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THE ROAD PLAN MODEL - INFORMATION MODEL FOR PLANNING ROAD BUILDING ACTIVITIES

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Abstract

The general building contractor is presented with an information model as an approach for deriving a high-level work plan of construction activities applied to road building. Road construction activities are represented in a Road Plan Model (RPM), which is modelled in the ISO standard STEP/ EXPRESS and adopts various concepts from the GARM notation. The integration with the preceding road design stage and the succeeding phase of resource scheduling is discussed within the framework of a Road Construction Model. Construction knowledge is applied to the road design and the terrain model of the surrounding road infrastructure for the instantiation of the RPM. Issues regarding the implementation of a road planner application supporting the RPM are discussed.

Introduction

The work presented in this paper is being done within the ESPRIT III project 6660 - *RoadRobot - Operator Assisted Mobile Road Robot for Heavy Duty Civil Engineering Applications*. The project is partially funded by the European Commission under the ESPRIT R&D programme and involves seven partners in five european countries, ranging from research and technology organizations, a manufacturing company as end producer and a building contractor as end user.

The objectives of this project are to adapt a generic control architecture to the requirements of the building industry and to build up and integrate components needed for automated out-door construction purposes. The operation of the developed subsystems and control strategies will be demonstrated under real conditions by the integration of two autonomous prototypes of the road building application: a road paving machine and an excavator.

The research institute Uninova is responsible for the development of the central site controller, which will integrate the working cells into a CIM environment, including functions of planning, scheduling, cost calculation, production and manufacturing supervision. Large amounts of information are generated and consumed during the various phases of a project life cycle. Sharing and maintaining these project data among multiple disciplines and throughout a project life cycle is a complex and difficult task. The project data needs to be stored, retrieved, manipulated and updated by many participants, each with his own view of the information. This leads to a step-by-step integration strategy, in which the several stages are carefully rationalized, automated and subsequently inserted in the global system. For a description of the multi-agent architecture proposed for the site controller, see [8]. This architecture is based on an object-oriented concept for modelling the product information as well as the processes, and is intended to link CAD systems, relational database, knowledge-based systems and other conventional application software.

The STEP standard

One of the problems of all CIM systems concerns the representation of the information to be accessed by the different agents of the (road) construction process. This implies the definition of common models for shared concepts in order to support an effective exchange of information. As the project favours the ideas of international standardisation works, we have considered the use of the ISO 10303 standard, the so-called STEP (STandard for the Exchange of Product model data) [5], to model the information inside the CIM system.

The STEP standard includes a formal information modelling language, called EXPRESS [4] used to specify the objects belonging to a universe of discourse, the information units pertaining to those objects and the constraints on those objects. All tools inside our site controller will model the information according to this formalism and be able to access instances of EXPRESS entities. This implies the development of STEP translators from supplier-specific file formats into EXPRESS entities which are then stored in the site controller's common information system.

The physical implementation of the information structure in a database will be based on a CIM architecture similar to the one presented in the ESPRIT II project IMPPACT (Integrated Manufacturing of Products and Processes using Advanced Computer Technologies) [3] - Chapter 2.4), and which was partially implemented by our research group within the European BRITE/ EURAM project CIMTOFI [10].

The GARM notation

The General AEC Reference Model [2], developed by W. Gielingh, describes the product model through so-called Product Definition Units (PDU). GARM is part of the draft proposal of the ISO standard STEP. The current version of the GARM concentrates on the requirement and design stages of the product life cycle.

Basically, PDUs describe the objects (or parts of an object) that have to be handled. A PDU appears in different stages during its life cycle: required stage, design stage, planning stage, production stage, etc. Only the first two life cycle stages are worked out. A PDU in the 'as-required' stage is called Functional Unit (FU). A PDU in the 'as-designed' stage is called Technical Solution (TS). These two stages are used for decomposition during the design of a PDU.

GARM is based on the FU-TS decomposition. This construct expresses the fact that a top-down design process is ruled by the divide-to-conquer principle. Searching a TS for a set of requirements collected in a FU is done by breaking the TS up into lower order FUs, i.e. by dividing the problem into a number of smaller design problems.

This principle can be visualized by means of a so-called Hamburger diagram (Fig. 1). Such a diagram represents the product model as a hierarchical tree whose nodes consist of two semi-circles. The upper side symbolizes a FU and the lower side the selected TS. Decomposition levels may coincide with responsibilities, disciplines, contractor/ subcontractor/ manufacturer relationships, etc.

