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Collaborative Factory Planning in Virtual Reality

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The competitive development and optimization of manufacturing systems challenge the collaboration and innovation of enterprises. Different information, thinking, and points of view have to be exchanged across engineering, decision-making, and executive levels safely and effectively. The Virtual Reality (VR) technologies provide the users advanced Human-Computer-Interfaces for designing, analyzing, and optimizing complex manufacturing systems. The objective of this paper is to describe a VR-based approach that allows the simultaneous visualization, investigation, and analysis for factory planning. This gives global entities a competitive advantage when conducting business.

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1. Introduction

To enhance the factory planning processes during production design, an immersive Virtual Reality (VR) supported approach for distance collaborative factory planning is described in this paper. A review of current research in the area of factory planning, various collaborative methods, as well as the implementations of immersive VR is provided.

Different types of interaction are then differentiated. For a classification of collaboration, interactions will be divided into Human-Human-Interaction and Human-Machine-Interaction. The interaction types are analyzed and assigned while taking into account the needs of factory planning in a virtual environment.

Based on the VR software VRUI (Virtual Reality User Interface), the visualization in a single immersive system will be extended to a platform which will consist of two or more connected, immersive systems. This allows users in different locations to cooperate, explore, and analyze within the same virtual model in real-time. An approach to achieve the described collaborative VR system is introduced.

2. Related Work*2.1. Factory Planning Process*

Factory planning is a multi-criteria problem dealing with optimization of material flows, resource utilization and logistics at all levels of a factory [1]. Competitive advantages can only be achieved through a comprehensive configuration of the factory as a whole system. Isolated configurations of processes won't lead to a complete solution [2]. To ensure this complementary strategy, several logically structured Factory Planning frameworks were developed. Despite the different approaches a common basic classification scheme is accepted throughout the scientific community. It structures the Factory Planning Process into the three main fields: target planning, conceptual planning, and realization planning. GRUNDIG refined this rough scheme into six factory planning stages (Fig. 1); they will be the conceptual basis in this paper [3].

In industrial factory planning cases, overlapping and parallelization of stages are often required. This is realized by attaching an iterative structure to the

concept. The stages ‘concept planning’ and ‘detailed planning’ (outlined as ‘central planning stages’) are the most crucial stages in the factory planning process. During these stages, the expertise of several planning specialists is merged to determine the capabilities of the factory [3]. Hence, the process improvement efforts are mostly focused on these stages.

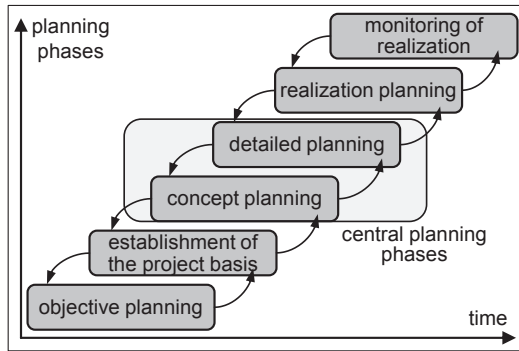


Fig. 1. Planning phases and systematics [3]

One of the key characteristics of current factory planning projects is the inclusion of a number of different planning fields. To avoid suboptimal planning results, several development tendencies within the affected planning fields have to be taken into account. Interdependencies must be respected, therefore the participation of employees from several divisions is recommended [4].

2.2. Current collaborative methods and tools

The extension of communication and cooperation beyond organizational and divisional boundaries will speed up planning processes and reduce the complexity during work by implementing collaborative factory planning tools. This will be realized by interconnected but spatially distributed VR systems [5]. For the optimized planning of factories three crucial tasks have to be tackled by all participants in a cooperative way [1]:

- Production parameter optimization
- Optimization of production control strategies
- Layout optimization

These tasks call for the distribution of necessary information and the current planning status to all project participants. To ensure the dissemination of information, requirements are determined which need to be fulfilled by collaboration methods in a proper way. Following SMPAROUNIS’ approach for collaborative product design, the preliminary features are identified as [6]:

- quick and easy data storage and sharing
- synchronous and asynchronous communication
- cooperation in designing and manipulating geometrical models

- multi-user visualization and interaction
- decision support

With regard to the previously defined planning stages and the identification of the central planning phases as the crucial phase of planning, they must be supported in a favorable manner by collaboration tools. Traditional methods to facilitate the factory planning are focused on functional-, demand oriented- and structural-design of a factory. Ordinarily the concept planning stage is concluded by a feasibility test. Often coordination activities for detailing the layout involving several divisions are planned only after this test [3].

