

**DRAFT: COMBINING PRODUCT INFORMATION AND PROCESS INFORMATION TO
BUILD VIRTUAL ASSEMBLY SITUATIONS FOR KNOWLEDGE ACQUISITION**

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ABSTRACT

Assembly is an important part of the product development process. To avoid potential issues during assembly in specialized domains such as aircraft assembly, expert knowledge to predict such issues is helpful. Knowledge based systems can act as virtual experts to provide assistance. Knowledge acquisition for such systems however, is a challenge, and this paper describes one part of an ongoing research to acquire knowledge through a dialog between an expert and a knowledge acquisition system. In particular this paper discusses the use of a situation model for assemblies to present experts with a virtual assembly and help them locate the specific context of the knowledge they provide to the system.

INTRODUCTION

Assembly is a process necessary to realize the final product which has acquired all the greater importance in view of the fact that many products today are meaningful combinations of various parts [1]. When the assembly consists of a large number of parts and complex processes that involves different parts and sub-assemblies being assembled from different places (e.g. aircraft assembly) the planning of the assembly (in terms of the sequence of parts, the process parameters, the fixturing needed etc.) has to be carried out in a systematic and informed manner. In such a scenario, a well informed decision making process is helpful. Assembly experts are the owners of knowledge that

can make an assembly process easier, by foreseeing issues that may come up during assembly. Once an expert can predict that an issue might be faced with a current assembly plan, a revised assembly plan can be drawn up to make the assembly less difficult. Such an activity might actually result in savings in time and cost [2]. However, it is not practical for an expert to be physically available to all the people involved in assembly planning all the time. It is also unlikely that the expertise would come from a single expert who possesses the knowledge in one single area, but rather from a set of experts from various areas, e.g. for aircraft assembly, assembly experts would involve people with expertise in structural engineering, manufacturing processes, hydraulics, electricals, etc. Virtual assembly can be a solution for such needs. Virtual assembly has been formally defined as the use of computer tools to make or assist with assembly-related engineering decisions through analysis, predictive models, visualization, and presentation of data without physical realization of the product or supporting processes [3]. As per this definition, the research presented here utilizes information from CAD assembly models and combines it with assembly processes for presentation of an assembly situation to experts, and then acquiring knowledge about the situation from the expert.

Assembly advisor system

One of the ways to overcome this issue, is to make the experts available to the assembly planners virtually, in terms of their knowledge. To do so, the research described here makes use of knowledge based systems [4]. One of the challenges that

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has been faced during the construction of knowledge based systems is the acquisition of expert knowledge that goes into building such systems [5]. The broader goal of this research is to build an assembly advisory system, which is responsible for acquiring knowledge about assemblies from domain experts and help assembly planners predict potential assembly issues using this knowledge. The acquisition of knowledge, which by itself constitutes various activities, is aimed to be achieved without the presence of an intermediate knowledge engineer, which is the traditional means of knowledge acquisition [8]. The interactive acquisition of knowledge is planned to be achieved using assembly situations as the contexts in which knowledge would be expressed. Assembly situations are discussed in more detail in the section 'Assembly Situation'.

Structure of the paper

The intent of this paper is to describe our research that integrates product information and process information for assembly so as to enable construction of a virtual model of an assembly situation from the perspective of the assembly as both a product and a process. The paper introduces the circumstances under which a situation model for knowledge acquisition became necessary in the section 'Overview of research'. In the section 'Assembly Situation', the Situation Model that was earlier developed is explained. The section 'Product and process information' explains the sources of product and process information for a Situation Model, and the section 'Integrating product and process information' shows how these are integrated into the Assembly Situation Model. Finally, the implementation of this integrated information is briefed in the section 'Implementation of situation model for knowledge acquisition', and the conclusions are drawn in the section 'Conclusions and future work'.