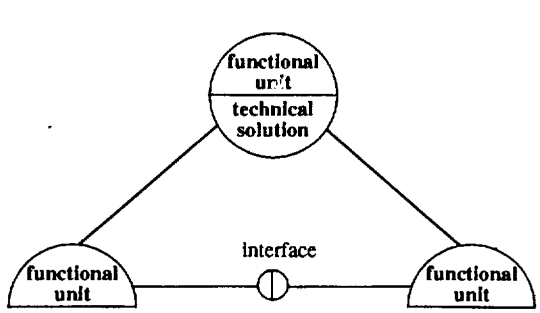

Fig. 1: Hamburger diagram: decomposition tree

Besides these vertical relations, which structure the FUs and TSs into a hierarchical tree, the various components at a FU-level may be related to each other (horizontal relations). GARM relates the FUs mutually by means of a network. These relations are called interfaces.

In the next chapter, we present a model that describes all the properties of a family of roads during the design process. Such a model is called a *product type model*. During the design process, a product model for a specific road is generated by choosing those properties from the product type model that are needed to fulfil the specific requirements of that road.

The Road Model Kernel

During the analysis of the state-of-the-art in integration of new technologies into building industry, it was evident that most established developments concentrate on computer-aided drafting. Here, several CAD packages from different software suppliers have been identified. Nevertheless, it also became obvious that one big problem associated to the rapid increase of specific CAD-software programs is the ability to exchange information between each other, not to mention with programs with other purposes during the life cycle of a product.

The Dutch Ministry of Transport, Public Works and Water Management, in conjunction with TNO Building and Construction Research, has seen the need to lay a new foundation of a new standard for road development. This has led to the development of the so-called "Road Model Kernel" [11], a product description of the road in the design stage based on the ISO/STEP standard. A STEP translator was developed which allows the exchange of the MOSS file format with the RMK without loss of information.

The RMK was developed using GARM's methods, and therefore describes the road in terms of FUs and TSs. However, the PDUs of the RMK are not real-world objects (or parts of objects) which can be obtained independently through construction processes and jointly form the 'as-built' road. Instead, they have been defined to reflect the viewpoint of the road designer as he conquers the complex problem of designing a road.

In several internal models used by road modelling packages, one often encounters two layers of decomposition: firstly a longitudinal decomposition and secondly a transversal decomposition. This longitudinal decomposition is often split into a longitudinal decomposition to describe the horizontal alignment and a longitudinal decomposition to describe the vertical alignment.

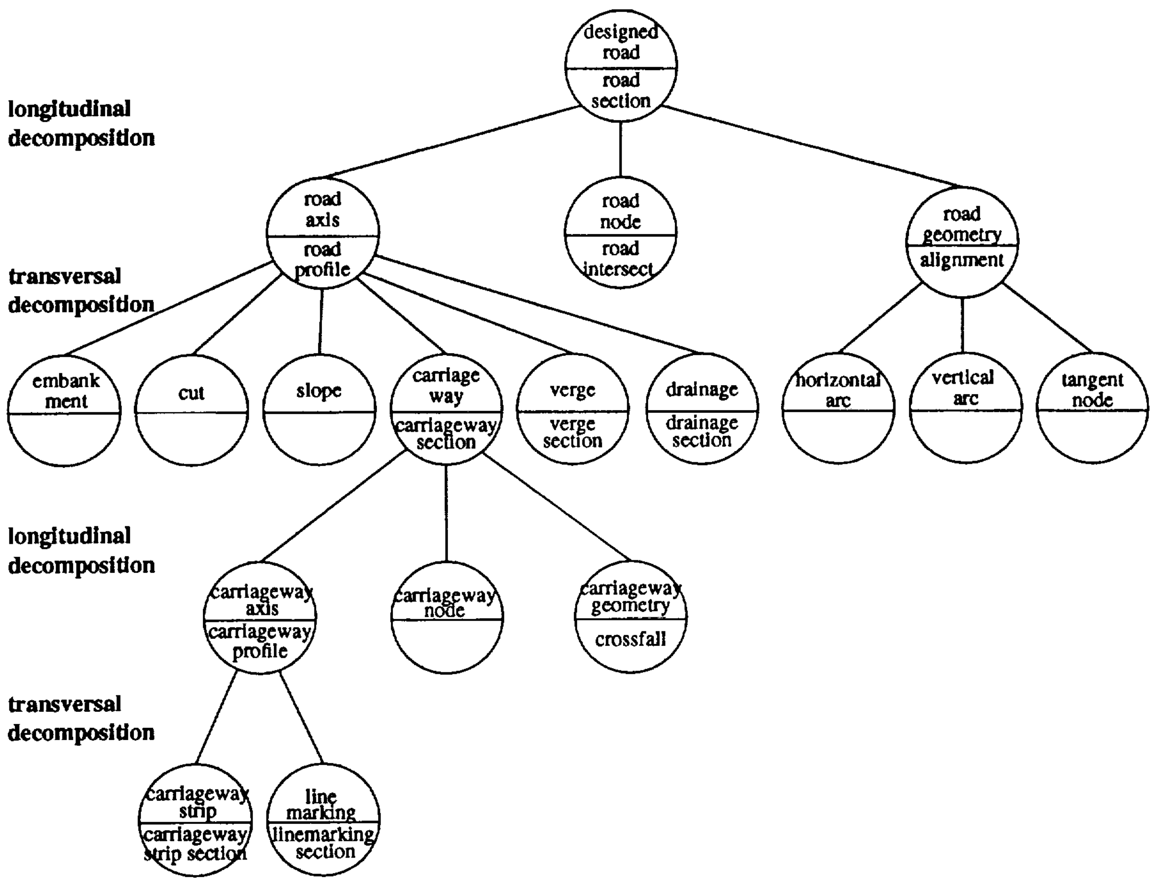

Fig. 2: The Road Model Kernel

The principle to decompose alternately and on hierarchically different levels into longitudinal and transversal seems to fit properly with the experience of the road designer, and was adopted by the RMK.

