# Increasing Customer's Benefit using Virtual Reality (VR) - Technologies in the Design of Ship Outfitting

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**Abstract**

*Successful competition requires an active sales process including the visualisation of potential customer's benefits. Merchant ships need a cost and time efficient ship operation. This is also influenced by an appropriate arrangement of the equipment. A suitable visualisation tool for this purpose is virtual reality (VR). VR allows flexible answers to customer requirements, which can be deployed in an interactive life-size VR simulation together with the customer. Due to extensive data preparation, several adjustments to the VR tool are necessary for efficient use in one-of-a-kind-production like shipbuilding. These adjustments include methods for variants design, based on modular equipment components and the analysis of typical operational scenarios (e.g. maintenance simulation or loading operations). They can be used for the evaluation of the VR-based modifications of the preliminary design. Besides the visualisation of the customers benefits, the usage of VR in the shown context has additional effects on standardisation and modularisation. It also influences the value-added chain significantly by reducing the modification costs: The design process has to be redefined in order to realise the potentials of VR. This new process is shorter and more efficient, which leads to a reduced risk of plan deviations concerning time and budget. Of course not only the customer, but all the involved business partners including the suppliers have to be considered when implementing this new technology and redefining the design process.*

## 1. Introduction

Customer satisfaction is always a major key to a successful competition. Next to building merchant ships cost- and time efficiently, it is at least as important to communicate the company's own competitive advantages and core competences to the customers. This has to be done by presenting appropriate and convincing information as customer's benefits.

The premise to do this successfully is to know the factors which influence the customer satisfaction. Although the sales process in shipbuilding is dominated by the price of a ship, it can also be important to communicate the additional value of the design solution to the customer. The key is to recognize the benefit and to communicate it in the right way to the customer. Also the production costs have to be known and justified. Some examples how to influence customer satisfaction positively are: The ship operation, e.g. cargo loading, can be included in the design phase and optimized to the customers needs. The future equipment and layout of the different ship areas can be presented in a very realistic way before the detailed design phase has started. The customer can be included actively in the production process and his needs and change requests can be addressed quickly and efficiently. All these aspects require a tool which supports this communication and which is able to transport the message in the right way. This tool must be useable for all the involved customer's employees. This explicitly includes people with no technical background at all, but also professional engineers.

As shown in Fig.1, Virtual Reality (VR) is a suitable tool for these purposes. It offers a wide range of capabilities in 3D-visualization and can also be used to interact intuitively with the presented 3D-model. Therefore, it can be used to consider the customers needs in a very flexible way. By using large area screens, it is possible to present the model in full size. Another advantage is the possibility to use the model in an early design stage. Concerning the design process VR allows error detection in design much earlier and easier or even to find them at all. It thereby reduces the failure costs significantly.

