. paving cell). Task sequencing is performed with the help of a planner and task scheduling follows it with the assignment of existing equipment to each cell and effective time scheduling. At due time, the Site Operator is supplied with the information needed for setting up the given Cell, and once the Cell reports its operational status, it is fed with the task information.

Because no DSS has been produced to decompose the Cell's assigned tasks into a set of machine tasks, this means that the process still has to be done manually with the aid of a specific editor. The tasks are then processed via planning and scheduling tools, in order to produce the scheduled tasks for each machine. At the scheduled time, each machine receives its tasks, and performs them under the control and supervision of the Cell Controller.

Although we did not go in deep detail regarding the information needed, it becomes clear that RoadRobot deals with a large amount of information flowing, and being processed, through several tools.

Since our purpose was to produce a flexible architecture, the consortium has agreed that the use of standards would provide the flexibility of the solution and, we had a clear notion that relying on standards was the only way to provide an open architecture where new software tools could be added without restrictions on vendor specific data formats.

The development status of STEP [ISO1.92] by that time (1992) and the previous experience of UNINOVA on its application to the furniture industry [Jardim-Gonçalves.93], led to the adoption of this ISO standard as the data modelling tool within RoadRobot.

STEP is not only used for the modelling of the data to be transferred among applications within a given controller (Site/Cell), but also for the modelling of the information passed among controllers; i.e. tasks, commands and responses.

Our first problem was "how to model a road throughout its life cycle?" [Jardim-Gonçalves.95a]. We became aware of the work by TNO and the Dutch ministry of Public Works on the "Road Model Kernel" (RMK), although the status of the model lacked lots of features that were needed for road construction (e.g. topological an geological data for excavating). So the consortium has produced a new model, based on RMK, that supports the RoadRobot requirements, for instance paving and excavating tasks. The production of this model was driven by the needs presented by the lower levels of the architecture. Besides this model, models were also developed to represent the road construction process at the various levels of the architecture; i.e. resource models, task models, planning information and scheduling information[3].

As mentioned previously, all information flows within RoadRobot were modelled using STEP, which means that besides data, control flows were also modelled in this way. A specific model exists for messages flowing control between all applications that compose RoadRobot.

4. THE STEP-BASED INTEGRATION PLATFORM - SIP TOOLKIT

A STEP (ISO10303) based platform for integration of applications - SIP - Toolkit [Jardim-Gonçalves.94], was developed by UNINOVA in the framework of the European BRITE/EURAM CIMTOFI (CIM sysTems with improved capabilities fOr Furniture Industry) project[Jardim-Gonçalves.93].

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[3] RoadRobot's EXPRESS models are available via URL, in issue "4. - Aspects and results contributing to standardisation":
http://www.uninova.pt/CRI/GR_SSNC/RESEARCH/roadrobot.html

A) a formal language for information modelling, denominated EXPRESS [ISO11.91]; B) a neutral file format in order to physically represent the data to be exchanged among tools[ISO21.92]; C) a set of Application Protocols (AP) defining the context, scope and application domain's information requirements; are some of the components of STEP. A mapping between the EXPRESS definition of an entity, and the physical representation of its objects in the exchange file is also defined by STEP.

4.1 REQUIREMENTS OF SIP

The SIP requirements were:

- Support the integration (data exchange) of all existing and future heterogeneous activity tools.
- Offer the possibility of product data exchange between different factories;
- Provide a good approach for data modelling at all levels, preferentially using a standard;
- Be reliable and efficient;
- Enable the management with expert knowledge related to specific activities, using a standard interface;
- Allow interfacing to different standard languages (e.g. C, C++, Object Oriented Data Bases and Relational Data Bases).

The use of an integration platform based on a standard, is related to problems like the following:

- Shortening product life cycles;
- Reduction of manual operations;
- Allow integrated sector oriented solutions;
- Facilitated information management.

Considering these aspects generally reduce system maintenance and upgrade efforts. To avoid a high number of required interfaces, a unique neutral data format should be used in the integration process [ISO21.92].

4.2 ARCHITECTURE OF SIP

SIP is fundamentally constituted of an Information Management System (IMS), an Information System Access Protocol (ISAP) and a Development System Tool Set (DSTS). Figure 2 shows the architecture of SIP.

The IMS handles the information based on a model (EXPRESS schema), elaborated previously. IMS is the kernel of the integration platform. It plays the role of an information server, supplying access to the data produced and consumed by external systems.

