THE ROLE OF STANDARDISED PRODUCT MODELS IN CONSTRUCTION ROBOTICS

R. P. Krom and F. P. Tolman
Delft University of Technology, TNO-Building Institute, PO Box 49 2600 AA Delft
The Netherlands. August 1990

Abstract

It is generally agreed that the construction industry needs to be industrialised. In the process of industrialisation many effort is put into the development of robot like devices. This paper describes why and how standardised product models can be of value in the development of construction robotics. Extensions to the state of the art product models towards production models are needed in order to provide construction robots with the necessary information. A conceptual data model is presented in which process planning definition data is integrated with product definition data.

1 Introduction

Many different research groups at universities, research organisations and (mainly Japanese) construction companies are working on the development of construction robots. Most of the efforts go into the development of mechanical designs of new robot-like tools suitable for applications in the building and construction industries. This might be called the bottom up approach. Our research does not deal with the development of such robots but with the control of construction robots and the integration of the robot control system with all other (existing) Computer Aided (CA) applications used in the construction industry. A more detailed description of our construction robotics research is given in [1].

Maybe instead of building very special purpose machines, we should build more general purpose robots and concentrate on the control of such construction robots. Therefore we would like to build libraries of building components which include neutral, robot processable "instruction manuals" which "instruct" a construction robot about the way to perform a specific job.

Our intention is to use the STEP[1] [2] standardized product models to "tell" a construction robot with what objects it is supposed to deal. But we also need to "instruct" a construction robot what to do with those objects. Therefore we are working on the integration of *construction knowledge* into the General AEC Reference Model (GARM) [3] which is part of the proposed STEP standard.

It is suggested that the paper "Product modelling at Work" [4] is read before this paper, because subjects referred in this paper are explained in that paper .

In the following sections a conceptual model of an integrated product and process model subsequently called a *production model* will be presented.

2 What do we mean with construction knowledge?

The ideal construction robot would be at least about as flexible and autonomous as a labourer. Unfortunately the state of the art technology is not advanced enough to realise this on a large scale. However we would like construction robots to have a certain level of intelligent behaviour in order to have some autonomy. Therefore we need to transfer construction knowledge into construction robots.

In this paper we look at the term *construction knowledge* from the construction robot's point of view. From this point of view we can define *construction knowledge* as information needed to install, assemble or create an object. This construction knowledge includes the answers to questions such as:

---

[1]Standard for the Exchange of Product model data

- what must be done?
- where should it be done?
- with what objects should it be done?
- in which order should it be done?
- using which tools?
- using which materials?

These questions can be devided into two groups:

- product related construction knowledge
- construction robot related construction knowledge

The last two of the above listed six questions are robot dependant. In this paper we will only look at the product related construction knowledge. Our aim is to describe the product related construction knowledge in such a way that robots of different vendors can perform the tasks.

Product models can provide a construction robot with the information about the objects to handle. However the activities to be performed and the sequential relations between these activities,is not included in current product models.

3 A conceptual model for process planning

We have chosen to model the process plan as a *network plan*. Network planning is a universal planning method which allows the determination of, for instance, the *critical path*. In network planning, activities are related to each other in a network structure, where sequences and dependencies of activities are described. Large activities can be decomposed into a number of smaller activities which in their turn form small networks on their own. The structure of a network plan, represented as a NIAM model, is shown in figure 1.

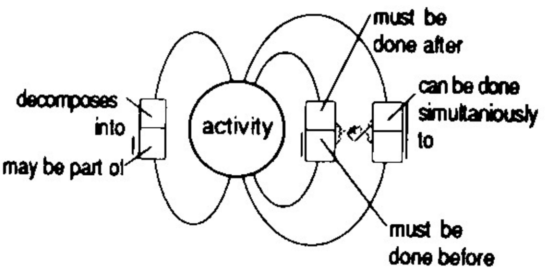

figure 1: NIAM diagram of network plan

The model shows three relations between activities:

- activities can decompose into a number of smaller activities, or an activity may be a part of a larger activity
- some activities must be performed before, or after other activities
- some activities can be performed simultaneously with other activities

So far nothing new. However we would very much like to integrate this network plan model with a GARM product model containing a product design. In [4] is described how a product design in the GARM is modelled in a PDU decomposition (called FU-TS decomposition). The decomposition of activities can be modelled similar to the PDU decomposition (see figure 2).