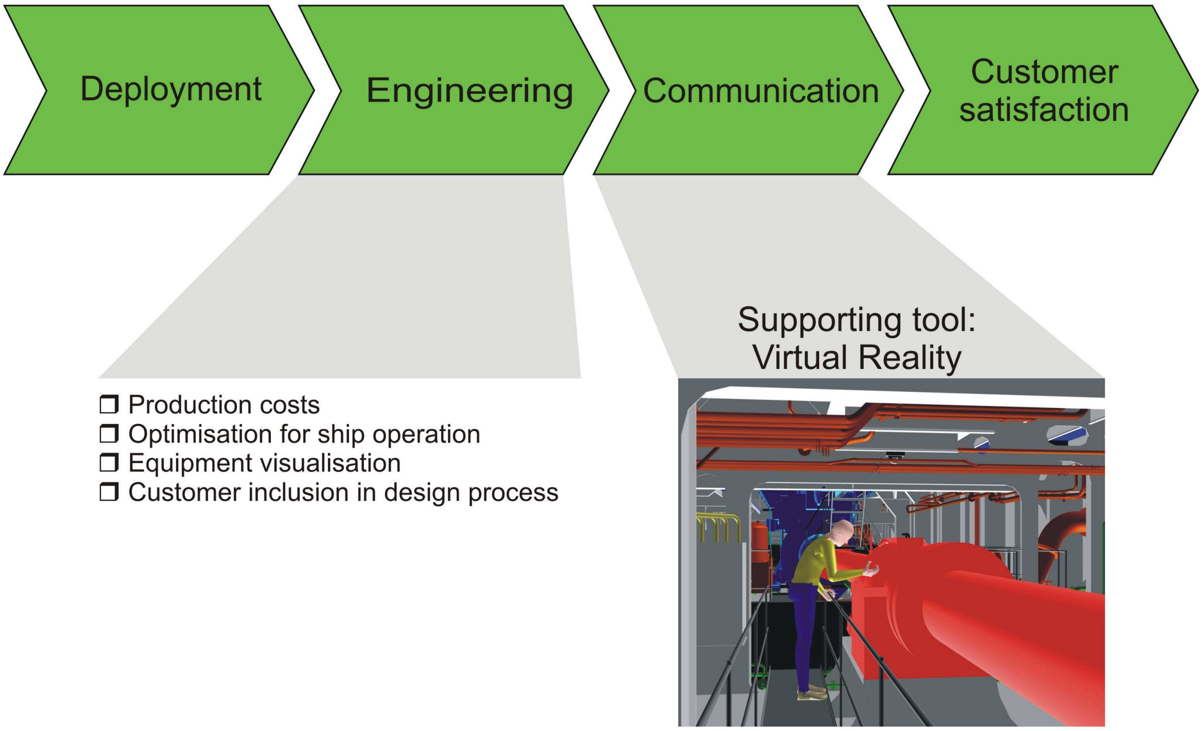


Fig.1: Customer satisfaction in shipbuilding

Typical VR software is not adopted to the special needs of shipbuilding or any other branch of industry. Thus, an extensive data preparation and several adjustments to the VR tool are necessary for efficient use in the typical one-of-a-kind-production. In order to receive an efficient tool, the basic VR nucleus offered by any software vendor has to be adopted to the special parameters of the shipbuilding branch: At first basic conditions of shipbuilding, e.g. requirements of the customer and the suppliers, have to be taken into account. Secondly the existing processes of the design phase have to be redesigned to take advantage of the new functionality of VR. After that interaction modules need to be defined to support this new process and thirdly the lack of support for variants design in VR has to be eliminated.

## 2. Basic Conditions of Shipbuilding

Taking the shown parameters and restrictions into account, the section Production Technology I of the Hamburg University of Technology (TUHH) first analysed the different operational scenarios of the VR-tools and also the general constraints of the value-added chain (customer – shipyard – supplier) in the maritime industry. The so called typological characteristics of the enterprise have to be considered for the development of the VR concept. In fact, the shipbuilding branch has to cope with significantly different aspects compared to VR users in other industries (in terms of an “every-day-tool”), such as automotive and aircraft industry shown in Fig.2. The one-of-a-kind-production is in influenced by the customer in various manners. Because of his special requirements, the shipyard has to react very flexible and offer a distinct change service. Another competitive factor in shipbuilding is the production time between inquiry and delivery, which is constantly getting shorter. This tends to result in an decreasing production time, which in turn means that the design phase has to be shortened steadily. These two characteristics, batch size and development time, give a severe input to the realisation of a VR solution.

Another aspect adresses the mode of cooperation (and innovation) between shipyard and supplier, *Nedeß et. al. (2002)*. The innovations of the supplier must also be demonstrated to the customer. Because of that, the VR concept has to include the possible input of data from the supplier.

| | Automotive Engineering | Aircraft Construction | Shipbuilding |
|---|---|---|---|
| **Production character** | Large-volume | Serial | One-of-a-kind |
| **Design process** | Low customer inclusion | Average customer inclusion | Very intensive customer inclusion |
| **Vertical range of manufacture** | 25 - 40% | 40 - 50% | 25 - 30% |
| **Design phase** | 3 - 5 years | 6 - 8 years | 0,5 - 3 years |

Fig.2: Basic conditions in different branches of industry

From the view of the shipyard as the user of VR technology this leads to external constraints, concerning both the customer / shipowner and the suppliers, Fig.3, which have to be taken into account for all operational scenarios described later. The most important parameter for the customer is the price of the ship. This factor usually dominates all the other decision criteria. During the design phase, the customer often wants to place further changes of the concept. This also means that the customer must have (at least temporary) access to the current design status. These change requests are usually placed with very short or even without any preliminary lead time. Accordingly, the planning tools have to support clear presentations and modifications of the current design status very quickly. This aspect is getting even more important when assuming a non-engineering-background of the customer's employees.