OVERVIEW OF RESEARCH

In order to put the contents of this paper in the right context, it is necessary to highlight the broader scope of the research work that has been presented in this paper. The overall objectives as stated before, are to develop an assembly advisor system that can

1. acquire knowledge about potential assembly issues and potential solutions to these issues, and then
2. to use this knowledge to predict potential issues on assemblies, in order to prevent them from occurring.

This will require building a system that would help construct knowledge bases through expert interaction, and make this knowledge usable by assembly planners.

Knowledge based systems

Knowledge based systems, or expert systems as they are also known, are systems capable of storing knowledge about a do-

main. When provided with information about the state of the world, such systems are capable of deriving new facts about the world, with the help of domain knowledge and through inference [7].

Knowledge acquisition The major bottleneck to building expert systems is the acquisition of knowledge [5]. Knowledge acquisition comprises of a sequence of activities: to acquire the knowledge from a human expert, formalize this knowledge, and represent it in a representation used by the knowledge based system [8]; attempts to automate this process have been made earlier [9] [10] [11].

Knowledge types

When dealing with our research problem, one of the first questions that needed to be answered was, what knowledge do we need to capture? After conducting a set of experiments with experts [6], the following types of knowledge about assembly that were identified as necessary: knowledge about *issues, constraints, parameters - derived and basic, and solutions*.

Questioning Procedure

After identifying the types of knowledge needed for acquiring knowledge for identifying potential assembly issues when presented with a situation, the next step was to develop a means of acquiring this knowledge. For this, a questioning procedure was developed. The procedure presents the expert with an assembly situation and asks a set of questions that resemble a dialogue with the expert. The questions are directed to the expert one after another, thereby acquiring necessary knowledge about the various issues in the assembly situation, which can be used by the system to predict later what issues might occur in new assembly situations.

Implementation of knowledge acquisition tool

The questioning procedure was implemented as a Windows OS based software tool named Expert Knowledge Acquisition and Validation (ExKAV). The implementation was done using MFC [13], with CLIPS [14] as the expert system shell. Initially the assembly situation was presented as a picture only; and subsequently as a view-only CAD format. Further, as described in the section 'CAD as a means of representing product information', CAD software SolidworksTM was integrated with the knowledge acquisition tool such that the presentation of assembly situation using 3D interactive models became possible.

ASSEMBLY SITUATION

For the purpose of conducting a dialog with an expert, an assembly situation is presented to the expert, and used as the con-

text within which the knowledge is acquired from the expert, and also as the context in which it is used by an assembly planner. The assembly situation is meant to be a representative example for a group of assembly examples that are similar. In the implementation of the knowledge acquisition tool, an assembly situation was initially presented just as a picture, and later as simply as a CAD model. However no image or CAD model of an assembly alone is sufficient to represent the whole process of the assembly. Gui et. al. opine that an assembly model that only places components together with their features cannot hold functional knowledge or design intent [15]. Extending this argument, we say that assembly involves not only artifacts in the form of parts and sub-assemblies, but also the processes that must be carried out on these parts and sub-assemblies. Hence, a means of representing an assembly situation that can accommodate both these details of an assembly, and at the same time is simple enough to be used to present an assembly situation to both assembly experts and assembly planners, is needed.

One of the frameworks for assembly modeling in CAD [15] involves a process model that refers to the producibility of the structure of assembly. However this is intended towards building a functional model for assemblies from a design point of view. It does not enable one to visualize or structure an assembly situation for presenting that situation. A similar situation exists in virtual prototyping systems [16] that integrate the use of task level human interaction, knowledge based descriptions of mating possibilities and dynamic knowledge representation of an assembly scene, to create a real-time assembly simulation based on CAD parts. However these simulations do not carry details of the industrial assembly processes (e.g. riveting) that might be required by an assembly expert, who needs to interact with the system for enabling knowledge acquisition.