This figure shows new entities *required activity*, *planned activity* and *realised activity*, subtypes of a generic entity called ADU (Activity Definition Unit) analogue to the PDU (Product Definition Unit).

A Planned Activity (a process plan) can fulfil a Required Activity, or alternatively a Planned Activity can decompose into lower order Required Activities, for which lower order Planned Activities can be sought. Finally it shows that a Planned Activity can actually be performed and then results in a Realized Activity.

A second analogue between the decomposition of PDU's and ADU's is that relations between lower order Required ADU's and Required PDU's can be modelled in networks. The Required PDU-network is mainly an adjacency network [4]. The Required ADU-network is the precedence network as given in figure 1.

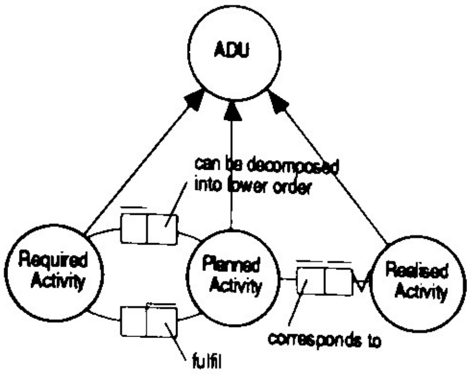

figure 2: ADU decomposition analogue to the GARM PDU decomposition

4 Production oriented product definition

A product design is specified in the PDU decomposition tree. In the process plan we would like to plan all activities related to the realisation of the technical solutions in the PDU decomposition.

Therefore we decided to categorise all PDU's into categories which need similar kinds of activities for their realisation. We decided to follow the terminology introduced by Turner [5], who distinguishes between:

- system
- sub system
- component

Besides those terms we introduce the term

- feature

Systems are composed of sub systems, sub systems are assembled of other sub systems or components. Components are prepared by realising all features of the components. Features can be created by activities (or operations). The term feature is used in manufacturing industries for all geometric shape properties (of components) which can be realised by shape transformation activities such as for instance milling, drilling, bending etc.

The NIAM model of this categorisation is shown in figure 3.

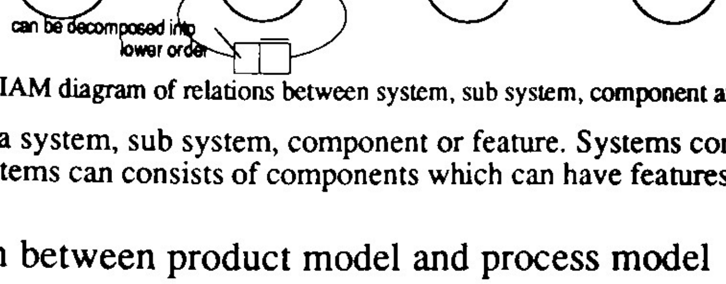

figure 3: NIAM diagram of relations between system, sub system, component and feature

Every PDU is either a system, sub system, component or feature. Systems consist of one or more sub systems, sub systems can consists of components which can have features.

5 The relation between product model and process model

So far we have presented a data structure for a (network) process plan of activities and an activity related PDU specialisation. The next step is to model the relation between PDU's and ADU's. The global relation between ADU and PDU is very simple as is shown in figure 4. With every PDU there exists an ADU which realises the PDU.

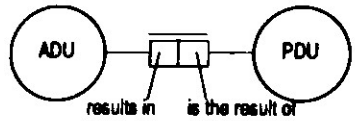

figure 4: Relation between ADU's and PDU's

This simple model give the connection of ADU's and PDU's and is therefore the basic structure of our production model.

As the next step we substitute the PDU decomposition and the ADU decomposition of figure 2 in he model of figure 4. The result of this substitution is shown in figure 5.