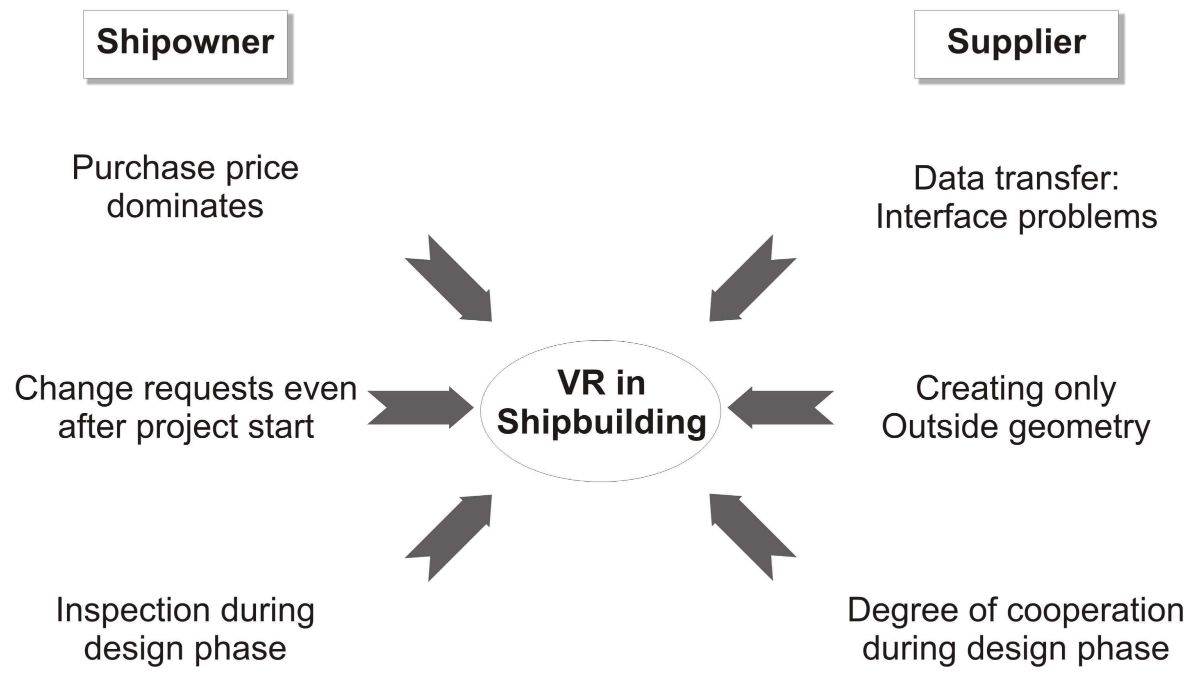


Fig.3: Influence of ship owner and supplier

German shipyards reduced their vertical range of manufacture to approximately 1/3 - with a decreasing tendency. The shipyard itself has become more and more a system integrator. This means that the suppliers play a very important role in the production process and have therefore to be taken into account when creating a concept with VR-technologies. The more intense the cooperation between the shipyard and the supplier turns out, the more problems concerning the IT-integration have to be solved. All the drawings must be converted without loss of information. When providing the drawings to the shipyard, the supplier wants to protect the know how. Thus, not the whole 3D-model, but just the outside geometry, has to be transferred. This approach has one advantage: When thinking of the main engine, the 3D-model usually has several gigabytes of data which also causes a significant render load. On the other hand, the shipyard usually has no interest in a fully modelled main engine, but just the main proportions and the installation data. The aspect of transferring 3D-CAD-data between two different systems is also a very time consuming problem, but will not be addressed in this article.

## 3. Operational Scenarios

The precise configuration of the VR support depends on the designated applications. For these purposes three general operational scenarios were defined, which build the basis for VR in the production phase from the user's point of view, Fig.4:

**Layout Modifications**

- ❒ Extended design review
- ❒ Modifications in immersive environment
- ❒ CAVE or powerwall

**Maintenance**

- ❒ Preparation at workstation
- ❒ Review and optimisation in CAVE
- ❒ Parameters: Accessibility, handling, ...

**Loading Operations**

- ❒ Standard goods: No VR
- ❒ Project and heavy lift cargo: Simulation with VR
- ❒ Optimisation and variants
- ❒ Linkage to weight distribution and deck load