Assembly Situation Model

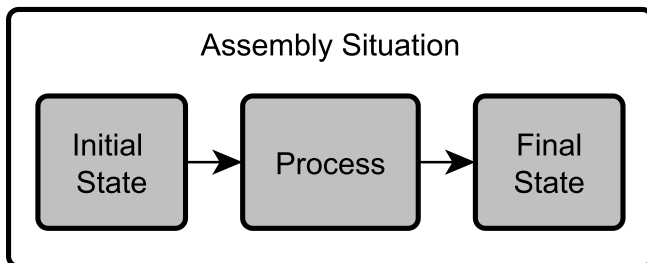


FIGURE 1. THE ASSEMBLY SITUATION MODEL (ASM) FOR A SINGLE STEP OF ASSEMBLY

The Assembly Situation Model (ASM) was developed with the aim of classifying important chunks within an assembly process with a simple model that was usable within the available information constraints of the project [6]. The ASM, at its most basic representation, identifies any assembly process as a transformation from an *initial state* of unassembled components, to the *final state* of assembled components by means of an *assembly process*. The distinctive feature of this model is that at any particular stage of assembly, all the components are always involved, but have different relations (like assembly constraints) among them. This means that while the information is available about what the current status of the assembly is, information about all the other parts of assembly that are not currently involved in the process for that stage is still retained. The notable application of this model is to enable the expert to point his knowledge of issues, cause of issues, etc. to a particular stage of the assembly or the assembly processes. When an expert's knowledge is placed in the context of a specific assembly situation it specifies one level of context. However, the ability to identify this knowledge with a particular stage of the assembly process specifies the context at a level deeper than the context of only the situation.

PRODUCT AND PROCESS INFORMATION

This section describes the different pieces of information about an assembly as a product as well as the different processes involved in an assembly. This information is the basic material from which an assembly situation has to be constructed. Being the only specifications of the parts and processes involved in the assembly, product and process information dictate the limits to which we can specify an assembly situation in a virtual manner during knowledge acquisition using the ASM.

Product information

Information about an assembly as a product- the artifact to be represented in an assembly situation, is about the parts and sub-assemblies that constitute the assembly. A part can be specified in terms of the name of the part, the number of instances of that part in the assembly, part geometry, mates between the parts, hierarchy, material information etc.

CAD as a means of representing product information The product specification of an assembly is what is usually followed in a CAD model of the assembly; this contains details about the individual parts of the assembly, the component sub-assemblies, and details of how the parts are related to one another in terms of assembly constraints (sometimes known as mating conditions). As mentioned above, the CAD model of an assembly is able to supply details about the geometry of its parts, their material specifications, the assembly tree structure, etc.(See

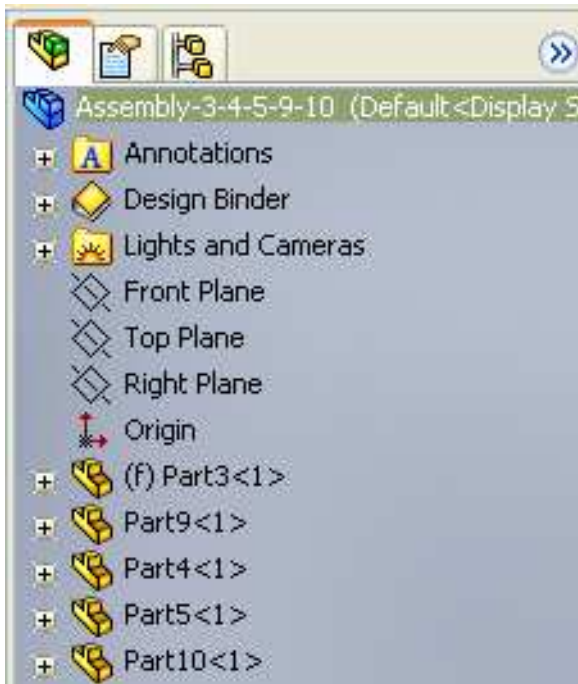


FIGURE 2. THE ASSEMBLY TREE STRUCTURE AS REPRESENTED IN A CAD SOFTWARE

Figure 2). Usually, each individual part is represented as a different CAD part, and a CAD assembly would combine these parts using defining relations of assembly, such as mates, that bring these parts together in the final assembly. Also, since CAD is used as the standard way of expressing the final assembly artifact in our work, it is a reliable source of product information for the purposes of presenting an assembly situation to an expert, and for subsequent use by an assembly planner.