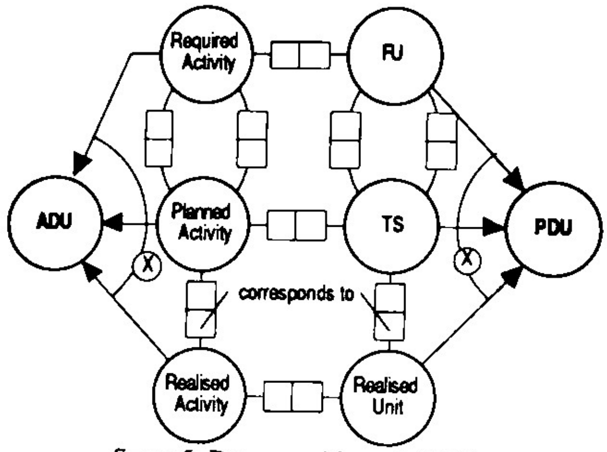

figure 5: Decomposition of ADU's

The model in figure 5 shows the ADU and PDU decomposition together with the relations between the two hierarchies. Ultimately each Realized Unit will have been realized by a Realized Activity. A door handle which has been installed in a door system has been realized by the activity "Install handle". Installing the handle is a sub activity required for the activity "Install lock". Installing a lock might require a number of lower order activities such as: "Make slot for mechanism", "Make hole", "Install mechanism", and "Install handle".

We have now modelled the ADU and PDU relation for decomposed ADU's and decomposed PDU's. We would now want to integrate the system, sub system component feature specialisation into the ADU-PDU relation.

Planning is the activity where is determined how a TS is realised in a Realised Unit. What kind of activity is required depends on whether the TS is a sub system, component or feature. Substituting the categories given in figure 4, leads to the model shown in figure 6.

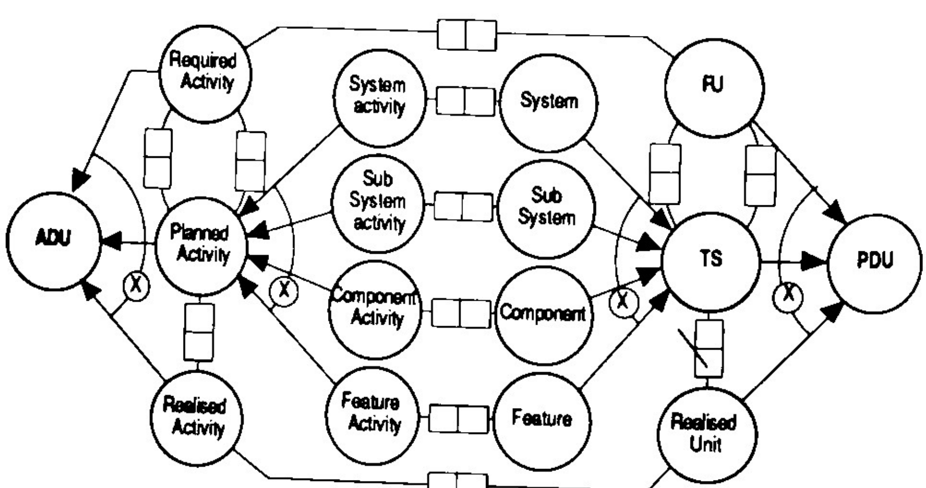

figure 6: Conceptual schema of the kernel of the production model

The conceptual schema of the production model of figure 6 gives the proposed relations between PDU's (with known shape and material properties) and ADU's, without specifying how the ADU's should be performed; e.g. which tools to use etc. Every robot activity operates on one or more objects that fall into the PDU classification of figure 3. Each PDU category has a group of related activities attached. Feature activities relate to simple manufacturing operations on components. Component activities relate to assembly operations etc.

In the next section we will discuss some possible applications of production models for construction robotics.

6 Applications of the production model

The first application of the production model of figure 6 is as a standard or reference model for data exchange. Because STEP already tries to formulate a standard for the exchange of product data (PDU's) it seems a good idea to extend the STEP interface with activity data. The model of figure 6 could serve as the conceptual schema for such an extension.

If information exchange between CAD/CAM systems and robots is based on this conceptual model and added to the existing STEP standard, robot vendor independent information exchange can be provided.

The second application of production models is as a reference model for the development of specialised production models. A specialised production model is a specialisation of the model into some specific "world" such as for instance the electrical systems world or the interior finishing world.

