Rapid One-of-a-Kind Project Planning Suite

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Abstract

To enable access to advanced technologies allowing rapid and sufficiently detailed one-of-a-kind project planning in the early project stage an affordable software suite has been developed. Product- and process-related data are directly derived by reconstruction of 3D models from point-clouds and using requirement engineering techniques based on advanced text analysis. Full-scale project scheduling and cost estimation is supported, including optimisation and 4D-animation targeting configurable goals (e.g. shortest time, best utilization, and minimized cost). An underlying data management system allows integration of generated data to an integrated simulation component to identify bottlenecks and minimise production risk, including what-if analysis.

1. Introduction and Background

In shipbuilding and offshore projects, which are characterised by their one-of-a-kind, made to custom order nature, reliable forecasts of project duration and estimation of costs at the bidding or early project planning stages prove to be a difficult trade-off between precision and effort. Since deadlines are typically very tight, it is not possible to achieve high precision within reasonable time unless a broad and well-maintained empirical data collection can be utilized. At the same time there are very limited possibilities to apply repetitive manufacturing principles for built-to-order products, since historical/empirical data does either not exist or is only of limited value and cannot be applied easily without major adaptation effort.

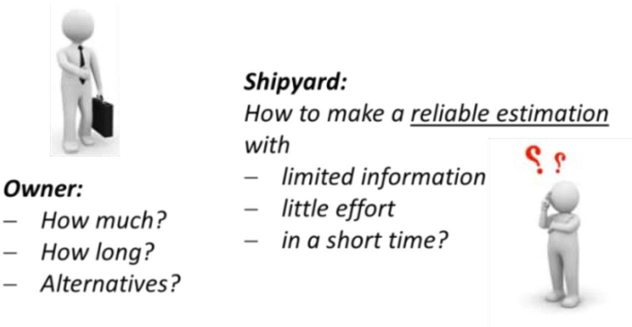

Fig.1: Inquiry scenario

Fig.1 illustrates the typical request-for-quotation situation in the shipbuilding industry, where the owner/customer provides only limited information of widely varying level of detail and scope (such as general arrangement drawings or textual specifications) to a shipyard to inquire the delivery dates and cost to build, retrofit or repair a vessel. For a shipyard or designer to provide a workable proposal is a demanding task. Considering several fundamental alternatives in more detail will result in a substantial effort for analysis, system engineering, estimation and planning. As a consequence, due to the lack of tailored tools to be applied in the maritime industry, shipyards commonly do "quick" estimations using empirically assessed or derived design solutions, schedule and cost, including appropriate empirical buffers during the negotiation and early design stages. In most cases there is insufficient time to investigate alternatives, as ship operators expect a quick response to minimize either time till service availability of the new vessel or disruptions of existing vessel operation in retrofitting or repair scenarios.

In consequence, the current common approach easily results in over- or under-estimated costs and/or durations and unmitigated risks. Since shipyards are nevertheless trying to manage potential risks (e.g. unplanned delays, unforeseen cost and technical or logistical problems) overestimated buffers can therefore result in losing the bid. On the other hand, in case costs and durations are underestimated, the project may be quickly in acute danger of becoming an economical failure due to delays, cost overruns and problems in fulfilling the specifications. Finally, although the common approach to planning provides only rough estimations, the effort for doing this can still be very high and thus costly, since up to 40% of the time may be spent on searching for information for documents and reports to be provided to the owner – which are mainly created manually, *Morais (2019)*. In summary, there is a considerable potential in saving by pushing forward the digital transformation in the bidding and early design and planning stages.

2. Improving Early Production Planning

In this paper an approach is described which has been developed during the SHIPLYS project resulting in a toolset named PPT (Production Planning Tool[kit]), *Bharadwadj (2017)*.
PPT represents a tool suite combining several technologies as shown in Fig.2 allowing **reliable estimation** of cost and schedule within short time by developing and using digital twin data during the early bidding project stage.

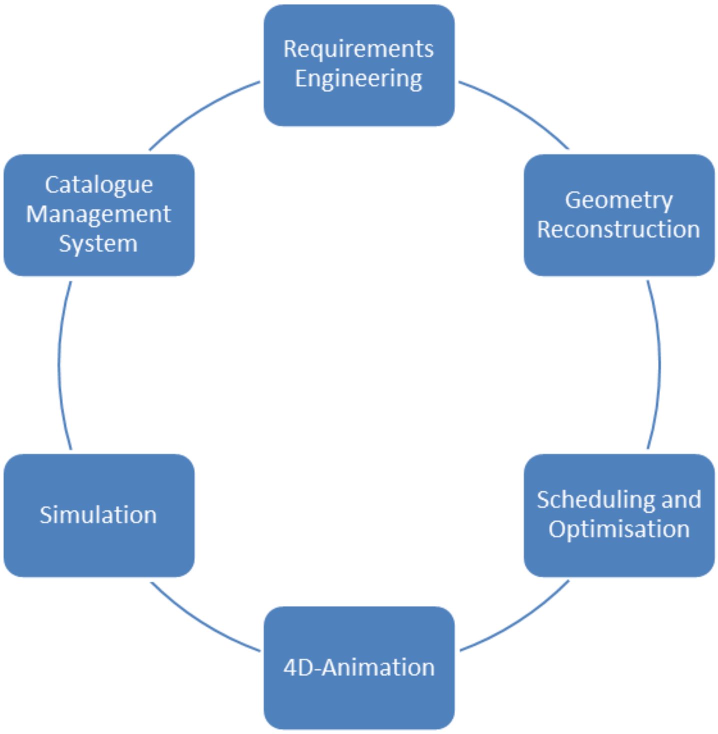

Fig.2: Technology Collection in PPT

Furthermore, cost and project duration can be reduced using the included optimisation functionality and various alternatives can be analysed to assist in preparation of more competitive offers.

The technologies applied have different grades of novelty. For instance, geometry reconstruction based on scan data represents a relatively new technology still undergoing development helping to rapidly create a digital twin in the shape of a 3D product model of the vessel itself. A method such as discrete event simulation (DES, *Banks (2013)*), which essentially provides and utilizes a digital twin of the production area (e.g. simulation model of the whole shipyard), are today used for daily business applications in other industries (e.g. automotive industry) where repetitive manufacturing principles can be applied. In shipbuilding only a few shipyards have started to use production simulation in limited ways to manage complex systems and related risks. However, it is commonly used only periodically to support investment decisions concerning new or refurbished, more advanced machinery or in order to improve the production flow. In particular, the effort of data acquisition and preparation for feeding into simulation model is considered as a major obstacle for everyday use. As a result, effective data acquisition and generation is a key factor in making simulation a feasible tool.