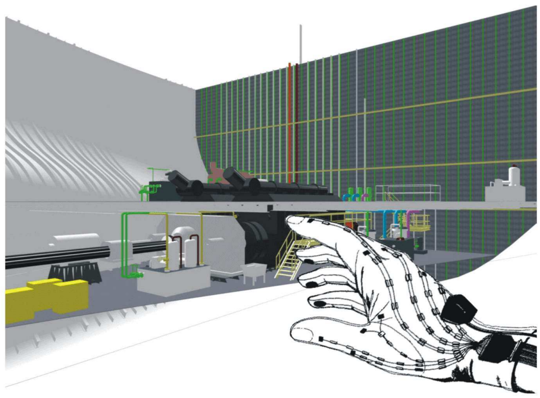

Fig.4: Operational scenarios

### 3.1 Layout Modifications

This operational scenario can also be described as an extended design review: Besides the possibility to review the model and discuss areas of interest with the team, more tools were developed to interact with the model intuitively. The typical analysis, as

- checking of compliance of free space areas,
- safety margins or
- checking the correct realisation of pipe diagrams,

can now be accomplished by the VR-user and not by a VR-expert operating in the background at a workstation. Of course, bigger modifications cannot be solved in an immersive environment and therefore still have to be addressed in 3D-CAD at the computer. But minor modifications or simple annotations can be carried out immersively by using appropriate interaction devices, like a data glove or a flystick combined with a 3D-toolbox. The functionality of these devices were adopted to the typical needs of the user to make it a feasible tool (detailed in Ch.5). Technically the ideal hardware for these types of analysis is either a CAVE (Cave Automated Virtual Environment, © Fakespace Systems) or a powerwall. A CAVE is a multiscreen environment with typically 2,5 x 2,5 m² per projection side. It can consist of only 2 sides (front and floor) or can be scaled up to 6 sides. For technical analysis, the 2-side-option, as also installed at the VR-Center of the TUHH, is fully sufficient. The powerwall has a lower degree of immersion compared to the CAVE, but offers up to 50 people to join the presentation, depending on the size of the single screen. Usually a single front projection is used here with 7,5x2,5 m².

**3.2 Maintenance**

As simple free space geometries are not always sufficient for a design which is also assembly compatible and optimised for ship operation, further simulations have to be undertaken: With the animation of certain assembly or ship operation tasks (e.g. maintenance of pistons or loading operations of special goods), it is possible to find out deficient design and to optimise these processes at early design phase. Also special tools can be modelled in 3D and used in combination with virtual humans to simulate maintenance operations, e.g. as described in *Burdea and Coiffet (2003)*. One can also include ergonomic aspects in these situations.

The following parameters are only some examples which can be optimised within this scenario:

- accessibility,
- handling,
- maintenance,
- optimal assembly order or
- required space for all kinds of operations.

The scenario will always be prepared at a workstation and afterwards be reviewed in an immersive surrounding, because the programming of animations with immersive devices would not be efficient. The main tasks, like visual inspection of variants and optimisation should be done in a CAVE with the involved engineering team.

**3.3 Loading Operations**

Loading operations can be separated in mainly two different categories: First, there are standard goods like containers and secondly project and heavy lift cargo. The simulation of loading operations with standard goods in an immersive environment will usually not be necessary. If it should still appear useful, placeholder geometries could be used for this purpose, because the effort for creating a realistic 3D-modell would most probably not pay off. When looking at the second category, the use of VR-technology offers a great benefit: The simulation can be used to optimise the complete loading operation and any conceivable loading variant can be observed. This includes the use of cranes, utilities and even fixing material (e.g. lashing). It is also possible to analyse, if the captain's view from the bridge is being blocked by the cargo. In future developments the VR-simulation should be linked to other software which can calculate weight distribution and deck load, because VR itself cannot generate this data.

The pre-condition for these visualisations are the 3D-CAD-models. It is absolutely necessary that the sender of cargo makes this information available to the shipowner, who in turn has to combine this with his own ship models and then create the simulation. In order to limit the scope of the further examinations, the focus will be the naval outfitting and the design phase. Both phases account for a major part of the added value. Errors in these areas can have a heavy influence on the whole project.

**4. Design Process**

In order to achieve an early integration of the customer the described operational scenarios require a modification of the design process. In Fig.5, a simplified design process is shown, which is based on the usage of 3D-CAD, but not yet VR. After the project has started, the design phase begins with the rough engine room layout: The shown approach is characterised by the workshop-principle: An interdisciplinary team, consisting of engineers, foremen, assemblers and machine operators, is designing the layout of the main aggregates in the engine room. Thereby, the final concept will be accepted by all involved departments. Afterwards the details will be designed by the according engineers.