Road-axes and road-nodes constitute the framework to describe the structure of the roads and their connectivity: the **topology**. However, this description does not incorporate sufficient information to extract the accurate shape of the road. This is done by adding the **geometry** to the road-axis as a separate entity.

The FU road-geometry shapes one or more road-axes which will assemble a continuous chain. The road-geometry will make demands on the progression of curvature, horizontal as well as vertical. Alignment is the TS which can be selected for the FU road-geometry. Alignment decomposes into two interconnected networks (chains) which describe separately the horizontal and vertical alignment.

For the geometrical representation of the road, a specific type of coordinate system must be chosen for the RMK. Because of its simplicity and flexibility, the RMK uses a floating around the z-axis rotating s-t-z coordinate system, which is related to the horizontal alignment curve.

The s-axis maps one-to-one on this curve (longitudinal direction) and is embedded in the x-y plane. The t-axis is orthogonal (perpendicular) to the s-axis (transversal direction) and is also embedded in the x-y plane. The z-axis is equivalent to the z-axis of the fixed x-y-z coordinate system.

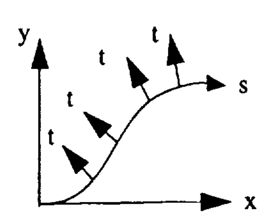

Fig. 3: Coordinate system s-t-z vs x-y-z

The horizontal and vertical alignment description in the RMK defines the curvature functions along the longitudinal (s-axis) direction of the road.

The alignment incorporates a chain of arcs interconnected by tangent nodes. Arcs may specify no curvature (straight), one (circular curve) or two curvatures to denote start and end magnitude (linear transition).

The horizontal and vertical alignments are defined at a high level, dragging all lower level entities to follow automatically this primary shape. However, the influence of a crossfall is dedicated to a specific transversal function. Therefore, a geometry entity should be imposed only to that specific transversal function (carriageway geometry, slope geometry, ...). The TS crossfall decomposes subsequently into a collection of tangent nodes containing the magnitude of a specific gradient.

The Road Construction Model

As presented by J. Everett in his paper [1], construction and manufacturing exhibit fundamental differences in where the interface or transition occurs between product design and process design or fabrication. In repetitive manufacturing operations, the product-process design team controls product and processes all the way down. However, in construction, there is little overlap between product design and process design or fabrication. Architect/ engineers control product design but do not get involved in the building process other than to inspect the finished work for conformance to design specifications. Constructors control the fabrication process design but generally have little or no input into product design. A distinct separation exists between the product designers and or architect/ engineers, and the process designers or craft workers. In construction, the product designers and process designers are almost always separate organizations with different objectives.

This is specially true for heavy-duty civil engineering applications, like road construction, where the gap between the lower limit of design detail and the upper limit of machine technology is substantial, as very few practical examples of construction robotics or highly automated machines have been developed.

As seen above, the Road Model Kernel represents the road design without any detail about the processes used to build the road. Until the product design and process design can be integrated by closing the gap between design and machine technology, we propose to use a step-by-step integration strategy which reflects the current way of work.

During contacts with the entity responsible for the construction of highways in Portugal, Brisa, the following agents were identified and a description of their roles in the construction process is given below:

- Based on the user's needs, the **construction owner** Brisa defines the requirements of the road to be built and delivers these to the design team.
- As the national **authority** for the design of highways, Brisa distributes the *design regulations* to the design team, which include for instance minimum values for the radius of curves depending on the requested speed, ways of calculating the earth volumes, norms about the composition and thickness of the paving layers depending on the soil resistance, etc.
- The **design team** returns to the construction owner a set of documents (descriptive memory) as result of several design activities, such as (a) geometric drawings, (b) earthworks based on geological/ geotechnical studies, and (c) paving layer composition of the road sections.
- As the national **authority** for the construction of highways, Brisa distributes *general technical norms* to the general contractor about the construction of highways, for instance about the material to use in earth-filling, classification of the soil based on specific attributes and their application, the notion that the vertical alignment as defined in the design drawings refers to the surface course of the road or to the compacted base platform as well as transversally to the line limiting the carriageway and the left verge, the proceedings for the quality control of the earthworks and the paving, etc.
- The **general contractor** hired receives the design documents from the construction owner as well as a contract specification book. The contract document specifies additional *construction requirements* to the general technical norms. Based on these, the general contractor plans how the road is to be built in order to maintain the requested deadlines and costs, requisitions the resources and carries out the site production, eventually by hiring sub-contractors.
- **Sub-contractors** perform tasks and produce the products or components for the construction, for instance a sub-contractor is hired to build the bridge, another is hired to do all earthworks, etc.
- **Machinery lending firms** provide equipment to the site.
- **Suppliers/ distributors** supply and distribute material for the site facility, such as the asphalt plant supplies the asphalt mixture for the road paver, and gas

stations supply petrol for the machinery, etc.

