INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 03 STOCKHOLM, AUGUST 19-21, 2003

GRAI ENGINEERING METHOD FOR DESIGN PERFORMANCE IMPROVEMENT

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Abstract

This paper deals with the development of a method to co-ordinate engineering design. It is based on the modelling of the engineering design system and its main objective is to improve engineering design performance.

The GRAI Methodology was developed by the GRAI research group of the University Bordeaux 1. It proposes to break down the design system into a decision sub-system that controls the technological sub-system, where product and process knowledge is transformed. An information sub-system manages the information flow between these two sub-systems. Analysing the activities of the personnel involved in the design system we demonstrate the need to manage co-ordination knowledge.

The GRAI Engineering method applies these principles to model the existing engineering design system. This leads to the establishment of a diagnostic of necessary improvements and then introduces the design of a new engineering design system.

Finally we conclude with the results of an experiment using the GRAI Engineering method in an SME company which produces mechanical and electronic products.

Keywords: engineering process, engineering management, knowledge management.

1. Introduction

Nowadays the development of products that fulfil customers' expectations depends on technical, social and economic factors. The challenge for companies is therefore to clarify these expectations in order to offer the corresponding final products and services. During product development, splitting the project into subparts depends on a number of factors. [1] suggest that task management, scheduling and planning, and resource management are the most important issues when it comes to operational co-ordination.

Recently the GRAI research group focuses on the co-ordination [2] of engineering design through the study of the engineering design system (in the sense of a systemic approach). This research is based on the GRAI Methodology which has been developed since 20 years and issued from many industrial experiments. Initially the GRAI Methodology was developed to design manufacturing systems [5]. Today, we extend it to design engineering design systems and to improve engineering performance [4]. The methodology is composed of a conceptual model, of graphical formalisms and of a generic structured method. The GRAI model proposes a framework to describe any system and especially the engineering design system [3]. This paper focuses on the operational method, called GRAI Engineering, to implement the GRAI model extended to the design system. This method defines guidelines for analysing the existing design system by using adequate models and for defining necessary improvements. Finally, we will present the results of an experiment to validate the GRAI Engineering method.

2. Methods

2.1 The GRAI model for engineering design

In the first place, the co-ordination of a system [5] consists in synchronising the availability of the materials to be processed and the raw materials needed for transformation. Secondly it co-ordinates the decisions between each hierarchical level (strategic and tactical, and operational). The GRAI reference model describes the engineering design system [6] as two subsystems called the decision system and the technological system. These two systems communicate through a third system called the information system (figure 1).

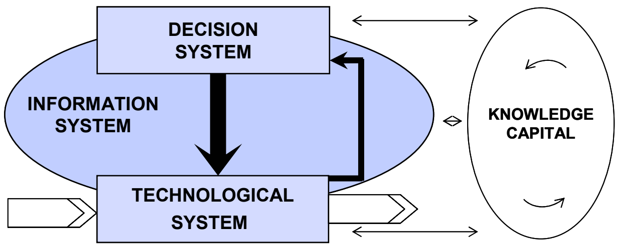

Figure 1. Design system model

The decision system co-ordinates and synchronises the technological system, which converts data flow into product knowledge [7]. The decision system is modelled by breaking it down in two ways: firstly, according to time criteria defining the strategic, tactical and operational decisions, and secondly, according to functional criteria defining products or project-oriented decisions. The decision system is divided into local decision centres, according to the fractal breakdown, and is represented by a GRAI R&D structure (see figure 7 for an example). In the technological system, each decision centre structures and controls the design centres, which in turn convert specific requirements into product knowledge according to the initial objectives. A decision centre defines the scheduling of activities or collaborative space according to design objectives and also defines indicators to enable performance evaluation [3]. Consequently, diagnostics are established and corrective actions defined.

Information is exchanged between the decision system and the technological system. It represents on the one hand the decision-making for co-ordinating design projects (a design frame) and on the other hand a feedback of the design issues so that it helps decision centre managers to make decisions (feedback information is composed of information about products and processes). Moreover there is a strong relationship between the organisation of the technological system and the decision levels. Each level co-ordinates a more or less agglomerated view of the technological system. The design centres' information flows are formalised and structured using a product model and a process model [8].