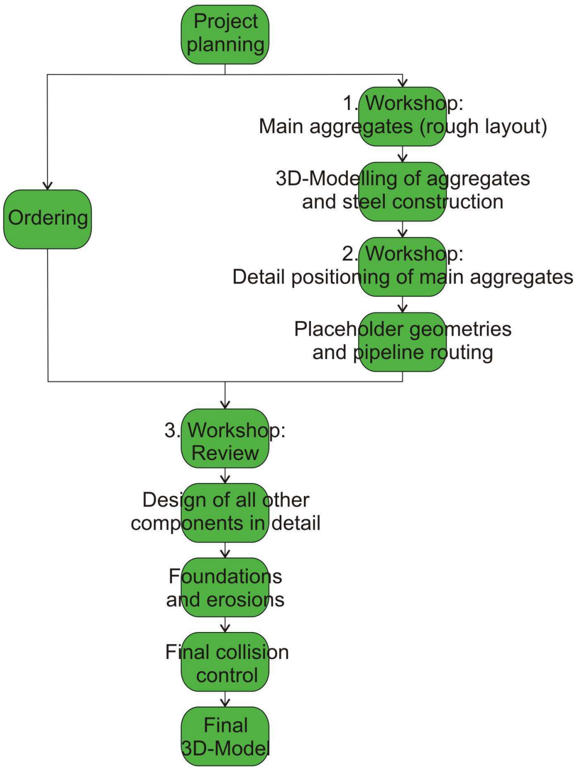


Fig.5: Design process without VR-usage

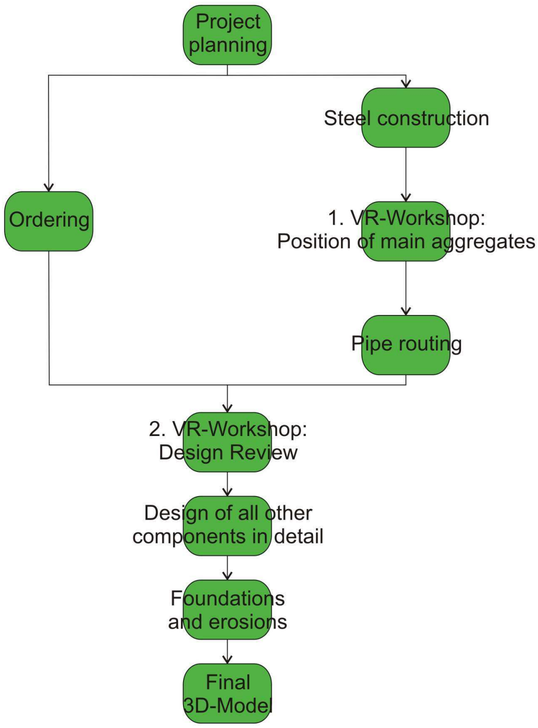


Fig.6: Design process with VR-usage

Concerning the workshops, there are strong deficits in interaction and visualisation. The whole process can be shortened by using VR-technologies. In order to implement these tools holistically, it is necessary to create a new process and not only some selective modifications. Another target is to integrate the customer more often and earlier, which also has to be taken into account.

The proposal for a new design process can also be found in Fig.5. Now the number of workshops is reduced due to an interactive design review using VR. Afterwards the process is supported by VR constantly. Whenever problems appear, they can be analysed in the immersive environment and also be solved to a certain extend. This requires the possibility to use the tool without a delay, e.g. for conversion of 3D-CAD-data. It also results in the necessity to transfer back the modifications which were made in VR to the CAD-system. This requires a basic analysis of the different types of data which are affected.

## 5. Variant Design

How can this modified process be realized? The optimisation of data-flows and –formats as described in *von Lukas et al. (2004),* is certainly a necessity, but not sufficient for VR-usage in shipbuilding. The key to fully realise all the capabilities of VR are the VR-applications in shipbuilding. That means the more important requirement is the integration of the customer into the decision making process, e.g. the discussion of alternative design solutions or the quick realisation of modifications during the VR session, especially in an immersive environment, Fig.7.

To avoid time consuming data conversion during the VR session following the possible modifications made in the CAD system, different variants must be addressable in VR and (with restrictions) able to be modified. The solution of this problem is a design process dominated by building the model based on standard parts from a library and only a minority of parts modelled from the scratch. Also change request from the customer require the possibility to realise variants rapidly.