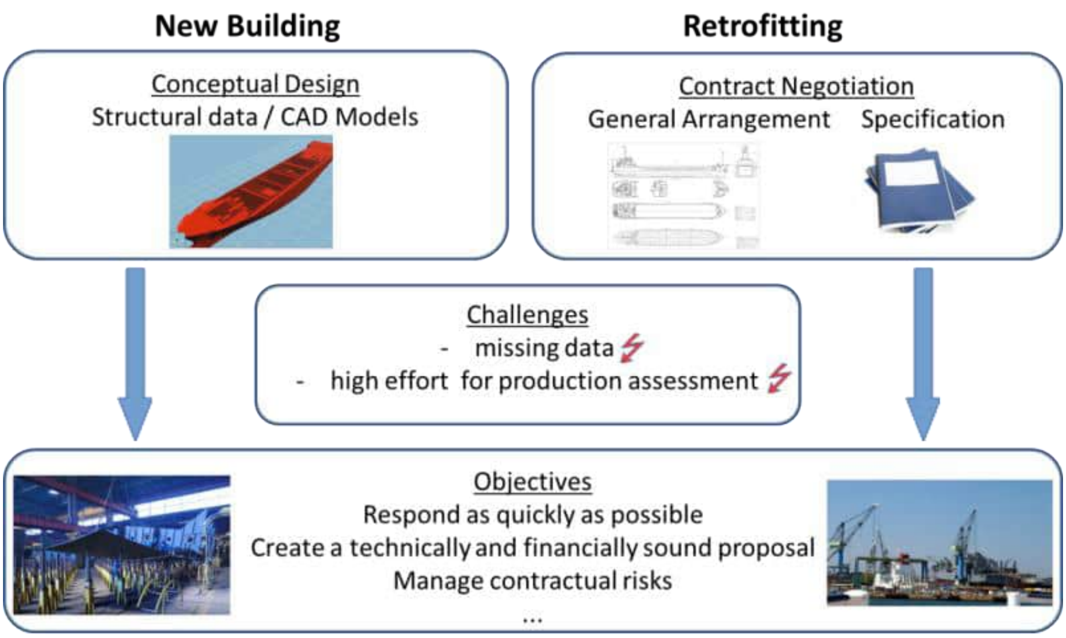

Fig.3: Newbuilding vs. Retrofitting

Since PPT has been built from a collection of specialized components, it has been an essential fundamental design decision to link all the relevant technologies tightly together ensuring fast and effortless data interchange by means of a rich and extendable data model implementation which has been developed and used over many years in shipbuilding industry applications.

The data model supports all stages of project execution and is as part of a commercially available data management platform, *AES (2018)*.

Furthermore, integrated rapid data generation functionality is another key factor allowing overcoming the mentioned hurdle and to perform optimization and to use the applied simulation technology at the very early planning stage. Tests in the industrial environment at shipyards during the SHIPLYS project have shown that the provided solution addresses these key issues as reported by end-users.

While newbuilding projects regularly allow for some more extended planning phase, repair or retrofitting scenarios will often be even more demanding since only a – possibly sketchy – specification containing task or problem descriptions is provided by the owner/operator and therefore shipyards need to estimate overall project duration and costs very rapidly. Fig.3 shows the similarities and differences between newbuilding and repair/retrofitting cases.

3. Technologies provided by PPT

PPT tools follow a unified approach for both new-building and retrofitting applications allowing to rapidly produce more reliable predictions regarding the overall project duration and costs during the early bidding stage in the shipbuilding industry resulting in more competitive offers while mitigating risks at the same time.

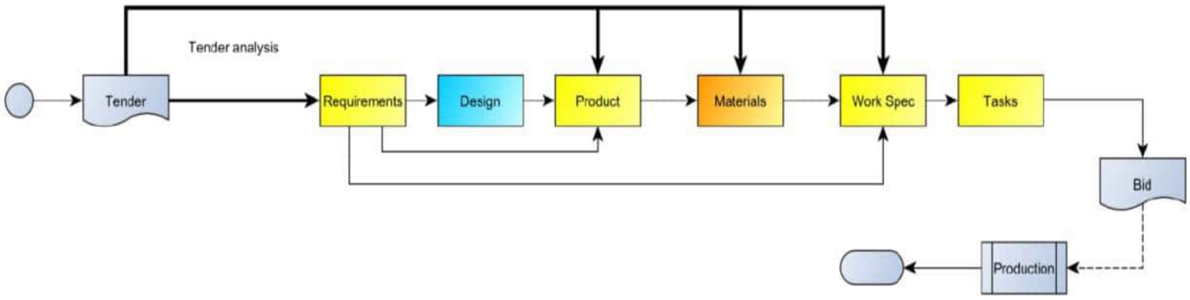

Fig.4: Unified Workflow

Fig.4 shows the general unified workflow beginning with a tender document provided by the owner/operator. Depending on the actual type and details of project (newbuilding, retrofitting or repair), some stages shown may be optional. The different stages are supported by the technologies provided by PPT whose interaction is ensured by appropriate data model presented as next. For development of the functional set the identification of similarities and differences between the different use cases was an important step to define a powerful combination of capabilities.

3.1. Data Management System

Planning and scheduling tools used in one-of-kind, on-demand projects in of today use have often quite limited capabilities to interact with engineering data. Therefore, a considerable effort is required to provide linkage between engineering data and planning. During early project stages such linkage is reduced to general estimates due to the lack of detailed information.

To facilitate advanced data integration and management features for the maritime industry, a rich extendable Business Data Model has been developed for many years covering most aspects of maritime industry requirements. It is based on various ISO standards and other industry standards (such as: ISO 10303-215, -216, -218, -227, ISO 15384, WfMC, X500) but extends beyond their scope and contains hundreds of different entity types considering e.g. product data (ship), production environment (shipyard) as well as tasks, supplies and organizational aspects, Fig.5.