In order to manage co-ordination and to improve it from one project to another (i.e. developing good design principles [9]) it is necessary to consider these heterogeneous information flows [10]: to identify them, to characterise corresponding information and to capitalise it [11]. At first, we analyse designers' activities in order to identify and characterise co-ordination knowledge. Then we define a method for engineering design co-ordination which integrates the modelling of knowledge capital, as shown in figure 1.

2.2 Design activities modelling

In order to define the co-ordination knowledge model, we analyse the generic activities of the personnel involved in the engineering design system.

According to the engineering design particularities we identify two roles: a co-ordination role in a decision centre and a design role for those involved in a design centre. Figure 2 illustrates the co-ordination mechanisms that take place at a local level between a decision centre and a design centre. The co-ordinator receives objectives from a decision frame and then establishes a strategy to satisfy these objectives. He sends a design frame to a designer. The designer has to satisfy these design objectives. He then returns information to the co-ordinator who identifies the gaps, and evaluates the diagnostics, and if necessary produces a new strategy.

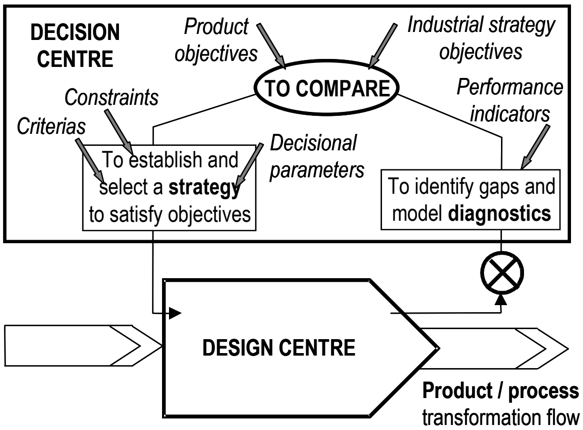

Figure 2. Co-ordination local model

So, a co-ordinator carries out the following project management activities (figure 3 and then 4):

1. he structures the project into sub-projects (i.e. identifies the design centres) and identifies related design objectives,

2. he selects resources and organises corresponding teams according to their skills and gives them roles and responsibilities and collaboration rules [12],

3. he drives the activities by giving teams resources and by scheduling, so as to satisfy their objectives, and by defining performance indicators and control mechanisms: the "co-ordination plan" merges all the information generated (design centres, objectives, organisation and driving information),

4. he then sends design frames extracted from the co-ordination plan to the design centres,

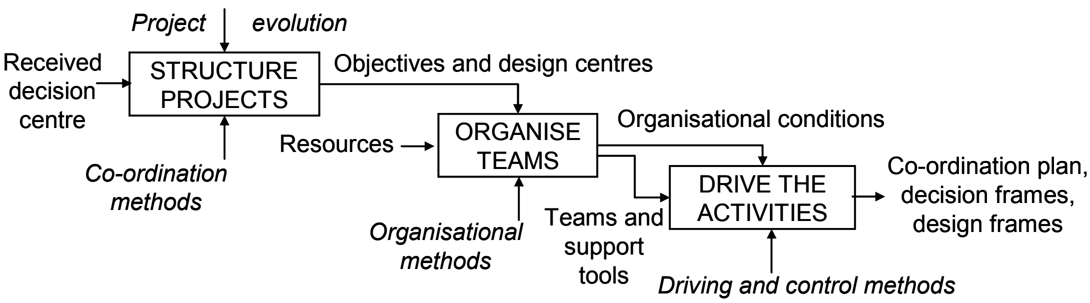

Figure 3. Co-ordination activities for co-ordination people

5. he analyses feedback information from design centres during control steps, validates indicators, and evaluates performance,

6. he identifies the gaps between indicators and the initial objectives,

7. he uses the diagnostics to define a new co-ordination plan.