Buildings are mutli systems products. Each type of system may require systems activities for it's creation. So for each system a specialised production model can be formalised, including specific features and feature activities, components and component activities etc. Such models would use the jargon of each "world" and would fit the terms used in that specific world.

The third application of production models is the application of production type models. A production type model is an extension of a product type model, of which an example is described in [6]. A product type model is a model which contains general knowledge of a group of products, for instance general knowledge of viaducts is modelled in a product type model for viaduct. When we extend product type models with activity data, we call it production type models.

So, as an example, general knowledge about door locks and installing a door locks in a door could be modelled in a production type model of door locks. An instance of the model would then only require some cardinalities and parameter values to be exchanged.

7 An example of a production model

In this section we describe an example production model. We have chosen a door lock sub system. An example of an instance of such a door lock sub system is shown in figure 7.

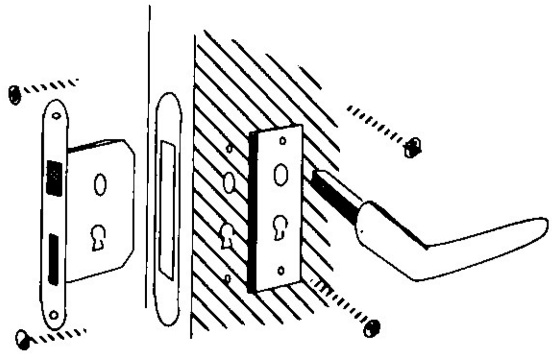

figure 7: door lock

In figure 8 the FU-TS decomposition of the door lock is shown. The FU-TS decomposition does not cover the complete door lock system because otherwise this example would become too complex. We only look at the lock mechanism, the door handle and the slot and hole which must be made in order to be able to install the mechanism and the door handle.

In figure 8 the TS "door lock # 3241" is decomposed into the lower order functional units: door handle, lock mechanism, mechanism slot and door handle hole. Each of these lower order FU's is fulfilled by a TS.