In current industrial projects the exchange of planning states is often realized in an unsystematic way with little support of digital tools. Even if digital data is provided by the several participants, approval is paper-based. This is grounded in the fact that visual analytic tools are typically insufficient for collaborative work. They are designed for single user operation on standard desktop systems [7].

To solve this problem, research projects regarding this topic were initiated in the recent past. They emerged from two main movements in the scientific community dealing with two aspects of collaborative work [8]. On the one hand is the ‘collaborative knowledge construction’ concerned with multi-party decision-making supported by visualization tools [9]. On the other hand ‘environmental planning’ is more focused on the discussion of problems through communication of options, plans, desired future outcomes and persuasion [10]. Depending on the focus, digital tools are more or less suitable to support both ideas. To support the factory planning process in a comprehensive way, future tools must be able to capture both movements in a holistic way.

	multi-party decision-making	problem introduction – exchange of ideas	focused on Factory Planning
VirCA	○	◐	◐
COLLAVIZ	◐	◐	○
VFM	◐	●	●

Fig. 2. Comparison of current collaboration tools

With these basic principles in mind, current research projects and their resulting tools are sketched and compared in Fig. 2.

For enabling ‘high level collaboration between humans and intelligent agents in a virtual reality’ the Virtual Collaboration Arena (VirCA) has been developed. The main idea behind this project is the

interaction of users with Virtual Reality itself. Therefore interaction is suggested to focus on the communication between the user and other humans, but also between humans and robots or other intelligent agents [11].

The COLLAVIZ Framework is developed for ‘collaborative visualization of 3D scientific datasets’. The aim is to enable the collaboration of scientific experts based on sharing their knowledge and research results. Therefore users are encouraged to share the same virtual environment [12]. The features are focused on a collaborative interpretation of abstract scientific data.

The ‘Virtual Factory Manager’ (VFM) is a facilitating server tool developed by the ‘Virtual Factory Framework program’ [13]. By applying the ‘GIOVE’ tool for 3D immersive representation and interaction within digital models [14] and the ‘Factory Layout Planer’ for designing and simulating factories, a set of digital tools has been provided [15]. Despite this extensive approach a comprehensive tool, which enables the two movements (collaborative model investigation and face-to-face decision-making) in an interconnected way, is not provided.

In addition to the categories shown in Fig. 2, the capability of the tools to enable interconnection between immersive Virtual Reality (VR) systems is crucial. Enhancing immersive VR with collaborative tools to support the decision making process by sharing information, will increase the benefit companies are receiving from the usage of immersive VR [14].

2.3. Implementation of immersive Virtual Reality

As a comprehensive and widely developed technology, it is difficult to find an unambiguous definition for Virtual Reality (VR). This term is also labeled as Virtual Environment, Artificial Reality, or Cyberspace. However, the common understanding of VR is a computer generated environment in which the users are able to interact or participate in real time. Immersion, interaction, and imagination are three main features of VR [16] and embody the advantages of VR systems. The virtual environment allows more people to be involved in the planning process, which leads to quicker and better result. Virtual analysis and comparison of planning options avoid many potential risks and costs [17]. Various implementations have already been made to facilitate industrial applications. Following is a brief review of factory planning issues and collaborative activities.

SCHENK et al. introduced [18] a method to combine VR and assembly simulation for production planning. As result, a fully-interactive and immersive 3D visualization of assembly lines and factories is implemented in VR. In [19] AURICH et al. discussed a VR based CIP-workshop (continuous improvement process). Using this

approach, it is possible to analyze and adapt the factory layout, work place design, and material flows in a virtual factory. The machine operators in a real factory are able to participate in the planning process and adapt the planning result further in the physical environment.

WAGNER and BLUMENAU developed a digital factory approach to integrate planning, simulation, and visualization on one platform. Using this platform, the product and production planning processes are undertaken more efficiently [20]. FRANCESCO et al. compared the commercial simulation and visualization software in the field of manufacturing system design and presented an approach to implement the ergonomic simulation in VR systems. The comparison shows there is no available software for factory planning, which supports full VR integration [21].

The literature review shows that the current research work focuses on either specified planning jobs or a local solution in virtual environment. A comprehensive approach is not found. Hence, there is still research needed on immersive VR implementation in field of factory planning, focusing the collaborative activities. In further sections an innovative approach to enable planning processes in connected CAVE systems is developed and discussed considering existing issues during factory planning.

3. Collaborative Factory Planning in VR

3.1. Classification of Interaction

The virtual environment related interaction has been discussed by various researchers. A characterization of various interaction tasks in a virtual environment is presented and evaluated by Bowman et al. in [22, 23].