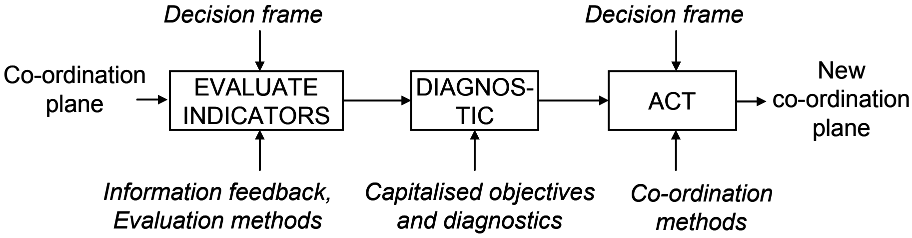

Figure 4. Control activities for co-ordination people

For design co-ordination, a designer has to (figure 5):

1. satisfy the objectives, according to the received design frame (analysing design problems and proposing, evaluating and defining solutions),

2. synthesise information concerning his activities according to control mechanisms and generate product and activities information using the product and process model (all being used as feedback information).

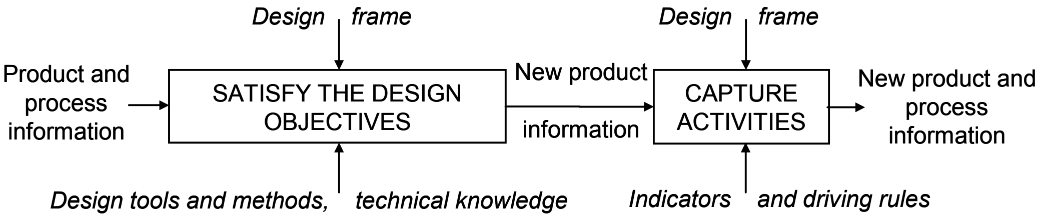

Figure 5. Design activities for design people

For each of these activities the required knowledge is identified and the information flows between personnel are identified. A knowledge model is proposed to capitalise this required knowledge during design projects [13]. It is based on the following characteristics in order to allow design actors to understand a given design situation:

- a knowledge element is represented by a set of information and the context of the element is described by an other set of information,
- each piece of information has a formal representation through a complexity level formalisation ([14] [15]) and is elaborated, by an operator, through the combination of information from a lower complexity level: this principle allow us to describe basic knowledge, then transformation knowledge, and finally rules and methods knowledge.

We now present the GRAI Engineering method for design co-ordination.

2.3 The GRAI Engineering Method

The GRAI Integrated Method (GIM [16]) structures actions to lead to the design of a new production system from an existing one. It is made up of three steps:

1. an initialisation step to structure the different groups of personnel involved in the study of the system;

2. a modelling step of the existing production system which provides the following models: the functional view (structural decomposition of the studied system), the physical view, the decision system model and finally the information system model. This modelling is completed by a diagnostic identifying the strong points, and areas needing improvement, of the current system;

3. a design step dedicated to modelling the new production system, the drawing up of the specifications of the new information system, and the new organisation to be integrated.

Based on GIM, the GRAI Engineering method (figure 6) is composed of an **initial step** to define objectives and the limits of the studied system, a **modelling step** to establish the diagnostic of the existing engineering design system and a **design step** to establish the future engineering design system and to specify the information system that will provide the required assistance to designers for design co-ordination. The modelling of both existing and future engineering design systems is based on:

1. the modelling of the decision system using the **GRAI R&D structure**;

2. the modelling of the technological system through a **functional view** representing the organisation and using actigram diagrams (IDEF∅ formalism [17]), then a **process view** using extended actigram diagrams [8]. We describe the project management process to highlight the development of design activities and the product data process to show design knowledge development;

3. the modelling of the knowledge capital for design co-ordination: the corresponding model is not presented in detail in this paper.