The following elements constitute the IMS: PISAP - Persistence Driver; MID - Meta-Information Dictionary; PDB - Product Data Base and EXPRESS MIS - EXPRESS Meta-Information Schema.

ISAP is related to the communication protocol. It constitutes the interface between external tools and IMS, allowing data exchange in a distributed way.

The architecture of SIP incorporates many of the concepts of Computer Integrated Manufacturing to bring productivity, flexibility and quality improvements. In order to get these advantages, we have adopted the suitable object-oriented approach for SIP's architecture design. This adoption will allow a gradual integration of automated functions as they become available. SIP's information flow is handled by the communication protocol, using clusters of objects.

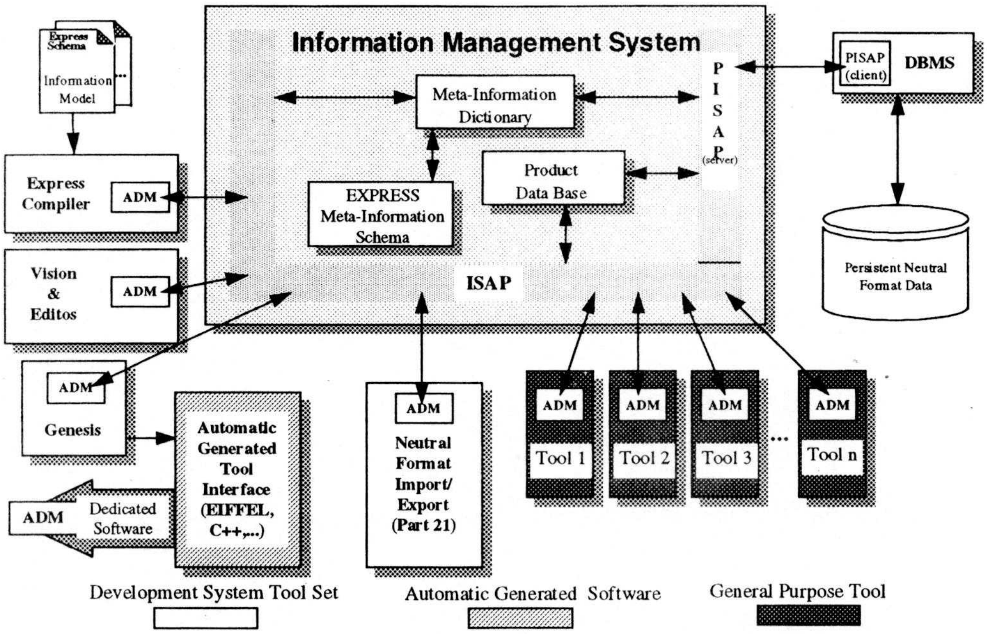

Figure 2. Architecture of SIP

4.2.1 SIP's Development System Tool Set components

The SIP's Development System Tool Set components are:

- An *EXPRESS compiler* (modelled itself in EXPRESS), has the responsibility of processing Express schemata, checking for lexical, syntactic and semantic errors, generating the equivalent meta-information representation structure, and updating the meta-information dictionary inside IMS.
- *Editus,* that allows the edition and browsing through the STEP-based Information System. With these components it is possible to observe on a graphical way the neutral format description of a specific object, or all the objects belonging to the Information System.
- *Genesis*, a tool that automatically generates interfaces for several programming languages. Every time it is necessary to integrate a new tool, a dedicated Application Dependent Module (ADM) has to be developed. The DSTS *Genesis* tool helps this task, generating code automatically. This code stands for a complete implementation of all entities described in EXPRESS schemata, generating automatically access primitives for the entities (for example those that make the data transference from/to SIP using ISAP). Front ends to C, C++ and ONTOS (Object oriented data base) are already done, and Relational Databases access languages (SQL is now in test) are being considered.

* Import/Export data tool, using neutral format (Part 21 of STEP) [ISO21.92]. With this tool it is possible to send and receive the description of any cluster of objects described in neutral format. All DSTS' components use ISAP to communicate.

4.2.2 Inside the IMS

As an implementation strategy, the information flowing inside the IMS, and between the IMS and the external systems, is modelled using EXPRESS schemata. Consequently, the data transmitted contains always instances of EXPRESS entities. This procedure becomes possible using the communication protocol itself for the transmission and manipulation of information (even meta-information).