As the RoadRobot project embarks all phases of road building from design to production, the RMK will be used as the 'as-designed' model of the road. For later processes like planning and production, and for the modelling of resources and activities, new modelling constructs have to be found and added to the previously presented GARM model. The Road Construction Model will be based on B. Luiten and F. Tolman's "Building Product Model (BPM)" [6], and will be used in our work for the integration of design and construction knowledge and information.

For the Road Construction Model, the following stages have been identified (see Fig. 4):

- the design stage, where the product road is described by the road designer in terms of its geometric requirements -> Road Model Kernel,
- the planning stage, where the activities are identified by the general contractor as constant road sections to which they apply -> Road Plan Model,
- the scheduling stage, where to each activity identified at the previous stage the resources to realize them are assigned by the general contractor, in order to optimize time and costs -> Road Schedule Model,
- the construction stage, where the tasks are effectively issued to the working cells and their execution monitored, resulting in a built road which will be inspected relatively to its requirements.

In a building project, three main groups of entities can be modelled: the Product, the Activities and the Resources. The information about these entities can be

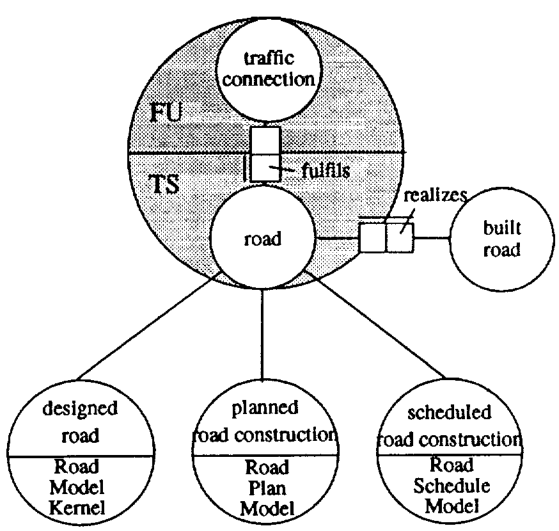

Fig. 4: The Road Construction Mode

modelled in respectively a Product Definition Unit (PDU), an Activity Definition Unit (ADU) and a Resource Definition Unit (RDU). GARM has worked out concepts for PDU which are also suitable for ADU and RDU. To reuse modelling constructs and to avoid redundancy, common properties for PDU, ADU and RDU are modelled in a new entity called Construction Definition Unit (CDU).

The relations between Product (PDU), Activities (ADU) and Resources (RDU) can be graphically modelled in NIAM (Fig. 5).

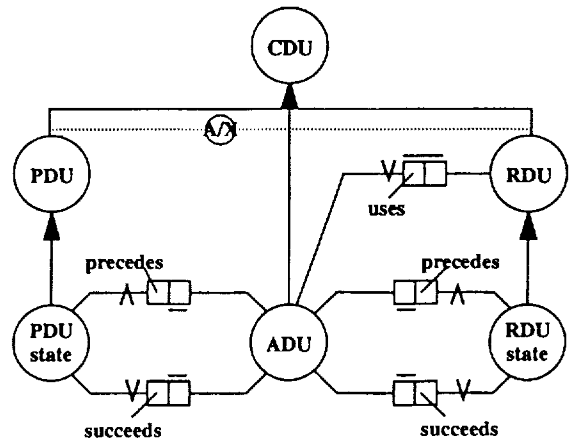

Fig. 5: NIAM diagram of the Building Product

Examples of PDUs are: the product itself, parts of the product or features. For ADUs one can think of all the processes during the project: management, design, planning, and production processes. RDUs are resources used by ADUs, like manpower, equipment and raw materials.

For a PDU the main characteristics are 'shape' and 'material'. Other characteristics can be derived from the main characteristics. For an ADU the main characteristics are 'time constraints', e.g. 'must be performed before or after', 'can be performed independently of'. For a RDU all characteristics have something to do with 'money', e.g. 'application costs', 'acquisition costs', 'remainder value'. When the ADUs are related to RDUs, absolute time can be derived, e.g. 'starting time, 'ending time' and 'duration'.