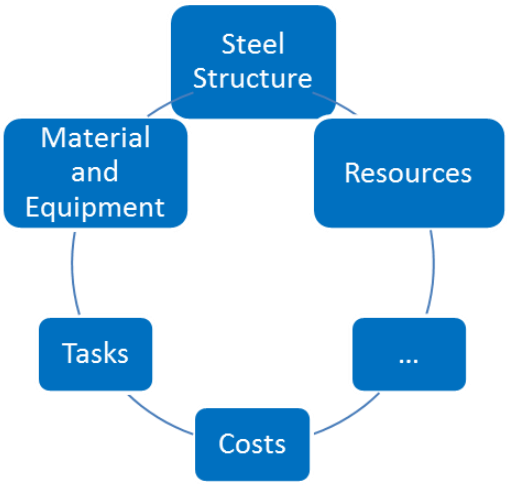

Fig.5: Data Model Scope

Furthermore, design related data can be versioned which helps bridging the gap to commonly used CAD systems lacking this capability while maintaining a history of changes. The related server infrastructure allows managing the information based on this data model and furthermore simplifies connecting to the existing system landscape of a shipyard by means of so-called adapters enabling to rapidly retrieve and receive any amount of data from different applications such as ERP- and/or CAD-systems etc.

In this way all required input data as well as the output data generated by PPT (described below) can be managed and interchanged with the existing systems.

3.2. Requirements Engineering

Requirements engineering is a well-established methodology originally evolving from very large scale projects in space technology, aircraft development and, to some extent, large scale information technology development projects. The benefit of using such systems is to register, monitor and evaluate requirements, thus being able to verify compliance and fulfilment. Unfortunately, due to the complexity and cost of introducing and using this technology, its application in shipbuilding has been quite limited to areas like large-scale offshore projects or in the defence industry. For commercial shipbuilding there exist at least the following obstacles:

- Cost of tools: requirements engineering tools are found in a high priced range both in licensing and operating cost
- Ease of use: while large-scale projects can accommodate the personnel effort to operate these systems, this seems prohibitive for most shipbuilding operations and in particular SMEs. This is related to the aspect that the level of detail and documentation is considered too high for smaller business types.

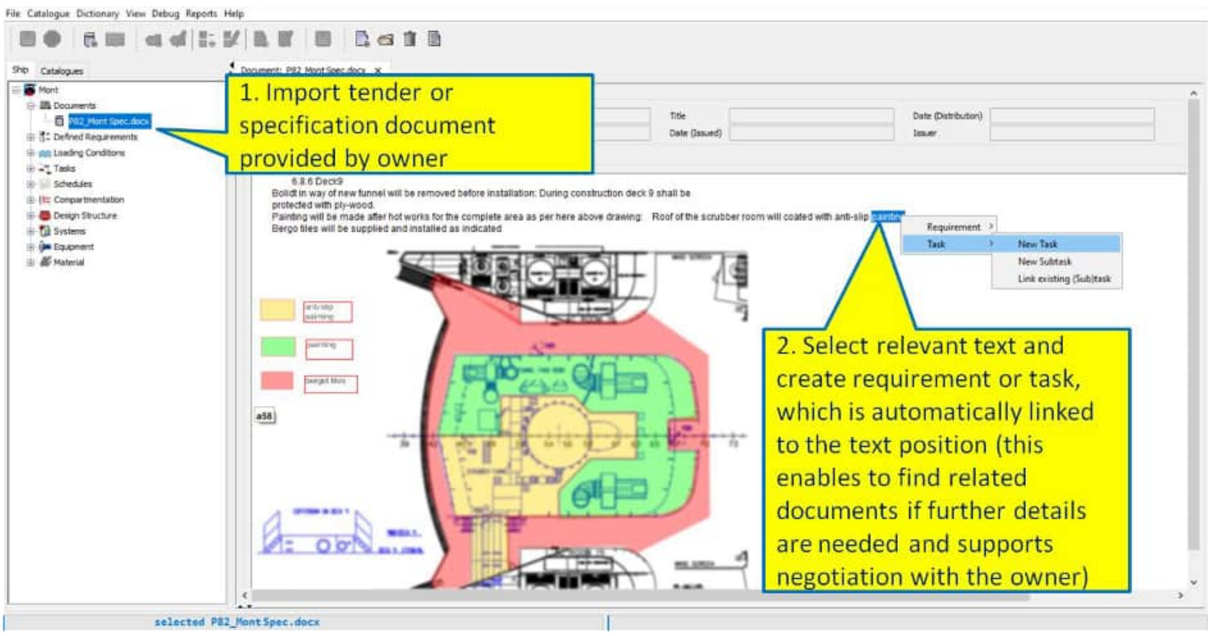

Fig.6: Requirement and Task identification

For PPT, two prototype editors have been developed and tested which are based on the combination of text analysis features with engineering-oriented classification of product components, tasks and design goals, to enable planners and engineers to quickly process technical specification documents while deriving a concrete data representation suitable for engineering analysis, schedule derivation etc. It is deliberately not intended to provide a fully automated process, since many decisions need to be made by creatively acting users during the planning and early design process steps. Nevertheless, this data substantially helps during data generation in the steps to follow, such as schedule derivation and cost estimation as well as during later steps for quality control and project validation. The editor components have been integrated into the PPT tool suite with the specific intention to be used in the early stages of the project execution. Tender or specification documents are used as input since these kinds of documents are typically provided by the vessel owner/operator as shown in Fig.6.