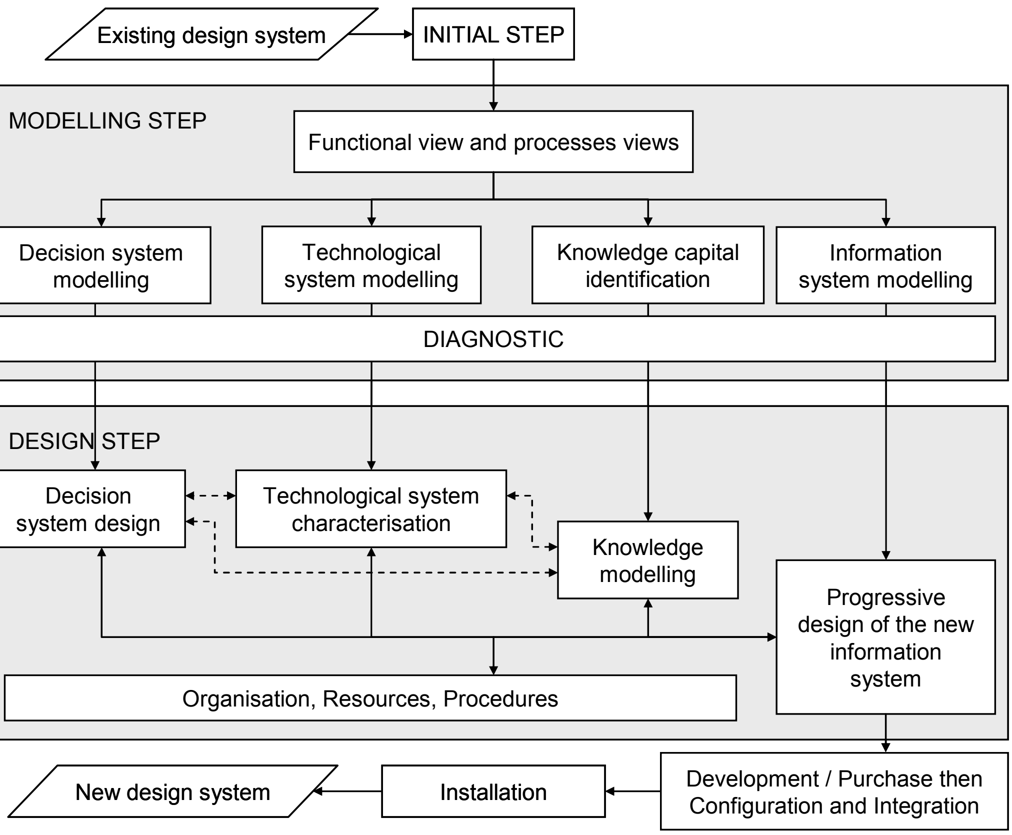

Figure 6. The GRAI Engineering method

During the modelling step the combined analysis of the project management process and of the GRAI R&D structure highlights the interactions between decision centres and their internal mechanisms and the information they need to manage. Using the product data management process the interactions between decision centres and design centres are characterised by the information flows between them. A diagnostic is established in order to identify necessary improvements.

During the design phase, these results are used to improve the design system and to model a new decision system. As the technological system structure is established and re-evaluated by the decision centres during a project, the modelling of the new technological system can only be global and completed by defining structuring rules. These rules will be used by the decision centres during the design projects. Then, we define specific design co-ordination knowledge. Finally, the modelling of the decision system, the technological system and the co-ordination knowledge are integrated to enable the definition of an adequate information system to allowing personnel to manage co-ordination information and to realise their related activities.

In the next section we present some experimental results that we obtained by applying the GRAI Engineering method to an SME. Thus, we validate the proposed models of developing design system modelling.

3. Results

3.1 Industrial case studies

Company A designs, manufactures, and commercialises several ranges of products dedicated to the oil sector such as pumps, sluices, and storage vats. The design office is made up of 25 people involved in mechanical, electronic, and data-processing aspects of product development.

The objective of the study is the modelling of the design system corresponding to new product development. We apply the preliminary step of the GRAI Engineering method to establish a diagnostic of A's design system. The analysis is based on interviews with different personnel involved in design projects; namely groups of designers, design managers and product committees from the marketing, design, planning and production departments. The case studies allow us to study different kinds of design projects (routine design, definition of prototypes and re-engineering of a product) and we formalise the specific processes involved for each kind of project. Then we hold group meetings to specifically analyse decision making during these design projects.

3.2 Case study results

By analysing the interviews, we first develop the representation of the functional view and of the process views describing the technological system. We formalise two kinds of processes: the project management process (figure 7) corresponding to a "design action" point of view, and the product data management process corresponding to the "design object" point of view.