Examples of states are 'as designed', 'as planned' and 'as built'. In general, an ADU is preceded by a PDU state and succeeded by a new PDU state. An ADU always uses one or more RDUs. It is possible that this ADU also changes the state of the RDU.

As an example of the use of the Road Construction

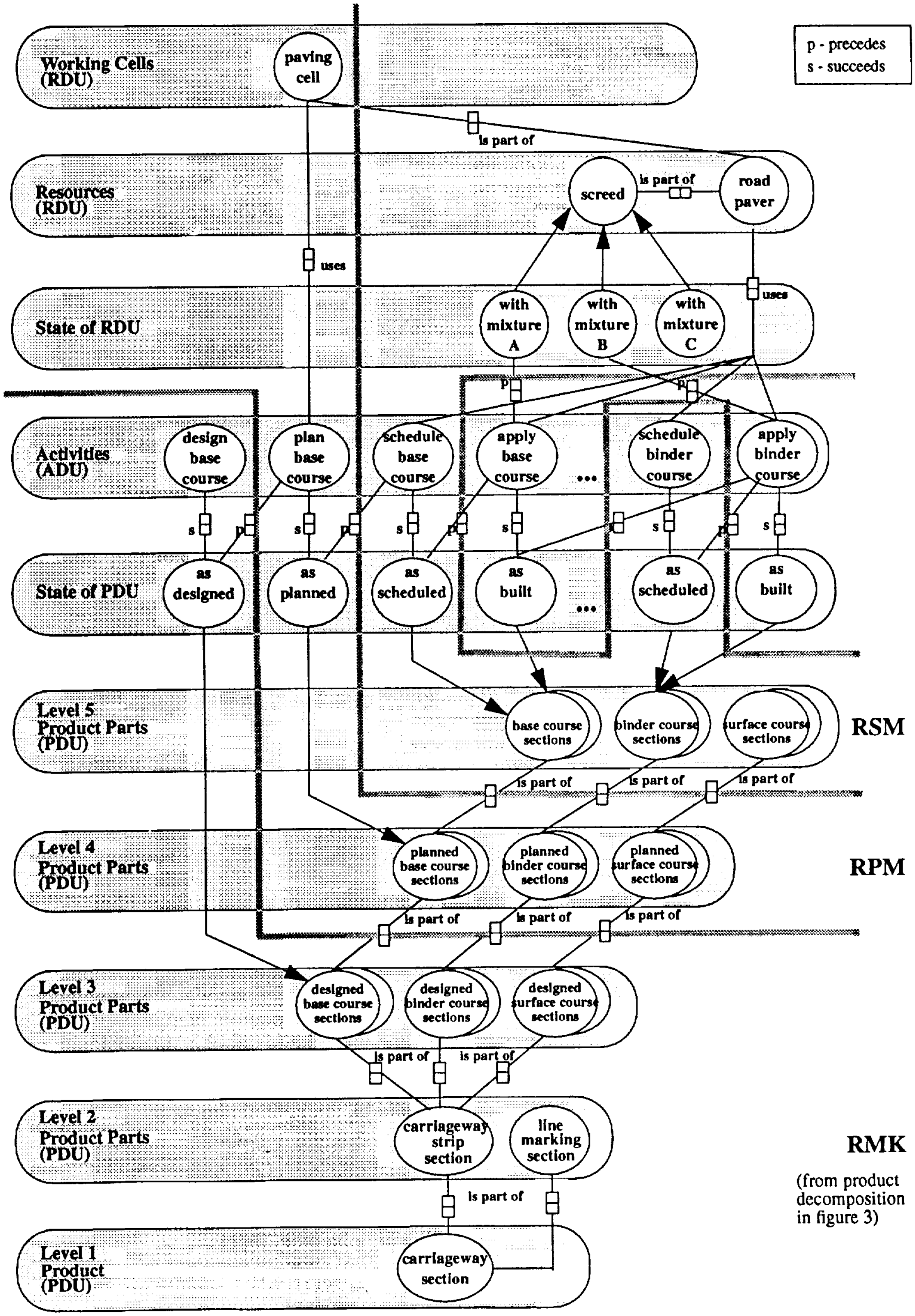

Fig. 6: NIAM diagram of the paving activity of a carriageway section

Model, the paving activity of a three course carriageway section is partially worked out. The pavement consists of three asphalt courses which are sequentially applied over the preceding course.

In Fig. 6, this activity is modelled in a NIAM diagram using the concepts of the Road Construction Model. At the three bottom levels of the diagram, the PDU decomposition is the one followed by the road designer as identified in the Road Model Kernel of Fig. 2. The fourth level models the PDUs identified by the general contractor when planning the paving process of the designed carriageway, as will be shown in the Road Plan Model at Fig. 7, taking into account only the restrictions imposed by the surrounding road infrastructure. The fifth level models the PDU decomposition followed for scheduling the planned paving process (Road Schedule Model), considering the time constraints and the resources available at the building site. Each of the Activities 'design', 'plan', 'schedule' and 'apply' models the transition of one Model to the succeeding Model of the Road Construction Model, changing the state of the PDU from 'as required' to 'as designed', to 'as planned', to 'as scheduled' and finally to 'as built', respectively.