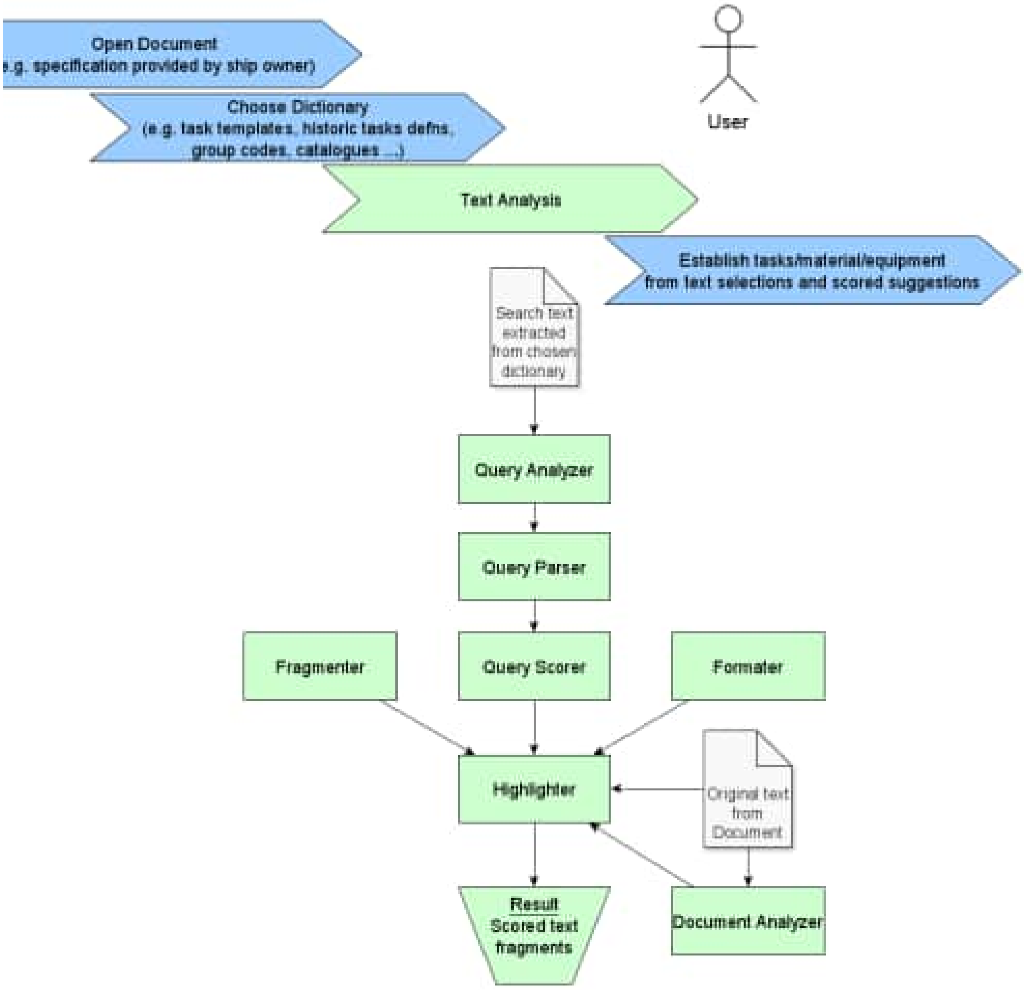

Fig.7: Text Analysis for RE

Documents are imported and requirements defined/identified, automatically linking them to the relevant text positions and submitting them to a text analysis engine, *McCandless (2010)*, with the aim of supporting the user in identifying the relevant statements and definitions in the document. Furthermore, scoring algorithms are applied to match the text portions against various dictionaries. The complete flow of text processing is shown in Fig.7. This concept is not intended to fully automate the process but to assist the users in their activities for extracting the relevant information to create requirement definitions and task descriptions.

Once the requirements are created, they are represented in machine-process-able format and can be used to evaluate the evolving design in respect to fulfilling the requirements. Wherever feasible, tasks descriptions can be directly derived, which is especially useful and relevant for the repair/ retrofitting cases, where tenders are often based on short specifications of work items or issues to be resolved.

To progress efficiently with the definition of requirements and tasks, PPT provides a catalogue management system to store general data such as material and equipment items, standards like SFI grouping codes or task templates, Fig.8. This predefined, but fully configurable information can be easily applied for a specific project and revised when required and constitutes an important feature for enhancing the task and schedule information based on engineering details. It also has the effect of normalizing data in such a way that duplications and deviations from yard standard practice are minimized. Since these catalogues will be configured for individual shipyards based on their organisation and work standards, it will also substantially simplify the validation of requirements and tasks against the individual shipyard standards.