In addition, social interaction is generally defined as an alternating exchange of messages between two or more persons. It is based on spoken language, facial expressions and gestures. This interaction consists of actions of a person to which another person can respond [25]. Social interaction using distributed VR systems is possible, if users share the same virtual environment, so that they are able to communicate with each other. They can interact as if they were interacting face-to-face [26].

In our approach, the interactions between both Human-Computer and Human-Human are taken into account. In order to account for the wide range of interaction forms, several interaction types were defined. An interaction type consists of several elements. The elements are represented by different interaction forms (e.g. modification, audio). There are four interaction types shown in Fig. 3.

Elements associated with the type ‘Social Interaction’ are auditory interaction, visual interaction and textual interaction. These interaction forms are especially used

for Human-Human-Communications in a virtual environment.

Social Interaction	Navigation
<ul style="list-style-type: none"> • Audio • Visual • Text 	<ul style="list-style-type: none"> • 6 Degrees of Freedom • Pre-defined Viewpoint
Annotation	Model Manipulation
<ul style="list-style-type: none"> • Highlighting • Remarks 	<ul style="list-style-type: none"> • Object Generation • Object Modification • Object Deletion

Fig. 3. Toolbox of interaction types

The interaction type ‘Navigation’ is the basic task of user in a virtual environment which is considered as the movement in or around an environment [24]. This type describes the viewpoint of a user in the virtual environment. Using the first interaction form, users can navigate through the virtual environment freely. Another form of navigation provides a pre-defined viewpoint in which the user can only see what they are allowed to see by the administrator. The user can also share the current viewpoint of another user, which facilitates a more personal view, and they can discuss the same object at the same time. Through this presence in VR, this interaction type is then strongly related to social interaction.

‘Annotation’ enables the user to highlight objects in a virtual environment. That is necessary to select a specific object. Users can also create remarks and tag them to involved objects. These highlighted objects and remarks can be defined to only be visible for the user who made them, or for a specific group of users with defined authorization or for all users. Remarks, which only one user can see, could contain information about the changes to be accomplished after the collaborative meeting. The ‘Model Manipulation’ defines the interaction forms of objects within the model. The users are able to modify the virtual environment and its objects, create new objects or delete existing ones. This enables the user to participate directly in the design process.

Within this toolbox we provide a set of essential elements for interaction activities. Depending on the applications, the four defined interaction types are implemented separately or in conjunction. A detailed discussion will follow below.

3.2. Facilitating Factory Planning by collaborative methods

The need to support the central planning phases of the factory planning process by collaborative measures is well known. For our systematic approach, they can be

assigned to three central collaboration methods in the realm of factory planning.

- Collaborative Meeting
- Collaborative Visualization
- Collaborative Design

Collaborative Meeting in the scope of factory planning describes a working method to enhance the personal communication. Despite the spatial distribution, it is comparable to a co-located, non-virtual meeting. This method is directly linked to the decision making objective and fosters not only the exchange of conceptual but also administrative tasks.

Collaborative Visualization focuses on the illustration of temporary and finalized project results. Our objective is to introduce planning states to other project participants and to provide a comprehensive view and alternatives. The exchange of ideas is the fundamental concept of this method.

Collaborative Design instead is oriented on the cooperative creation and manipulation of digital models. In addition to the pure visualization of planning stages, it is a co-creative method which enables the active contribution of all participants. As the inclusion of virtual models is crucial, means to provide efficient handling of them is imperative.

3.3. Correlation between collaboration and interaction

By describing interaction and collaboration as clearly separated types and methods an investigation of their relationships is possible. Our objective is to create a well-defined set of interaction types for each collaboration method. In Fig. 4 the mapping between collaborative methods and interaction types are provided in detail.

	collaborative meeting	collaborative visualization	collaborative design
Social Interaction	-audio -video -text	-audio	-audio -image/avatar
Navigation	-	-pre-defined	-6 DOF
Annotation	-	-highlighting -private remarks	-highlighting -private remarks -public remarks
Model Manipulation	-	-	-object generation -modification -deletion

Fig. 4. Correlations between collaboration and interaction

Collaborative Meeting is described above as extremely focused on social exchange. Therefore the ‘Social Interaction’ type should be a high configuration level. This richness of media can be provided by covering a wide range of communication channels like

audio, visual and textual. Any further interaction type is not mandatory for this collaboration method.