The Road Plan Model

In the present work, a "Road Plan Model" will be proposed, which describes the road in the 'as-planned' stage. In the same way as the RMK, the RPM represents the viewpoint of the general contractor when he takes the complete contract document delivered by the construction owner and creates the high-level work plan of construction activities.

The purpose at the planning stage is to identify the road sections which require different types of construction activities, and their dependencies. Each of these activities can be visualized as being executed by a working cell composed of a set of resources which work jointly to realize that activity. These working cells are logical entities which will be instantiated during the scheduling stage with the necessary quantity of resources (machines and humans) in order to maintain deadlines and budgets.

During contacts with several building contractors, the following high-level construction activities were identified, which are presented graphically in the GARM tree of Fig. 7. This tree forms the basis of the so-called "Road Plan Model".

A problem which was encountered in this stage of development, was the selection of proper names for all entities and objects essential to construct the data model. To provide some pattern to it, the next schema was used: The FU of the RPM identifies the *activity* to execute over a specific road section. The TS specifies the *working cell* which satisfies that requirement.

For example, suppose a specific road section passes over a valley or a river. The FU describes this road section with *bridge construction activity,* indicating that the TS to obtain such a road section is the construction of a bridge by a *bridge construction cell.*

Another example relates to the land *clearing activity,* which is satisfied by the *clearing cell.* The selection of the equipment composing this particular working cell depends on the diameter of the vegetation and on the size of the area. However, these questions are answered only at the scheduling stage, as the selection of equipment is also affected by whether there are alternate uses for equipment as well as by time limits.

During the development of this model, a decision had to be taken concerning the depth of the RPM decomposition tree, i.e. the granularity of the working cells. As our purpose is to model the way of thinking of the general contractor while building the high-level work plan, the result is the one shown in Fig. 7. However, the adopted GARM concept, which separates FUs and TSs, allows for more details to be added at the end (leaves) of the model. Specifically, this is done when planning and scheduling the resources inside a working cell.

The granularity of the lower-order activities in the RPM (level of the leaves) defines the functionality of the working cells which can realize them and which will be allocated in the scheduling stage. In turn, each of the working cells must be able to plan and monitor the execution of each of its resources (machines and humans). The higher the functionality of the working cells is, the more complex is the management of their resources. Here, the same approach to the just described CIM system can be applied.

The vertical decomposition identifies road sections where the named activity is applicable and their decomposition into sub-sections for lower-order activities. The identification of each road section depends on the activity to perform over it, which in turn depends on the connection of the road design to the surrounding road infrastructure. Usually, the general contractor defines a road section by indicating the initial and final station, i.e. the s-ordinate in the s-t-z coordinate system of the road design.

The horizontal network structure describes the sequences and dependencies of the construction of each of the road sections, and therefore of the activities which