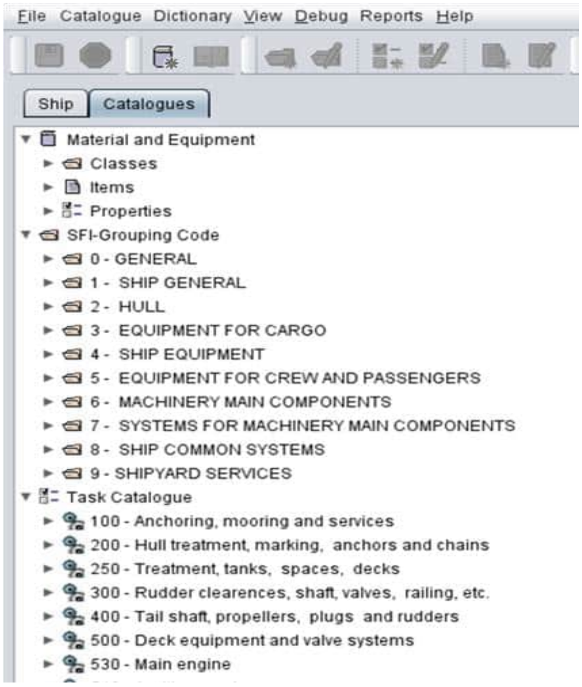

Fig.8: Catalogue

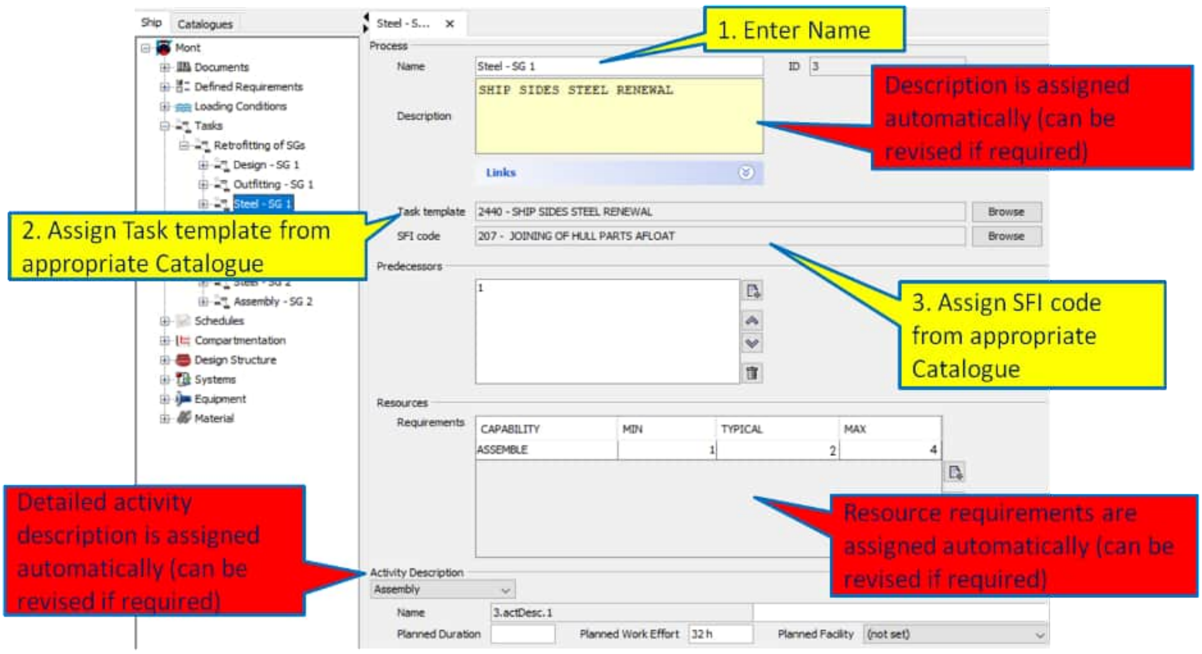

Fig.9: Rapid Task definition

Fig.9 shows how the functions for requirement and task definition can be applied using the definition of a task as example. Furthermore, equipment and material information can be identified or extracted in a similar fashion to define them ad hoc using the mentioned catalogue management system.

3.3. Geometry Reconstruction

This topic is particularly relevant in retrofitting and repair scenarios. Vessels that have been operating for years are no longer in the same shape as when they were originally designed or built. Numerous modifications have usually been applied to the vessel since its initial delivery. Therefore, reliable CAD model information representing the actual on board situation is lacking (often due to IP right restrictions of the original builder or non-existence of such a model).

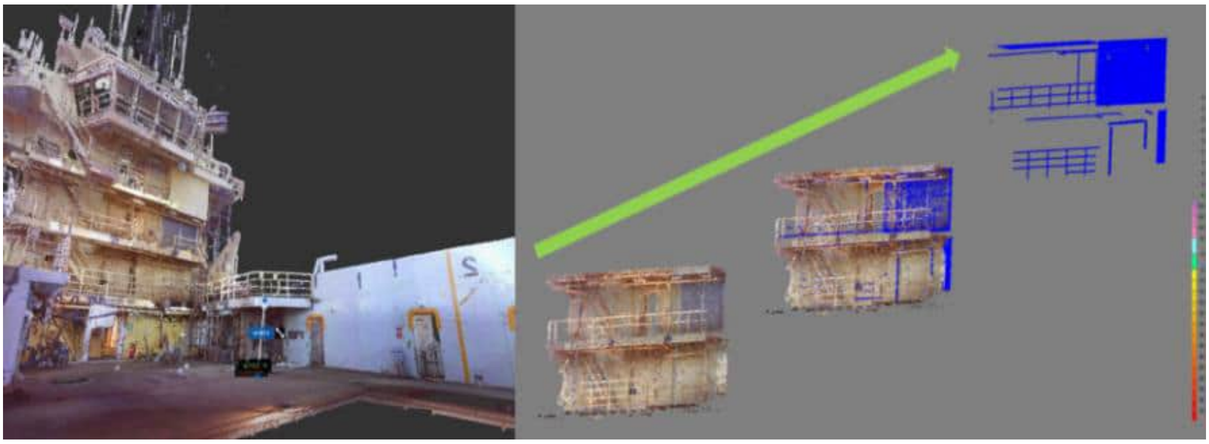

Fig.10: Geometry Reconstruction

This situation forces shipyards regularly to assess the actual situation on board a vessel with a lot of effort. Unfortunately, until today such investigations do not provide an attributed geometry model of the as-is-state of the vessel, but rather a compilation of photographs, measurements, sketches and, to a growing degree, photogrammetry or point-cloud data acquired from laser scanning. If such scanned data is available, attempts are being made to reconstruct geometry models by means of interactively modelled CAD models using the point cloud data as reference. This "almost manual" reconstruction is labour intensive and has proven to be prohibitively expensive for general application so far, so existing state-of-the-art CAD tools cannot be applied efficiently.

Software-assisted semi-automatic geometry reconstruction based on such point cloud data, which can be created by various scanning tools, is an evolving innovative approach addressing the need to generate 3D models faster and, most importantly, with less effort. Tools focusing on specific requirements of the shipbuilding domain are missing not at least because requirements are very specific in this area. In the SHIPLYS project, promising tests were carried out using a prototype of reconstruction software specifically targeting the shipbuilding industry needs, which has been integrated into the PPT suite. This makes it possible to reconstruct "real-world" geometry and to merge it with newly designed partial models, normally required in case of extensive modifications such as lengthening, scrubber installation etc.

Another important benefit is gained from this is the option of establishing an interim product structure as it reflects the base information for production planning and which is essential for defining the work breakdown structure (WBS). A 3D model of the interim product structure (representing the ship or relevant parts thereof) is therefore a key input to determine details like job sequences, task dependencies (e.g. a painting task depends on the surface to be painted), work content, required material, available space, access paths etc. as a prerequisite for accurate production planning.

Fig.10 shows a sample of the reconstruction procedure of a relevant portion of a point cloud. By selecting only few points within the cloud the algorithm automatically identifies points belonging together and forming a part such as a wall, deck, profile, plate, pipe, flange, valve etc. In doing so, time and cost compared to manual creation of a 3D model are substantially reduced.

3.4. Scheduling and Optimisation

Having defined tasks using PPT functionality, a schedule can be automatically derived afterwards considering the predecessor/successor relations and duration of tasks (Fig.11). Most importantly, this tool relates the scheduling information to the underlying engineering and planning data which goes well beyond the capabilities of common scheduling tools.