Collaborative Visualization in the realm of factory planning is described as an introductory method for the digital model. Hence, interaction types dealing with the investigation of 3D models must be considered. The minimum requirement is the guided variation of the users' viewpoint to have multiple impressions of the model. The 'Annotation' type will further provide the capability to highlight a model component or to focus the attention on a specific feature. Social exchange, although it is not the focus of this method, will be needed to explain model characteristics.

Collaborative Design is the method dedicated most to the digital model. This method requests a maximum number of degrees of freedom to the user in order to solve problems in a creative way. We formulated requirements to all interaction types to create and adapt a virtual factory model. 'Social Interaction' type elements for problem discussion are provided. An audio channel and a visual image of the project participants are essential to describe problems in a swift way. The 'Navigation' must be set in a flexible manner for the participants to allow a self-determined and flexible perspective on the model. 'Annotations' to indicate change requests and to note remarks on the digital model are provided. The interaction type 'Model Manipulation' is mandatory for this method, which enables the co-creative modification and creation of digital models.

By allocating collaborative methods and interaction types, we defined the minimum set of interaction types needed to support each collaborative method. Each set of interaction type is thereby a minimum configuration of what is necessary to foster the collaborative factory planning.

4. Implementation of a collaborative platform

After showing the correlation between interaction types and collaborative methods, we give an outlook on the implementation of a Collaborative Platform. Specifications concerning requirements for the network and data transmission are highlighted, especially in regard of a distributed collaboration.

The interaction types and collaboration methods can be operated by every user within the VR. If they are used synchronously, a conflict of accessing the objects can occur. A coordinated model access must be guaranteed to avoid competing processes, which could lead to a conflict in the system. The result would be an inconsistency in the model. The coordination has to be implemented on an abstract level, so that every subsystem has a granted access control to avoid competing processes before they arise. This will minimize the chance for inconsistencies within the

models. Additionally, specifications for data transmission and network requirements must be formulated. To facilitate cooperation between two systems, any required and any available product and process data in digital form has to be provided to users. During a synchronous session, changes of model data have to be synchronized and adjusted.

A Collaborative Platform will be built upon VRUI. VRUI is a development toolkit for VR applications written in C++. In comparison to the previously introduced collaborative tools and implementations, VRUI has multiple advantages in regard of manufacturing system design and factory planning tasks. Specific planning jobs can be managed without neglecting other processes in different virtual environments. Another benefit is the abstraction of input devices. A change of display systems is often accompanied with a change of the input device. Most VR applications do not support various input devices since they are written for a certain set of devices. A Collaborative Platform with VRUI, the user can change or implement his input devices to match the respective systems during the different planning phases. The major advantage of collaboration can be seen in the abstraction of distribution which supports the linking of several spatially distributed VR systems [27].

Our introduced approach aims to be functional on three different implementation levels. The initial starting point for the Collaboration Platform consists of two users and their systems, spatially separated, using the same VR application build on VRUI.

On the first level of implementation, both users store the complete data set for the model visualization and interaction on their systems. They are able to work individually with the model, or they can choose to collaborate. In order to guarantee collision-free interaction, only one user at the time has the right to interact with the model. They are in a master-slave relation. One user (master) interacts with the model while the other user (slave) is in follow-mode. In follow-mode a user perceives the environment from the other user's viewpoint, who is interacting with the model at this time.

On the second level of implementation, the users do not need to store the model data on their systems to interact with the model. This level is needed to keep an intended information asymmetry (e.g. to protect expert knowledge for competitive advantages or because of specific compliance regulations). In this case only one user (master) would own the complete model data. If he interacts with the model, only the model changes will be transmitted. The rights of interaction and the processing of interaction stay on his side of the relationship. Different from the first level, the slave will not be forced into a follow-mode. He can navigate through the

environment parallel to the master's interaction. The master can hand over the rights to interact. In this case all the changes will be still processed at the master's system side, and the changed model states can be seen by the slave.

On the third level the option of handling multiple models will be enabled. Every user will be able to interact with its own model and additionally with the model of his collaboration partner. The information asymmetry will still exist. User rights for working on the same model need to be distributed by the Collaboration Platform.

5. Conclusion

This paper focuses on our approach of a distance Collaborative Platform for factory planning using VR. Current collaborative methods and tools cannot take full advantage of immersive systems to support factory planning. The categorization of interaction types and the allocation of collaboration methods are necessary pillars to support a Collaborative Platform. Based on the toolbox of interaction types, we build up three configuration levels for the collaborative platform. They differ through involved interaction capabilities. A use case will be established to illustrate the benefit of different interaction types during factory planning. Therefore a software application will be implemented.

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