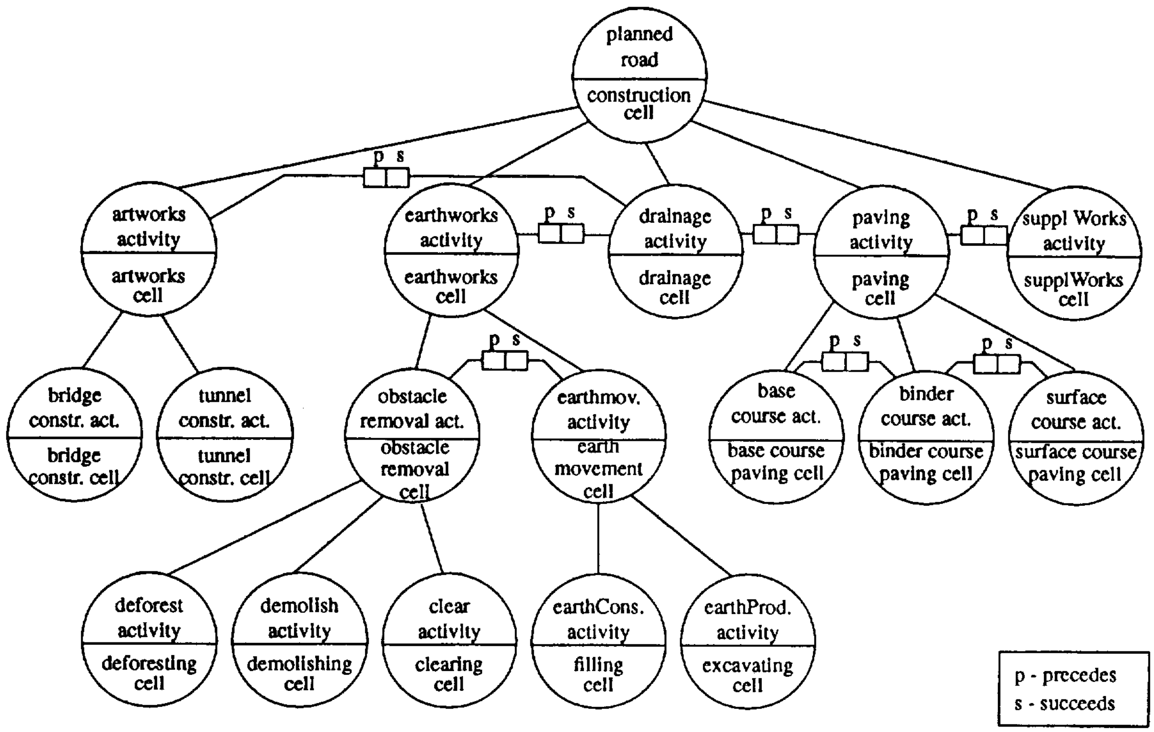

Fig. 7: The Road Plan Model

realize them (*precedes*, *succeeds*).

Over the same road section, the activities have a well-defined precedence. For instance, earthmoving is performed before drainage, and drainage is done before paving, the surface course is put on top of the binder course, the art works (bridges, tunnels) are done in parallel with the earthworks prior to paving.

Between different road sections, it is also possible to define precedency. For instance, paving a road section is an activity which is further decomposed into lower-order activities: apply base course, then binder course and finally surface course. However, the successive application of each of the courses does not have to be made over the total length of the road section. That is, the road section to be paved may be decomposed into sub-sections, which allow a different, even simultaneous application of the layers; for instance apply the base course over the initial sub-section, then apply the binder course over that same sub-section, while applying the base course over the second sub-section, etc.

This flexibility facilitates the scheduling of the activities, allowing for the optimization of the temporal allocation of the working cells to each of the planned activities. For example, if two paving cells are available at the building site, their simultaneous use makes it possible to optimize the execution time of the global activity of paving a road section. Once activities are attached to product parts and resources to activities, production time and costs can be predicted.

Implementation issues

Within the RoadRobot project, this work will result in the implementation of a "Computer-Aided Planner". Taking the instantiated RMK, the construction specifications and some terrain model, this expert system will aid the general contractor in creating an instance of the RPM by specifying the road sections and the construction activities which have to be realized over them.