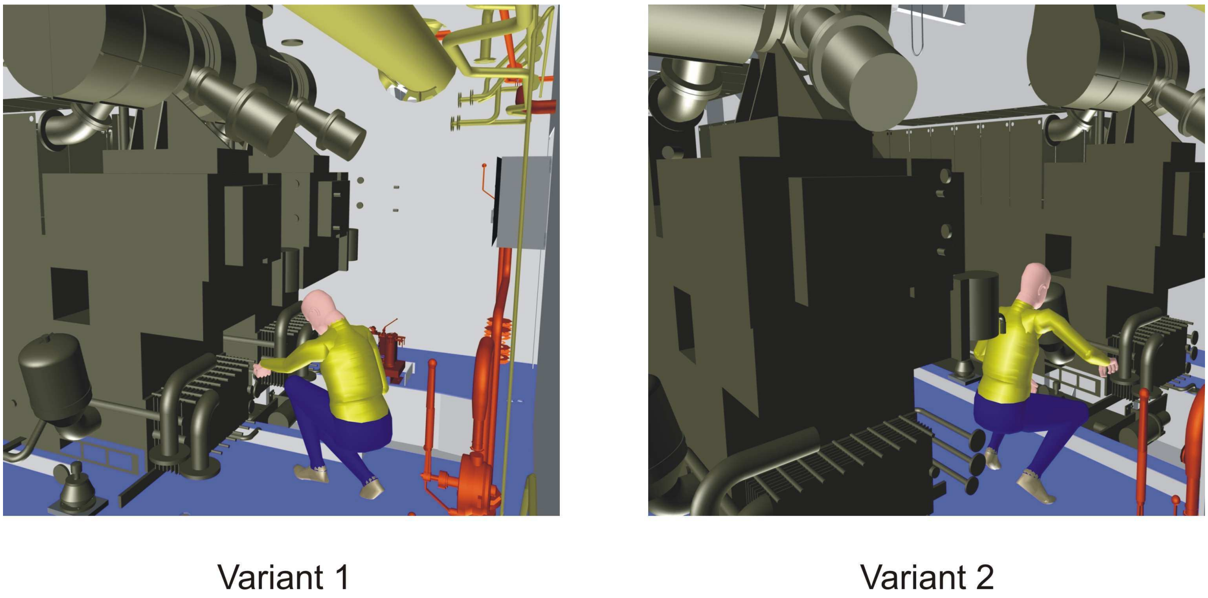


Fig.7: Variants design: Maintenance of auxiliary engine

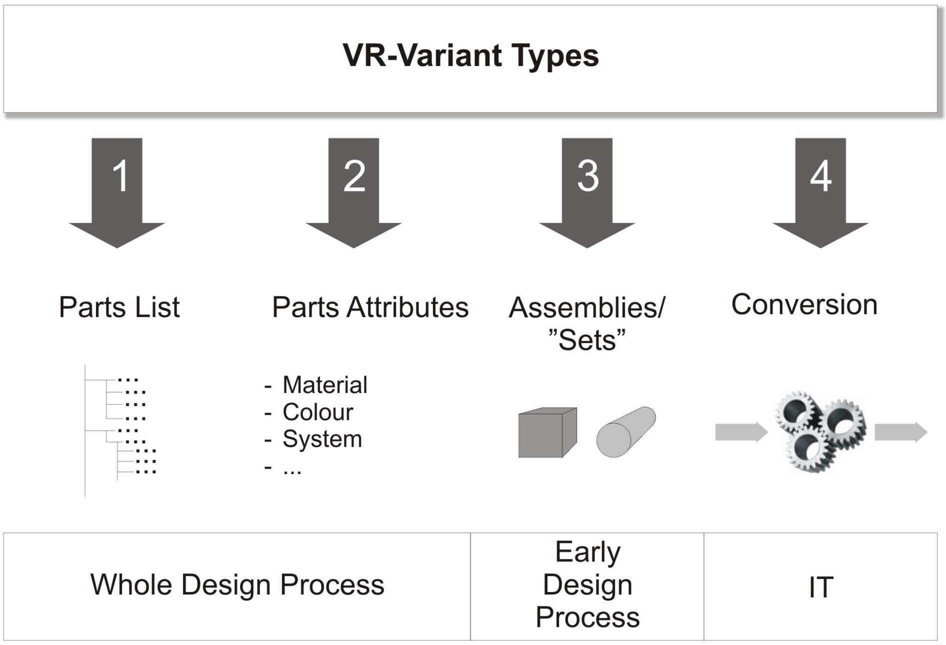


Fig.8: VR-variant types

Variant design does not only consist of the possibility to add new parts to a 3D-model, but also to change certain attributes and parameters of the parts. When analysing the relevant variant types it is necessary to consider the typical IT-environment where VR should be used efficiently. These aspects lead to the following variant types, Fig.8, for the specific data model:

(1) Variation of the parts list
This means that parts must be added, removed or changed in position and orientation within the model. In shipbuilding this feature is mainly used in the early design phase and is based on standard parts.