Assembly process information

For assembly of parts, a major element is the *sequence* in which the parts are put together to form the assembly. Of the variety of methods proposed to compute feasible assembly sequence(s), one is the geometric method, wherein the blocking directions for the parts are used to determine the sequence in which the parts are to be assembled [17]. In our work, the set of possible assembly sequences is directly supplied to the knowledge acquisition module, and this forms one part of the assembly process information.

The other set of information is the individual assembly processes that are responsible for each step of the assembly. An associated research within our group is used to identify the relationships between the process model and the product model for an assembly, by evaluating the liaisons between the parts on the basis of their features [18]. Information about the assembly processes involved serves as an input to our knowledge acquisition tool. Informa-

tion about a process consists of : the name of the main process (e.g. riveting), the processes that must precede (e.g. drilling, deburring) and succeed (e.g. cleaning) it, as well as detailed description of the main process itself. Current virtual prototyping systems enable simulation of manufacturing processes [12], but not the assembly processes involved; our work uses a combination of the assembly sequence, individual processes and the parts involved in these processes together to describe an assembly situation.

INTEGRATING PRODUCT AND PROCESS INFORMATION

Once the assembly product information is available in terms of a CAD assembly model, and the assembly process information is available in terms of an assembly sequence, the assembly liaison and process information, the next issue is to how to smoothly integrate these pieces of information, so that an assembly situation can be adequately represented. The general structure of the overall assembly situation resembles that of an assembly tree itself [6]. Currently, only linear assembly sequences have been represented.

For the situation shown in Figure 3(a), we see that the assembly sequence information is available on one hand, and the assembly liaison information (represented here by a liaison graph) and hence the assembly process information is available on the other hand (Figure 3(b)). Taking assembly sequence (Figure 3(a)) as the basis, product and process information (Figure 3(b)) can be brought together as in Figure 3(c). To achieve this, from Part-1, the next part to be assembled into the assembly is looked for, which, in this case, is Part-2. Then, from the liaison information, the association of Part-1 with Part-2 is checked for and the required assembly process information is retrieved. This entire chunk of information is organized using the ASM, and we obtain the first step of this assembly represented using the ASM, see Figure 3(c). Repeating this process for the entire assembly, we obtain the entire ASM for the assembly situation.

IMPLEMENTATION OF SITUATION MODEL FOR KNOWLEDGE ACQUISITION

The assembly situation modeled using the ASM needs to be utilized in knowledge acquisition. Implementation involved the following two steps:

Before the questioning procedure starts, the ASM is used for presenting an assembly situation to an expert, serving as an example around which knowledge acquisition would be based

During knowledge acquisition, the questioning procedure is deployed with the ASM being used for enabling the expert to better clarify the contents of his/her knowledge, by sug-