The proposed situation for the planning process is

Extract of the EXPRESS description of the Road Plan Model

```
SCHEMA RoadPlanModel;

...

ENTITY RoadPlan;
    plannedRoadActivity: ConstructionCell;
END_ENTITY;

ENTITY ConstructionCell;
    artWorkActivity:    LIST [1:?] of ArtWorkActivity;
    earthWorkActivity: LIST [1:?] of EarthWorkActivity;
    drainageActivit:y  LIST [1:?] of DrainageActivity;
    pavingActivity:    LIST [1:?] of PavingActivity;
    supplWorkActivity: LIST [1:?] of SupplWorkActivity;
END_ENTITY;

...

---------------------- Paving -------------------------

ENTITY PavingActivity;
    requiredCell:       PavingCell;
    precedes:           SupplWorkActivity;
    section:            Section;
END_ENTITY;

ENTITY PavingCell;
    baseActivity:       LIST [1:?] of BaseCourseActivity;
    binderActivity:     LIST [1:?] of BinderCourseActivity;
    surfaceActivity:    LIST [1:?] of SurfaceCourseActivity;
END_ENTITY;

ENTITY BaseCourseActivity;
    requiredCell:       BaseCoursePavingCell;
    precedes:           BinderCourseActivity;
    section:            Section;
    qt:                 Ton;
END_ENTITY;

...

END_SCHEMA;
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described by the IDEF0 diagram [9] on Fig. 8.

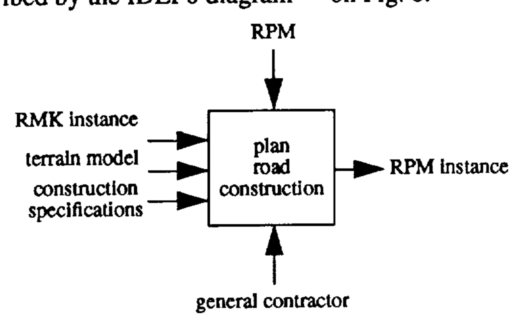

Fig. 8: IDEF0 representation of the planning stage

Construction specifications

The translation of design information into process planning information is a translation process in which construction knowledge is applied to the design information. This knowledge can be classified into three categories according to the scope of the statements:

- *general building knowledge*
  knowledge applicable to every building product and project.
- *product type specific building knowledge*
  knowledge applicable to specific product types, e.g. roads.

- *product specific building knowledge*
  knowledge applicable to specific products of a certain supplier, e.g. highways.

- *project specific building knowledge*
  knowledge applicable to a specific building project..

The first category of knowledge refers to general construction knowledge. An example is the selection of the activity depending of the type of vegetation of the terrain at the building site. If there are trees, then there has to be an activity which cuts them off; if there is a building, then it must be demolished, be it for the construction of a road or of a building.

The following two categories of knowledge are usually available in regulations. For example, the width of the paving courses is determined by the type of soil under the road and the traffic which should be supported by the road. The first variable is given by the terrain model, the second one is specified in the requirements of the road design.

The last category of knowledge is specific to a particular construction project. The construction owner may specify that, during the earthworks, the soil of the platform is to be made constant, even when this means getting soil of the required resistance from a distant earth deposit, as it is impractical to vary the thickness of the asphalt courses during the paving process. Another example is the specification of the quality control points.

Terrain model

One problem of the RPM is the integration of the road design with the surrounding terrain model. Two viewpoints over the terrain are relevant: the geotechnical and the topographical.

The geotechnical model describes the road corridor in terms of the geological characteristics of the underground soil: sand, rock, underground water rivers, etc. This model is important for the planning of construction activities and at the scheduling stage for the selection of resources to apply during a specific construction activity: use a motorscraper for earthmoving sand, but an excavator for earthmoving clay.

The topographical model describes the surface of the road corridor, including the identification and location of natural and human-made obstacles: vegetation, rivers, buildings, etc. This model allows the general contractor to plan the way to deal with each of the obstacles, namely which construction activity to use: demolish a building, cut off trees, build a bridge over a river, etc.

Obviously, the functional modelling of the terrain in ISO/STEP is by itself an own project. Therefore, within the RoadRobot project, for the implementation of the site controller, an industry standard format will be selected for the digital terrain model (DTM), for instance the format TIN, which defines the surfaces by means of triangulated 3D facets.

Conclusion

This work suggests a Road Construction Model using concepts of GARM. For the decomposition of a PDU during its life-cycle, we chose to follow the construction process as much as possible, which resulted in the creation of several models, because such a decomposition supports all the aspect views without being far away from the mental world of the users in practice.

The first model dedicated to the design process, the Road Model Kernel, was developed by the TNO- Building and Construction Research institute and has already a working computer version.

The present paper presents a conceptual model for the planning process of the road construction as practised by the general contractor, the Road Plan Model.

Further work

To allow for the integration of design and construction with the developed Road Construction Model, models for activities and resources have to be worked out, similar to the product model, as well as the relations between these three entities. This includes detailing and implementing the Road Plan Model and the Road Schedule Model as was done with the Road Model Kernel.

References

[1] John G. Everett. Design-Fabrication Interface: Construction vs. Manufacturing. In R.L. Tucker G.H. Watson and J.K. Walters, editors, *Automation and Robotics in Construction X*, number ISBN 0 444 81523 6 in Proceedings of the 10th ISARC, pages 391–397, Houston, Texas, U.S.A, May 1993. Elsevier Science Publishers.

[2] W. Gielingh. General AEC Reference Model (GARM). In *Proceedings CIB W74+78*, Lund, Sweden, October 1988.

[3] W.F. Gielingh and A.K.Suhm, editors. *IMPPACT Reference Model*. Number ISBN 3-540-56150-1 and 0-387-56150-1 in Research Reports ESPRIT, Project 2165 IMPPACT Vol.1. Springer-Verlag, 1993. An Approach to Integrated Product and Process Modelling for Discrete Parts Manufacturing.

[4] International Standards Organization. *Part 11: Descriptive Methods: EXPRESS Language Reference Manual*, ISO DIS 10303-11 edition.

[5] International Standards Organization. *STEP - Standard for the Exchange of Product Model Data*, ISO DIS 10303 edition.

[6] Bart Luiten and F.P. Tolman. Design for Construction (DFC) in the Building and Construction Industries. In Harry Wagter, editor, *Proceedings CIB W74+78*, number ISBN 0 444 89262 1 in Computer Integrated Construction, pages 137–144, Tokyo, Japan, September 1992. Elsevier Science Publishers.

[7] G.M. Nijssen and T.A. Halpin. *Conceptual Schema and Relational Database Design*. Prentice-Hall, Sydney, 1989.

[8] J.P. Pimentão et al. Architecture of the Site Controller for Road Building Applications. In P.A. MacConaill C. Kooij and J. Bastos, editors, *Realising CIM's Industrial Potential*, pages 358–367. IOS Press, Amsterdam, May 1993.

[9] Douglas T. Ross. Structured Analysis (SA): A Language for Communicating Ideas. In *IEEE Transactions on Software Engineering*, volume Vol.3, No.1, pages 16–33. IEEE, January 1977.

[10] M. Tavares et al. Tool Integration in CIM Environment - Looking for Standardisation. European BRITE/EURAM Project B-E 3653 - CIMTOFI.

[11] P. Willems. The Road Model Kernel. Technical Report TNO B-89-831(E), TNO - Building and Construction Research, January 1990.