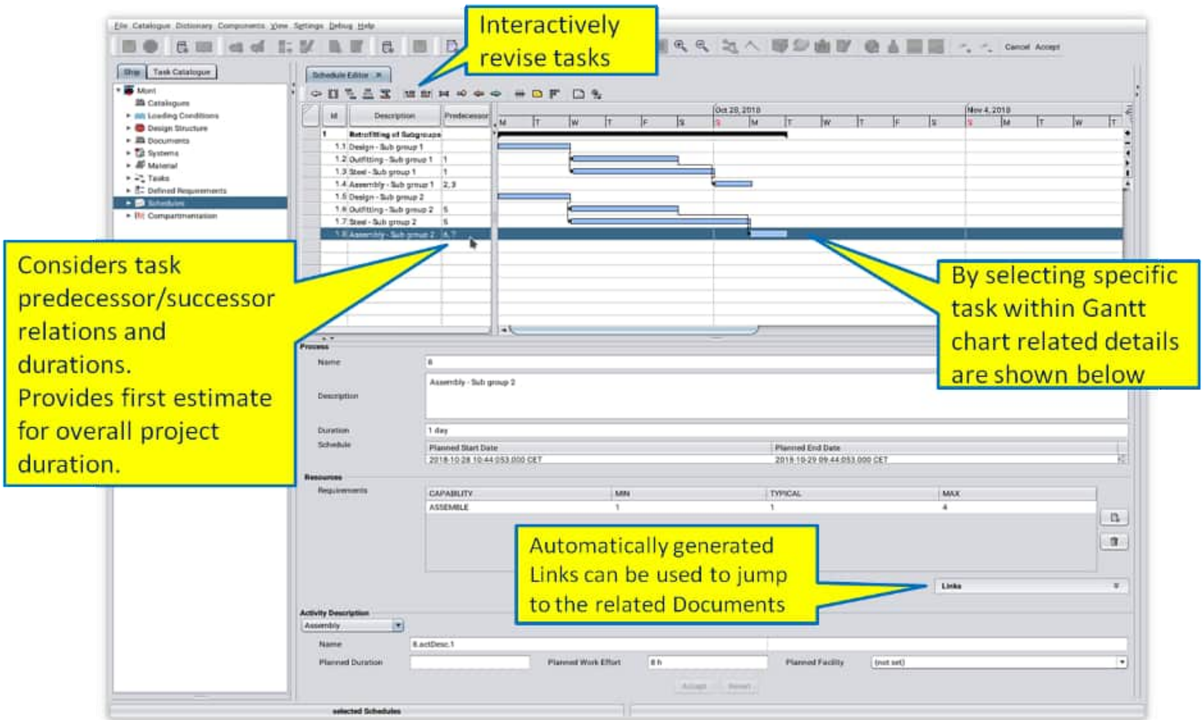

Fig.11: Schedule Editor

Due to the lack of time and the high effort spent in data acquisition the optimisation of project duration, costs, resource utilization etc. is often neglected and therefore considerable potential for improvement is wasted. This is particularly important during the early bid preparation stage where data is often unreliable or missing. Furthermore, the optimisation component has to be fully integrated into the existing IT system in such a way that all required data can be retrieved without much effort for data selection or conversion.

Due to the rapid data generation functionality and the possibility to connect to various data sources, the optimisation component can be easily supplied with the relevant input data such as tasks and resource capacities. It then provides optimized problem solutions in short time, considering a variety and combination of goals as selected by the user (e.g. shortest time, limited or levelled resources, best utilization, lowest cost, etc.), see Fig.12.

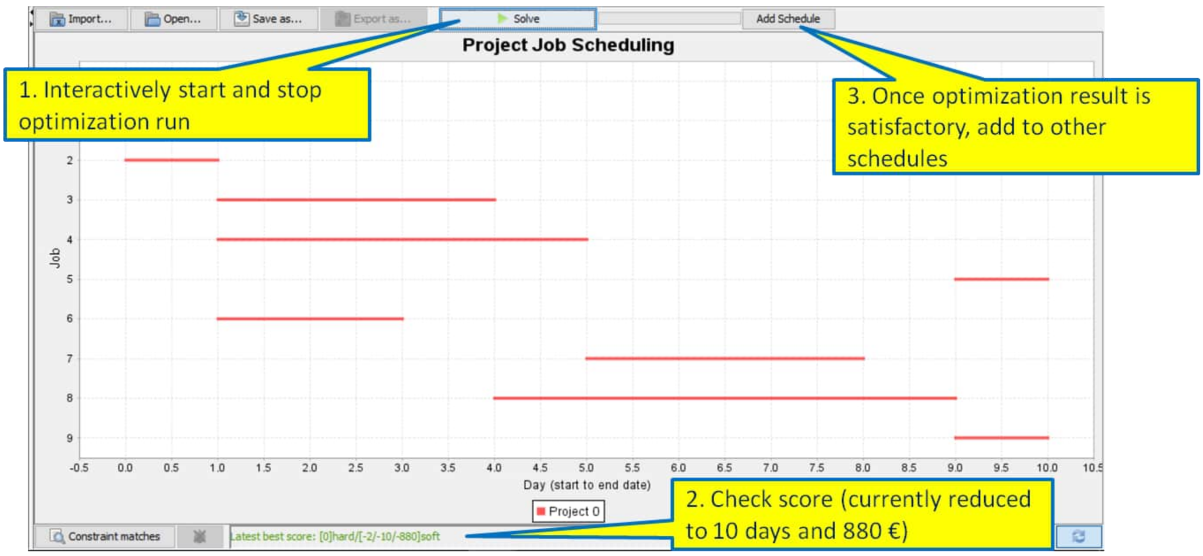

Fig.12: Schedule Optimisation Editor

The related project duration and resource cost can be used to prepare a competitive offer. Thanks to the report generation functionality available in PPT the related bid can be created automatically resulting in further time savings.