The EXPRESS Meta-Information schema represents the meta-information model. This schema is loaded in the meta-information dictionary at initialisation time of IMS.

The concept of Private, Public and External object is supported by SIP. This feature is very important when we are working in industrial environments, because typically industrial applications need mechanisms to cope with complex model structures, where dependent structures are often stored in individual physical files. For example a solid model may have components 'shared' by other solid models stored in different physical files. To allow external references among them this concept must be applied.

4.2.3 Connection with external systems

As it was already mentioned, the platform offers local and remote capabilities of communication. In the local approach, the IS is directly linked to external systems, which means that the client and the server parts are linked together generating one unique application.

In the remote approach, the RPC (Remote Procedure Calls) service of TCP/IP (Transmission Control Protocol / Internet Protocol) is used. Client and server are remote processes that can be running in different computers.

The communication protocol consists of a library of functions that supplies the capabilities of local and remote access between the Information System and the external systems.

In order to be able to maintain flexibility, SIP runs on several platforms (IBM PC compatible, IBM RISC 6000, workstations SUN), and uses TCP/IP as the communication protocol.

4.3 STEPS TO INTEGRATE APPLICATIONS USING SIP

In order to understand the company's information system, and the life cycle of its components, the use of structured planning and analysis techniques is quite helpful. To implement an integration process it is necessary to proceed through different steps. The suggestion is:

* Find what applications will be integrated.
* Recognise what data will be transferred among applications, in order to identify application groups that use same purpose data. Each of these groups should be associated generating an integration task.

- Seek an application protocol (AP), already defined by STEP, that modulates the selected data. If the application protocol does not exist, then develop one that solves the integration problem. Never forget that in the near future new tools can be appended to the system, requiring the use of already defined schemata.
- Compile the EXPRESS [ISO11.91] schema, using the SIP's EXPRESS compiler. The objective of this procedure is to translate the model described in EXPRESS to a computable format, enabling the platform for automatic model handling. For example, to validate the semantic of a cluster of objects the system needs first to know the model. That information can be loaded using the EXPRESS compiler.
- Develop an ADM (Application Dependent Module) for each tool. This module makes the translation between the tool's internal data structure and the neutral data format, and vice versa. This task can be supported by *Genesis*, a Development System ToolSet component, which generates front ends for different languages (e.g., for C++).
- Use, in a transparent way, the Information System Access Protocol (ISAP) to perform the transference of information from the tool (using the developed ADM) to the STEP-based Information System.

5. IMPLEMENTATION OF SIP IN SMALL AND MEDIUM SIZE INDUSTRIAL COMPANIES

The SIP starter was the European project CIMTOFI, for the furniture industry. Today SIP is used in three other projects: (1) The European ESPRIT III RoadRobot project, for the road construction industry; (2) the Portuguese ATECNIC project, for the metalomechanical industry, and (3) The European ESPRIT IV FunSTEP project, for the furniture industry.

The basic aim of the BRITE/EURAM CIMTOFI (CIM sysTems with improved capabilities fOr Furniture Industry) project was to reduce the "Idea-to-Production" cycle for furniture product development, by integration of tools selected in the market. Tools and methods developed and implemented in this project shall enable the introduction of the CIM philosophy in a step by step way, not only in furniture industry, but also in other industrial sectors. The tools integrated were modelled using STEP, and the integration tasks supported by SIP.

The objective of the ATECNIC project [Jardim-Gonçalves.95] is to implement the CIM concept inside an electromechanical company, transferring to the Portuguese industry the results achieved by the CIMTOFI project.

The objective of the FunSTEP project is to improve the results achieved during the CIMTOFI project, developing an AP for the furniture industry, to be submitted to ISO.

6. CONCLUSIONS AND ACKNOWLEDGEMENTS

The utilisation of IT in construction industry should deserve more attention. The use of standards in the modelling process, can help to proceed towards automated and integrated construction sites. The SIP toolkit, developed by UNINOVA, helps to reach this goal using STEP. SIP has been used in several projects for different industries, with encouraging results. The results achieved during the RoadRobot project states these conclusions based on experiences executed under real conditions.

We would like to thank, without exception, all the partners working in the RoadRobot project's consortium. In particular we acknowledge the UNINOVA - Institute for Development of New Technologies, that has supporteda with credibility our ideas and developments, and the European Commission for the financed budget.

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