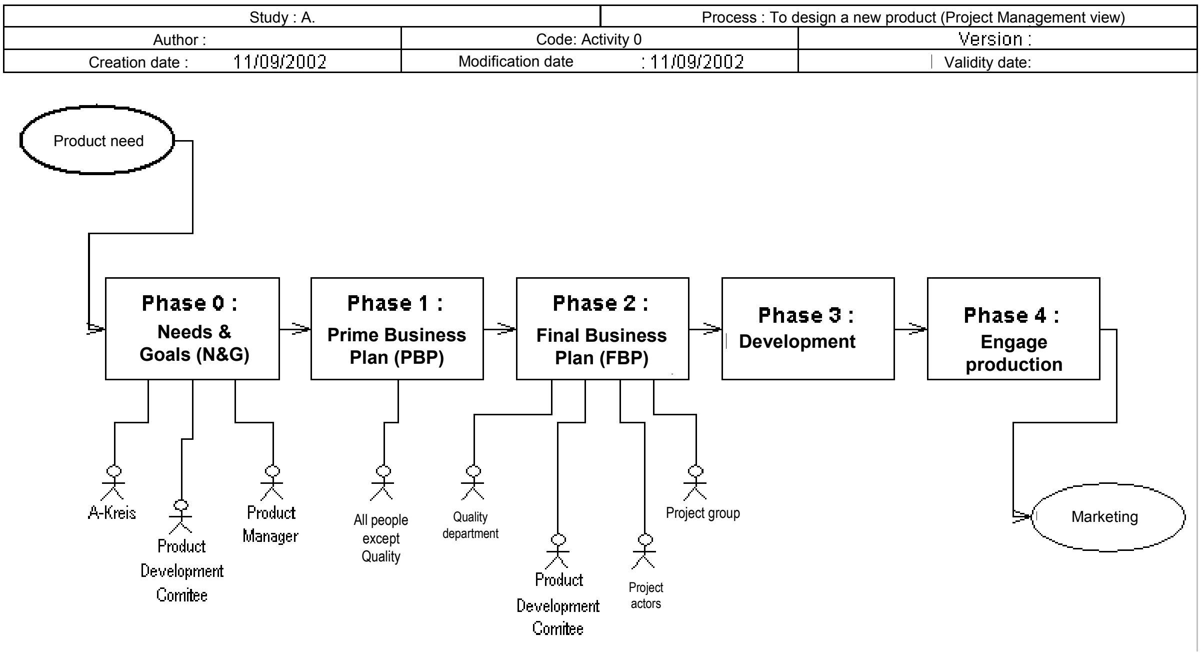

Figure 7. Technological system modelling: project management process, level 1

The representation of the technological model using this double point of view facilitates the analysis and the formalisation by the interviewer of an intermediate GRAI R&D structure, even if these two points of view generate interconnected processes. Secondly, this intermediate GRAI R&D structure is used to prepare the meeting with the synthesis committee. The final GRAI R&D structure is established during this meeting (figure 8) and represents the existing decision system.