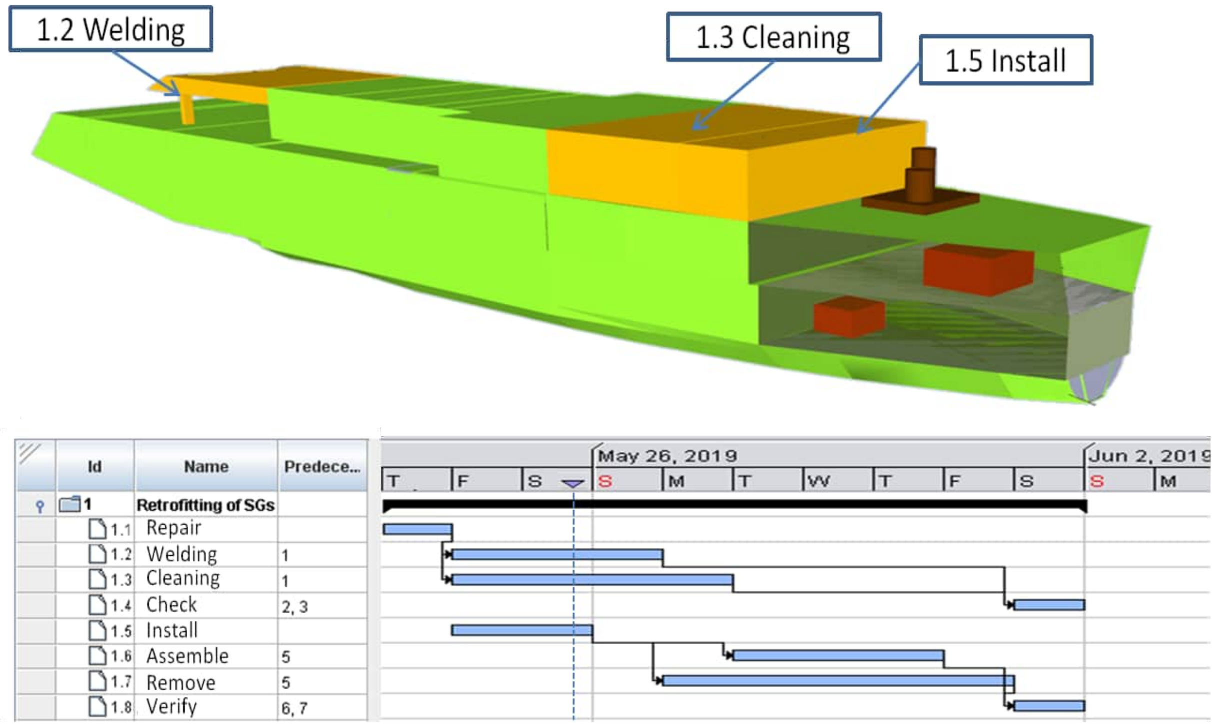

Fig.13: 4D-Animation

3.5. 4D-Animation

As there is a tight interlinkage between schedule, requirements and engineering, it is useful to provide 4D-Animation capabilities allowing navigating through a fully attributed 3D model of the vessel as well as along the project timeline. This can be used to support the internal planning and discussions/ reporting/negotiations with the vessel operator/owner. In the viewer prototype, shown in Fig.13, by shifting a "time" slider within the schedule, the appropriate tasks are visualized in the 3D pointing to the related ship components. 4D-Animation can be applied for both new building and retrofitting projects.

3.6. Production Simulation

Discrete event simulation represents an approach for managing the complexity related to the production planning in shipbuilding and provides more realistic estimations for the common KPIs (such as duration, resource utilization etc.). To use simulation, a considerable amount of data is required to reflect reality at a sufficiently high level of detail as a prerequisite obtain realistic results. Besides production facilities and resources, which in most of cases are defined only once as an initial set-up activity, the data describing the product itself is needed. For this reason, simulation is used in repetitive manufacturing environments since the product does not change too frequently. In a one-of-a-kind industry setting such as the maritime sector each ship is to a large extent unique and product data is not complete especially during the early project stages. Therefore, the application of existing simulation solutions is very labour intensive. Due to lack of sophisticated data-generation functions only few shipyards are applying simulation in limited ways. Their focus is on later stages of the project execution by applying tailored interfaces to the existing current system landscape. Fig.14 shows the effort distribution related to simulation-based analysis where data collection represents the most time-consuming part, *Hübler (2017)*.

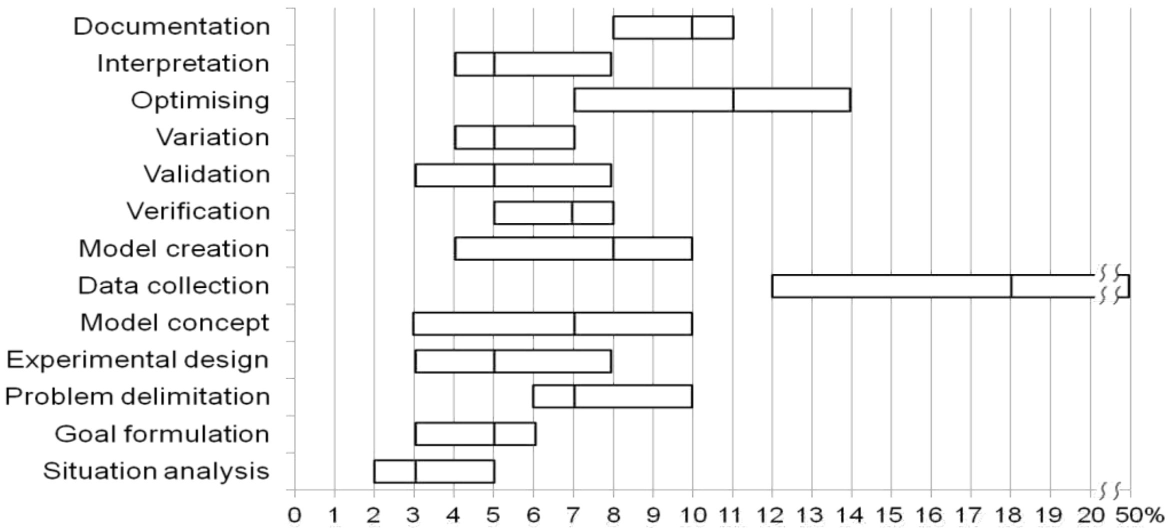

Fig.14: Distribution of effort for simulation projects

The functions included in PPT as described above can help to overcome this hurdle such that rapidly generated product data, task and resource definitions can be used by the simulation component in order to provide a more detailed analysis. This is used to locate bottlenecks, investigate technical aspects of production processes (e.g. evaluation of new production technologies or processes), and to minimize production risks by carrying out a what-if analysis. Furthermore, LCC/LCCA relevant data such as environmental footprint and consumables of production facilities and related cost can be determined in a quite detailed way, as required. In case an optimized schedule has been generated before, the resulting optimal task and resource allocation can also be considered during the simulation run by higher prioritisation of tasks to be carried out first. In Fig.15 the main steps required for simulation runs are shown. The second phase to establish the product model has to be carried out for each project for one-of-kind products and represents the most time-consuming activity when operating without using the rapid definition functions of PPT.