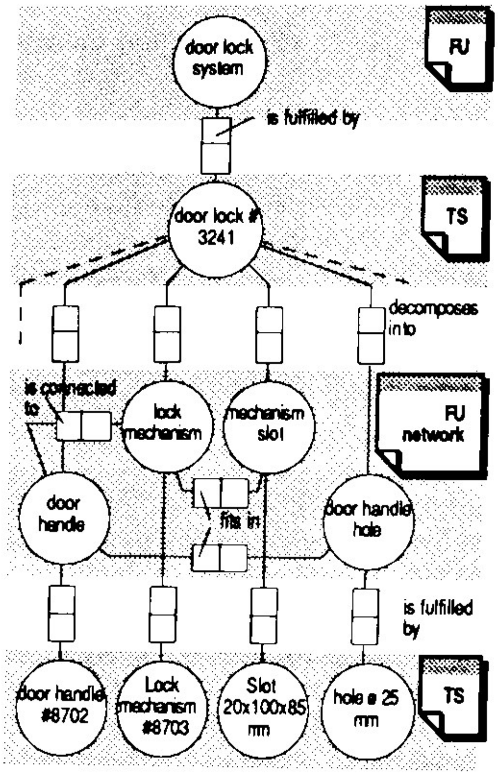

figure 8: PDU decomposition of door lock

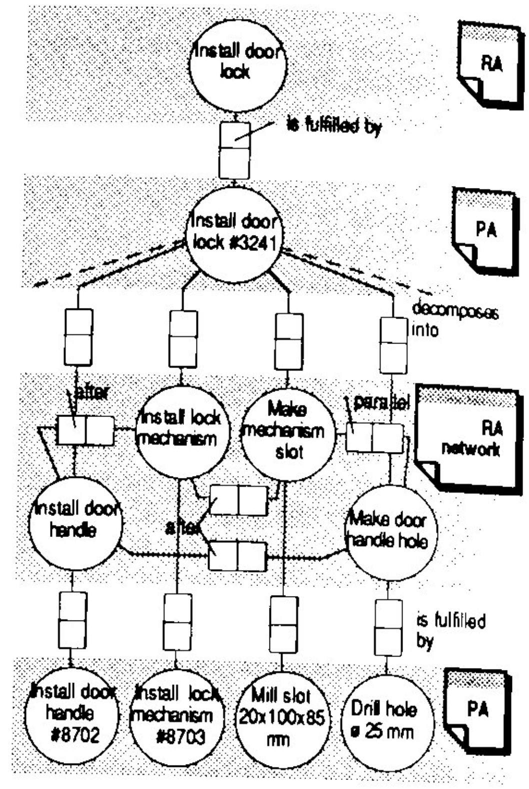

figure 9: ADU decomposition of door lock

In the process plan we would like to plan the activities needed to realise the TS "door lock system #3241" Figure 9 shows the decomposition of the Proposed activity "Install door lock #3241". This proposed activity decomposes into a number of smaller required activities which each are fulfilled by a proposed activity. Examples of alternative proposed activities would be to burn a hole with a laser beam instead of drilling.

The FU network of figure 8 and the RA network of figure 9 have relations as presented in the conceptual model of figure 6. Figure 10 shows these relations.

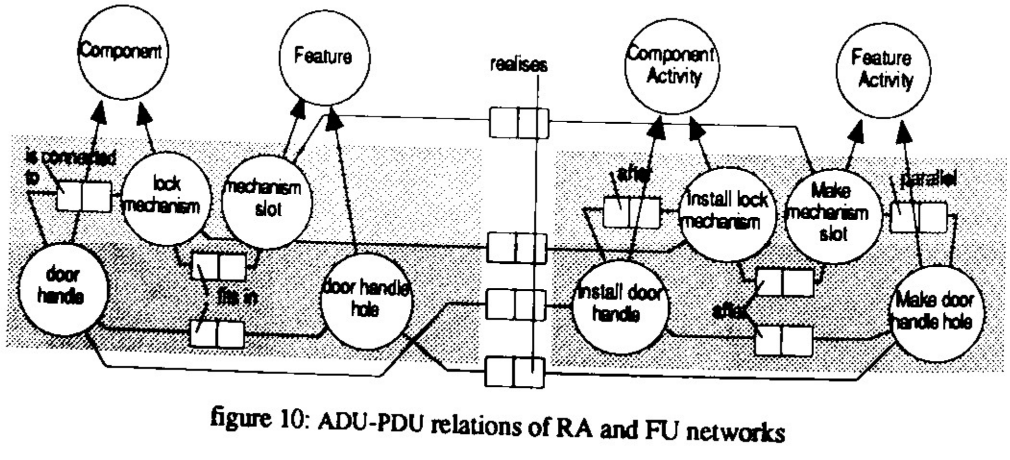

figure 10: ADU-PDU relations of RA and FU networks

8 Conclusions

The paper presented a conceptual model for the "neutral" description of activities required for the construction of (AEC) products. This model might serve as the data exchange interface between CAD/CAM systems and construction robots following STEP.

References

[1] Krom, R. P., Vos, L. de, Tolman, F.P., *Standard Components for Construction Robotics*, Proceedings 7th ISARC, Bristol (GB), June 1990.

[2] ISO, *Exchange of Product Model Data - Representation and Formal Description*. ISO DP 10300, February 1989.

[3] Gielingh, W. F., *General AEC Reference Model (GARM)*, proceedings CIB W74 + W78, October 1988, Lund Sweden, also part of [2]

[4] Tolman, F. P., Kuiper, P., Luiten, G. T., *Product modelling at Work*, Proceedings 7th CIB W 74 + W78, September 1990, Tokyo Japan.

[5] Turner, J. A., *AEC Building Systems ModeL*, IGES/PDES AEC Committee Report, Version 3.6, 1988, ISO TC184/SC3/WG1.

[6] Luiten, G. T., Tolman, F. P., *Design for Construction in the Building and Construction Industries*, Proceedings 7th CIB W 74 + W78, September 1990, Tokyo Japan.

[7] Waard, M. de, Tolman, F. P., *Implementing the Standards and Regulations View on Buildings*, Proceedings 7th CIB W 74 + W78, September 1990, Tokyo Japan.