(2) Variation of part attributes

These attributes can be: Material, colour or the system to which the part belongs.

(3) Alternative assemblies
As already described in Ch.3.2 this feature has to be supported by the VR-system.

(4) Conversion of the 3D-CAD-data
The conversion itself is not a typical shipbuilding problem but a pure technical one. Still it has to be taken into account, because it is not acceptable to wait for a part to be converted while users are in a VR session. Depending on the amount of data a certain part occupies, the conversion time can last very long.

The variant types are not the only aspects, which were taken into account when defining the data model for the integration of VR in a typical IT-environment. Another factor are the data types which were derived from the operational scenarios and the interaction modules. The most important data types are:

**3D-Geometries**
The basis of every 3D-model is the geometry information, which also includes the connecting hierarchy. Two different types of geometry have to be distinguished: The fully modelled geometries and the assemblies or parts from suppliers which usually only consist of the outside surface, e.g. main engine. The hierarchy is not a generic one, but is oriented to PROFI ("Produktionsfortschritts-orientiertes Referenz-Informationsmodell") as described in *Nedeß and Kersten (2002)* and is therefore optimised for shipbuilding. To every part, a corresponding colour has to be defined, which in shipbuilding usually represents the system to which the part belongs. For engineering purposes these colour codes should be used in the VR-system without change. All these data types have to be extracted from the PDM-system (Product Data Management-system), where this kind of information is typically stored.

**VR-Relevant Information**
Viewpoints are absolutely necessary to mark areas of interest. Due to the fact that the models in shipbuilding are typically very complex, viewpoints are an important functionality for the user not to loose orientation. They play a major role especially in the first and second VR-workshop to support the design reviews. The animation and simulation data also belong to this data group, which is responsible e.g. for assembly simulations or loading operations. This also includes ergonomic aspects with a virtual human model, for example when analysing the field-of-view or reachability during certain tasks. Parallel to the whole design process, but especially during the detail design phase, after the VR-workshops, this information is needed to optimise the ship for special customer needs.

**Documentation Data**
This kind of information can be separated in part specific information and system specific data. The former can be installation information for an aggregate and the latter could be a pipe routing plan or electricity layout, which are relevant for the whole model, e.g. the entire ship. Documentation has a basic character and has to be updated constantly, but especially when using VR with the team, the results of the discussions have to be added to the model. Therefore, this data will mainly be generated within the VR-workshops.

**Part Database**
New parts are added to the model even in the immersive environment to allow variant design. These parts have to be stored in a corresponding part database, consisting of the geometry already converted to the VR-data format. The database contains not only the parts and assemblies for designing the ship itself, but also geometry which is necessary for VR-analysis. This can be geometry representing free spaces or utilities for maintenance simulations. The analysis of different variants will typically be done by an interdisciplinary team. This could be the regular VR-workshop, but also a meeting to analyse a special problem which occurs during the detailed design phase.

With these variant- and data-types, the data model was developed which (1) integrates VR in a typical IT-environment by connecting the major software systems (PDM-shipyard, PDM-supplier and VR) and (2) makes variants design in VR possible. This model can be found in *Nedeß et al. Kerse (2005)*.

## 6. Interaction Modules

The operational scenarios, in which customer and engineer work together, need a technical basis which enables the user to carry out these scenarios. This basis consists of the interaction functions, which in turn are grouped in interaction modules. All these functions were designed for immersive usage. The functionality which will be described is usually not available in the standard VR software solutions, but can be added by using the respective API (application programming interface) or other programming capabilities of the VR software. The modules, which are going to be developed in the next future, do not only contain the technical basis, but also provide a set of predefined standard items which are needed in shipbuilding repeatedly. The user therefore can setup his VR-models much faster by mainly using these predefined items instead of always building the model from scratch.