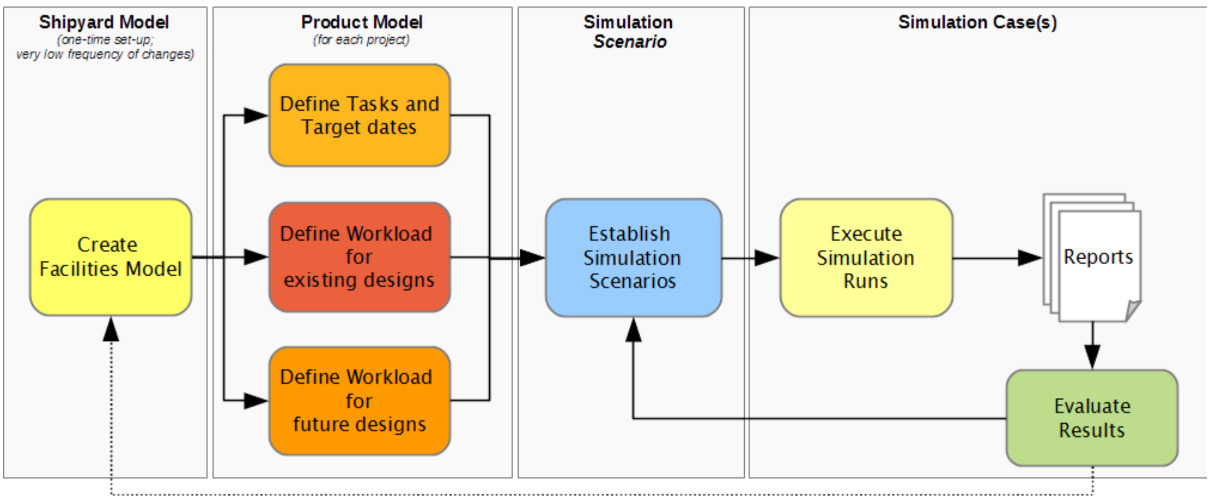

Fig.15: Simulation Procedure

A component for facility modelling has also been integrated into PPT as part of the simulation functions to support the definition of various types of facilities of a production site. This can then be directly used by the simulation component which aids the first phase of setting up a shipyard (asset) model as depicted in Fig.15. A wide range of production equipment types and transportation means commonly found in ship production can be instantiated in such a model.

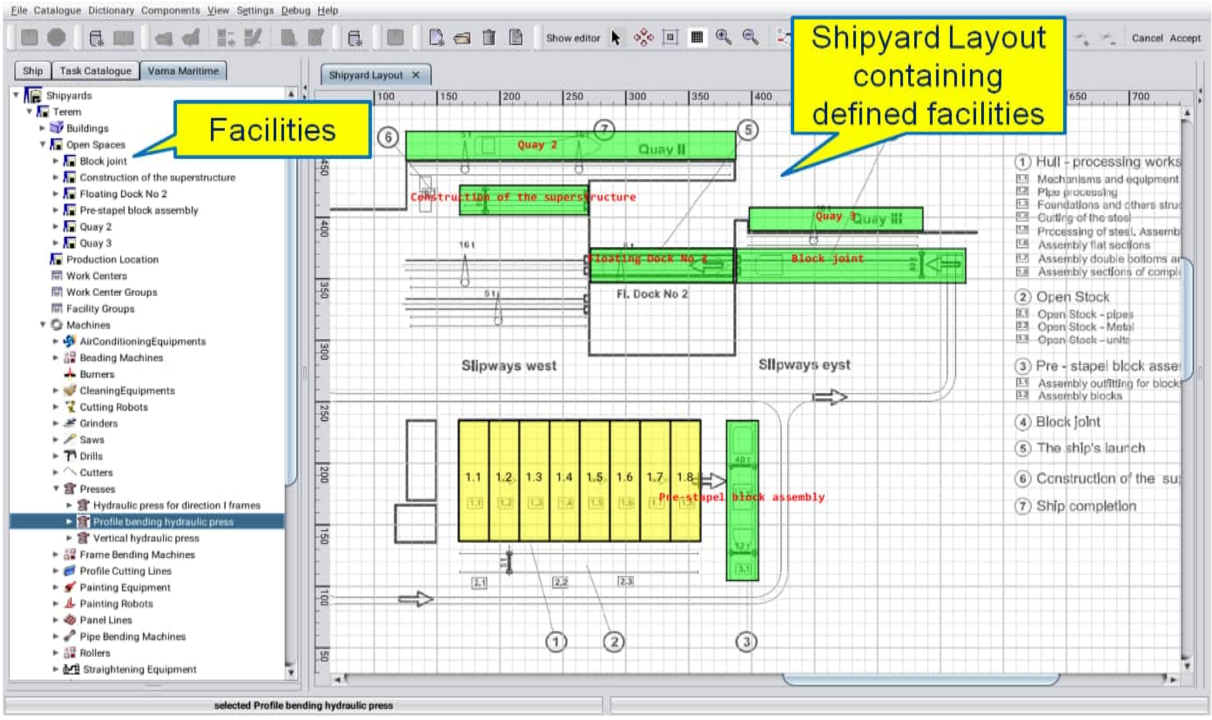

Fig.16: Facility modelling for a shipyard

In Fig.16, an example of a shipyard model is shown allowing further investigations by the use of simulation engine. Since the effort of setting up the shipyard model does not have to be repeated for each project, it is an investment well spent to provide a reasonably detailed digital twin of the shipyard's production environment.

Nevertheless modifications of such a model can be provided at any time, e.g. include new equipment, modifications of production processes etc. Since the activation of such items can be controlled during simulation model configuration and simulation runs, respectively, it is possible to investigate alternative production methods in a straightforward way.

Technical "hot-spot"/risk identification

The simulation component enables the analysis of the various technical hot-spots and risks by investigating what-if scenarios, e.g.:

- Ship design changes
- Use of special facilities
- Essential logistics operations
- Alternatives of production sequences
- External impacts such as weather conditions, business disruptions, equipment failure etc.

After a simulation run is finished, various generated reports can be used to detect possible bottlenecks and underutilization of resources. Consequently, precautionary measures can be taken to minimize production risks and keep deadlines.

4. Conclusions and Outlook

PPT represents a software suite using a unique combination of advanced tools to enable rapid and sufficiently detailed one-of-a-kind production planning applicable to the early project stage based on limited information. The suite can be used for newbuilding as well as repair/retrofitting projects to derive more detailed and reliable data regarding cost and schedule instead of experience-based estimations commonly used nowadays especially in SME shipyards. Therefore, the following benefits for the shipyards seem possible:

- Faster and more reliable evaluation and preparation of bids,
- Winning more contracts by reducing the response time during the bidding stage and by being able to provide more competitive offers by reducing the overall project duration and related costs,
- Creating more reliable production plans will result in improved adherence to delivery dates and therefore increase the customer satisfaction and loyalty,
- Reduction of planning effort will reduce the related costs, whereby the reduction of risks will avoid large cost deviations.

Future development should focus on:

- Further automation of the geometry reconstruction process based on point clouds,
- Extension of functionality for production control allowing reacting in an optimal way with respect to unforeseen changes by connecting optimization and simulation tools to the actual operating data.

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