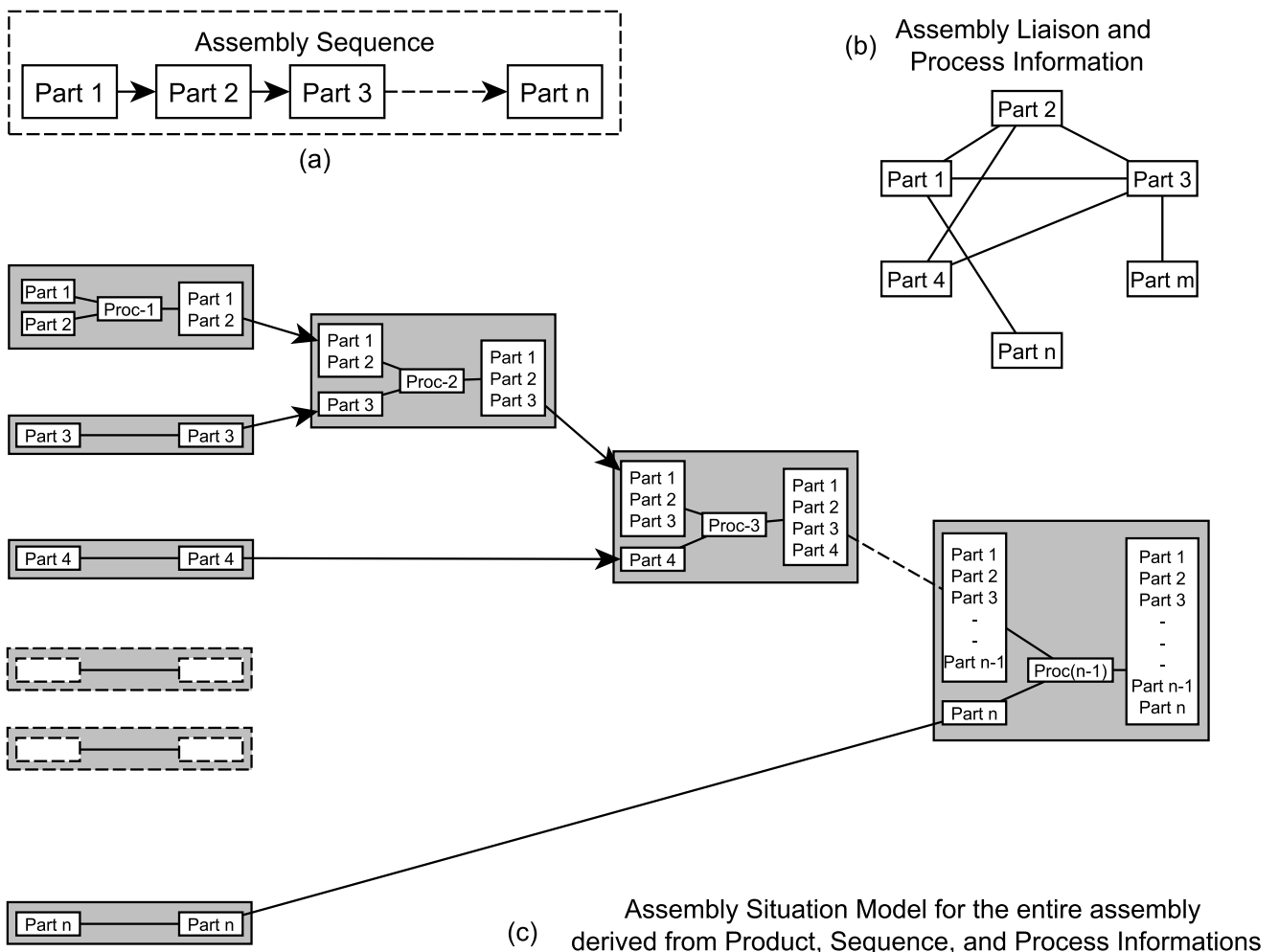


FIGURE 3. THE INTEGRATED SITUATION MODEL AFTER COMBINING THE PRODUCT, SEQUENCE AND PROCESS INFORMATIONS

gesting suitable phrases or terms, based on the stage of assembly to which this knowledge is relevant (and has been earlier clarified as such by the questioning procedure)

In order to explain the above two steps, we use the assembly shown in Figure 4.