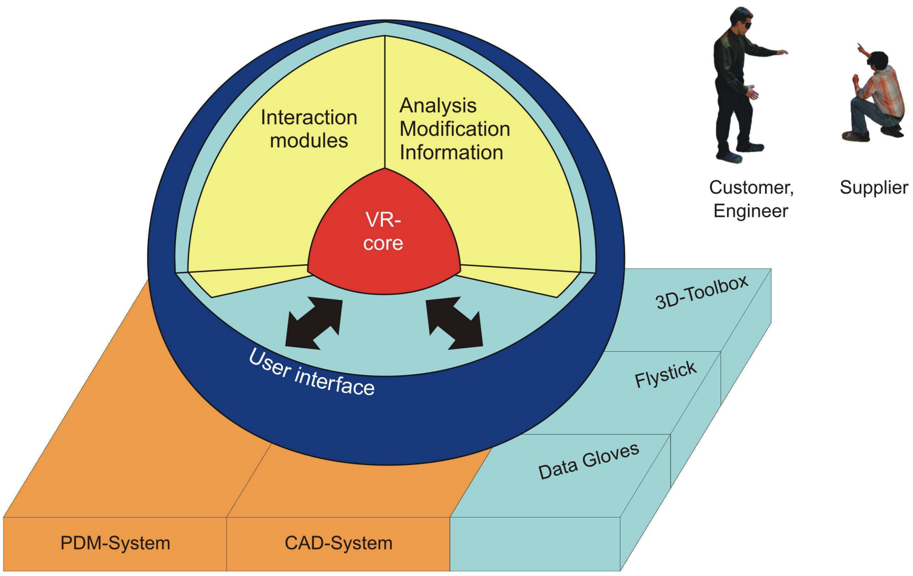


Fig. 9: Interaction modules

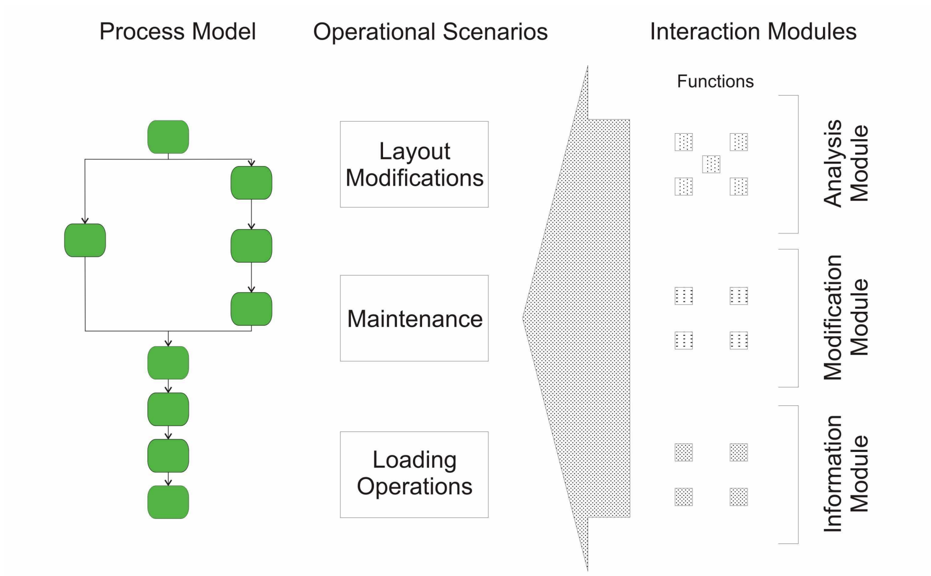


Fig.10: Linkage between process model, operational scenarios and interaction modules

As shown in Fig.9 the modules are technically based on the VR core (the VR software) and are grouped in analysis, modification, and information modules. In combination with data from the PDM system and the CAD system, the user can interact with the model by using immersive input devices. The analysis module is providing basic functionality, e.g. distance measurement, sections, animations or collisions analysis. In order to make efficient modifications, the according module offers immersive access to part databases which is also an important premise for variants design. The information module is necessary to add all kinds of documentation to specific parts or the whole model. Fig.10 shows the linkage between the new process model, the operational scenarios and the interaction modules.

## 7. Summary and Outlook

An active sales process requires the shipyard to know about the parameters influencing customer satisfaction and to communicate the benefit with a suitable tool. This tool can be VR, which has to be adopted to the specific needs of the shipbuilding branch, as it is a highly functional tool, but not specialised. The adoption does not only affect the VR tool itself, but also the environment in which it is used: The design process had to be redesigned where it is mainly used. In order to generate the most benefit from the tool, operational scenarios were developed and as the necessary technical basis, the interaction modules. The last important component of a holistic VR application is the support for variants design, which plays a major role in the design process in shipbuilding.

In the future the operational scenarios and the interaction modules have to be detailed and extended. The key to a successful VR installation is not only the data conversion between different formats, but the adoption to the user, the applications and the parameters of the shipbuilding branch. Also the data model which integrates VR software in the typical IT environment has to be detailed in the future.

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