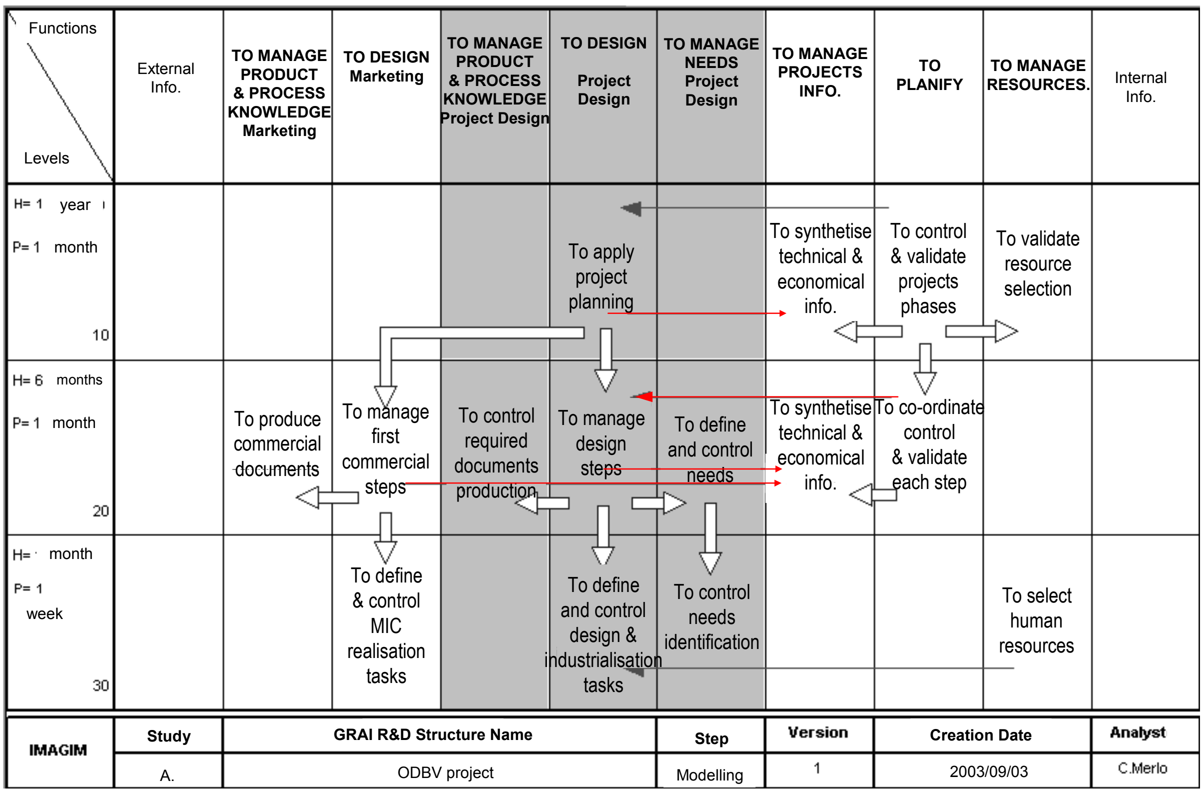

Figure 8. GRAI R&D structure of the decision system

In this case study three levels have been formalised: a strategic level for long-term project decisions, a tactical level to prepare the design activity, and an operational level to control design activities. The scheduling part of the GRAI R&D structure (on the right) co-ordinates and controls the design part (middle and left) which expresses the predominance of project management committees over operational departments. Analysing the middle and left parts, the marketing department is involved in design projects but with specific objectives: that's why control arrows come from the middle to the left. Marketing activities are directly under the control of the design department, but not the project management committees. This is the situation for routine design products but it generates useless iterations when innovation is needed because of a lack of direct co-ordination. This effect is reinforced by the fact that no global scheduling is defined at the operational level.

3.3 Synthesis of the GRAI Engineering method

Comment on the case studies: the structure of these models (process models and GRAI R&D structure) depends on the characteristics of the design project: e.g. product type, nature of product development cycle, organisation and relations between personnel within the company. The diagnostics of these models allow us to define a new organisation of personnel in order to improve the management of design projects.

Comment on the modelling of the decision system: the intermediate GRAI R&D structure is used by the interviewer to feed the discussion with the synthesis committee because formalising the different decision levels and objectives may be difficult for them. The comparison between the intermediate GRAI R&D structure and the final one brings in a lot of elements that reveal erroneous interpretation between engineers (designers) and managers (co-ordinators) or a lack of communication. These identified gaps help to establishment improvements in the diagnostics.

Comment on the method: this study demonstrates the principle of applying the GRAI Engineering Method to models of the decision system and the technological system. At the end of the study we have compared the modelling of the GRAI R&D structure associated to several kinds of design projects. We have concluded that the model of the decision system in the design phase cannot be unique. Several GRAI R&D structures should be generated for each kind of project or product (depending, for example, on the level of innovation).

4. Key conclusions and future work

In this paper we have described the engineering design system and the different models that allow us to represent it. We have introduced the GRAI Engineering Method whose objective is to study the existing engineering design system and to design an improved system to perform engineering co-ordination. In order to improve performance of design projects the GRAI engineering method is composed of guidelines and tools dedicated to support the designer's design activities. Guidelines result from the GRAI models, based on the modelling of the technological system, the decision system, co-ordination knowledge capital, and of the information system.

We validate the first steps of the GRAI Engineering method by defining guidelines for the analysis and the improvement of design system and for the modelling of processes and decision making. The modelling of the design system has been carried out in an experiment using an SME company. It demonstrates the validity of the method and shows the need to define an information system [18] that will help personnel in formalising, archiving, exchanging, capitalising and re-using co-ordination knowledge.

The specification of this information system is based on these models and especially on their analysis from the point of view of the personnel performing the tasks. We show in [19] that the resulting information system is a distributed environment and provides great assistance in the automation of tiresome tasks. A prototype of the environment is actually made in the IPPOP project (http://www.opencascade.org/IPPOP/) [20].

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