Presentation of situation

Before acquisition of knowledge via the questioning procedure starts, the ASM is used first to present the relevant assembly situation to the expert. The assembly situation is an example of a typical assembly that would be encountered in the domain of aircraft assembly. There could be many possible assembly situations in the database of the knowledge acquisition system, out of which one is chosen for viewing by first presenting the first

part of the assembly, then the processes involved in assembling of the second part to the first part, and then the geometry of the subassembly of the two parts. Then, similar details of the next process for assembling the third part to the above subassembly is presented, followed by the resulting subassembly of these three parts. The situation presentation for the first three parts of the assembly example (shown in Fig.4) is shown in Fig. 6. Information about the geometry, features, material compositions, and other parameters related to these parts can be sourced from their respective CAD part models. Although the assembly mate information can be derived from the CAD assembly model, this is not utilized here. This is because the liaison and process information used here (see the section 'Assembly process information') is richer in content - it has information about the interfaces involved in the mate, the respective liaisons, the processes that

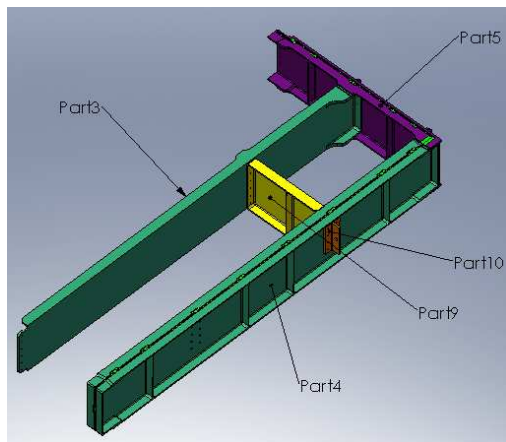


FIGURE 4. AN EXAMPLE ASSEMBLY THAT SHOWS THE PARTS LABELED

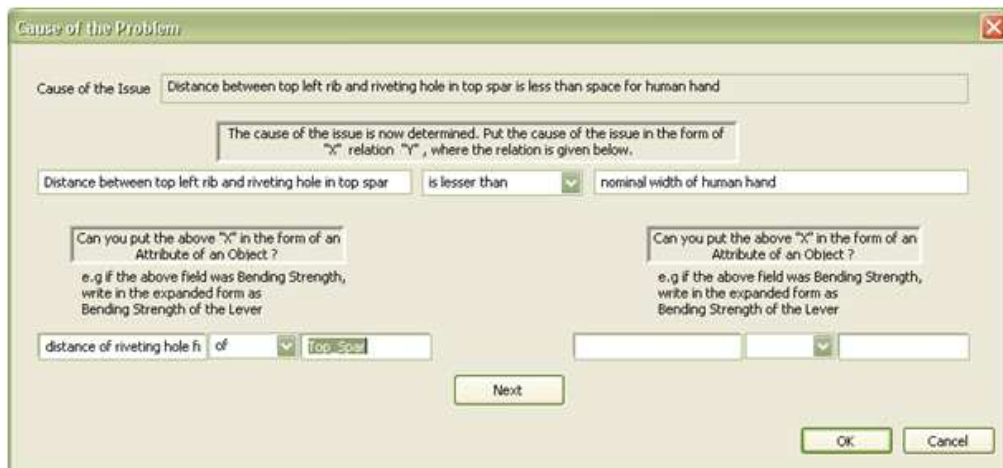


FIGURE 5. THE FIGURE SHOWS A WINDOW OF THE KNOWLEDGE ACQUISITION TOOL. A PIECE OF KNOWLEDGE NECESSARY TO ACQUIRE IS THE ATTRIBUTE OF AN OBJECT INVOLVED IN THE ASSEMBLY. BASED ON THE EXPERT'S EARLIER FEEDBACK OF WHERE THE ISSUE IS SITUATED, THE TOOL PROVIDES SUGGESTIONS FOR THE PART-NAME (THE HIGHLIGHTED TEXT BOX)

need to be performed, and the respective pre- and post- operations for these processes. Hence we see that a virtual assembly presentation that uses CAD representation as the basis, and is also capable of conveying information about assembly processes has been developed as part of ExKAV.

Placement of expert knowledge

Another use of the ASM is in providing assistance to experts by helping them to refine the context of the knowledge acquired to levels beyond than only that of the situation. This is done by asking the expert early on about the stage of assembly to which the knowledge in terms of the issue, its cause and potential resolution acquired from the expert can be attributed, and then using this knowledge for supplementing the context in which these issues etc. should be placed in the system. For example (from

Figure 4) an issue that might be faced at the stage when Part10 is assembled to Part4, using the the if one of the issues was that the riveting gun cannot be used in the gap between Part-9 and Part-4 as shown in the Figure 4. The expert inputs this issue into the knowledge acquisition tool, and chooses the stage where it occurs (During assembly of Part10). The cause of this issue is also input by the expert. The cause is resolved into a relational form between two attributes. These attributes are put to a standard form using assistance provided by the ASM. As shown in Figure 5 the tool suggests the part names concerned with that step of assembly one by one.

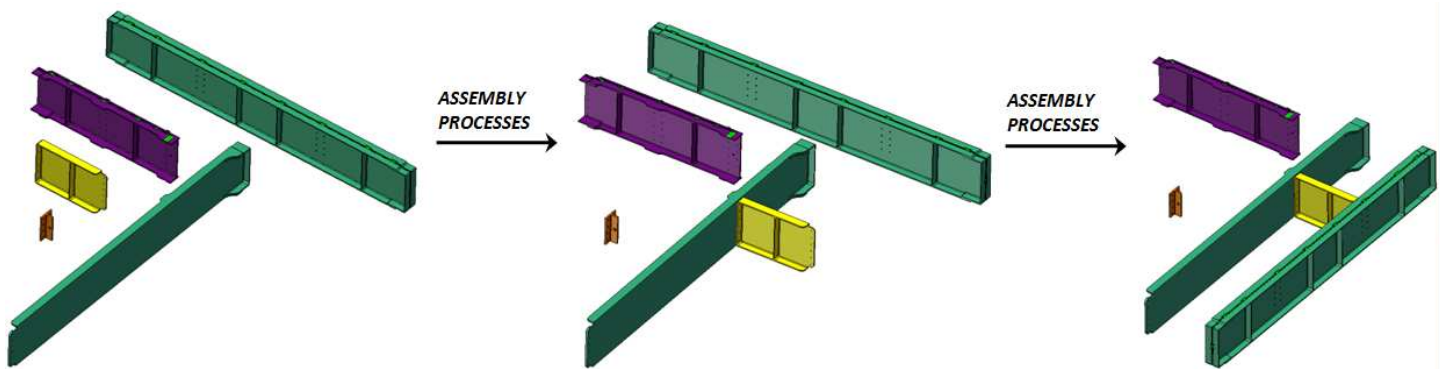


FIGURE 6. THE PRESENTATION OF THE ASSEMBLY SITUATION TO THE EXPERT IN A VIRTUAL MANNER IS SHOWN HERE FOR THE FIRST THREE PARTS OF THE ASSEMBLY EXAMPLE

CONCLUSIONS AND FUTURE WORK

A model that combines both product information and process information (in terms of the assembly sequence and processes) for assembly has been proposed in this paper. We argue that the combination of these pieces of information and the implementation on computers of a method for combining these makes the model a simple and practical way of presenting virtual assembly situations that can be used for knowledge acquisition. The method helps to capture the context of the acquired knowledge at an appropriate level of the assembly processes, which was one of our original intentions for developing an Assembly Situation Model. Although the current implementation is not integrated with virtual reality aids (e.g. HMD's, motion trackers) we argue that there is a framework in place that should enable this transition over time. It is to be noted that the assembly sequence, and hence the assembly situation have been currently implemented for linear assembly sequences only. This needs to be generalized to accommodate general assembly tree structures. Another task for the future is implementation of the knowledge acquired for its utilization in the right context, and subsequent testing to evaluate the effectiveness of the knowledge acquisition process, including the role of CAD and process information in this process.

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