

Ivana Kaliterna

E-mail: ikaliterna@uniri.hr

Marko Hadjina

E-mail: hadjina@uniri.hr

Davor Bolf

E-mail: dbolf@uniri.hr

Tin Matulja

E-mail: tmatulja@uniri.hr

University of Rijeka, Faculty of Engineering, Vukovarska 58, Rijeka, Croatia

Development of a Digital Ship Model as a Foundational Framework for Ship Construction Technology Design

Abstract

Shipbuilding is a specific and very complex branch of industry, and each segment of the shipbuilding process needs to be supported by detailed documentation in line with international standards and regulations. In an advanced shipbuilding process, the entire process must be supported by the implementation of modern digital technologies. The application of 3D ship models in today's shipbuilding is mainly based on a model created later in the design and construction phase of the ship. Namely, the technology project may already be in the advanced stage, while the digital model is still in the development phase. Modern shipbuilding should strive for greater and faster implementation of 3D models in the design process at the earliest possible stage. A timely model enables a better and higher quality technology project, and an optimally technologically acceptable method of manufacturing and assembling the ship's hull. This paper analyzes the project-technological documentation of ship construction with an emphasis on the implementation of the 3D Experience software for the creation of ship models in the earliest possible design phase. This enables better technology design, which results in a more efficient computer-supported integration of designing, building and ship outfitting. The advantages of such approach to technology design are manifested through an increase in the quality of the final product, a lower consumption of working hours, a better redistribution of work and, ultimately, a reduction in total costs. The basis for the design of the technology described in this paper is the division of the ship into technological units that are adapted to the technology of a particular shipyard. An 3D model presented in this paper enables an insight into the structure of the ship and its technological characteristics significantly before the construction phase of the ship. Such a technological analysis of the ship model defines a preliminary calculation of the weight and center of gravity of individual sections of the ship at an early stage of the process. It also reduces the occurrence of errors and repetitive work in the expensive phase of building and ship outfitting. Ultimately, this paper emphasizes that the creation detailed digital model of the ship at the earliest possible stage of the ship design is a fundamental step in the process of digital twin concept implementation, which is stated as further work of this research.

Keywords: shipbuilding, design, technology, 3D Experience, digital twin

1. Introduction

Shipbuilding is an industrial which divided into the preparatory and production sections, within which further subdivisions take place, all leading to the construction of floating vessels. A ship is a product of high capital value and large dimensions, built from a vast number of structural elements and are equipped with diverse machinery and equipment, all manufactured and assembled thanks to qualified workers of various professions, [1].

All construction phases are carried out in a precisely defined sequence within planned deadlines. The success of a shipyard depends on effective contracting of new projects, securing reliable financing sources, continuous investment in technology, and improvement of production processes according to the shipyard's capabilities. The goal of every operation is to produce a high-quality product that complies with all regulations and standards, at minimal cost and without financial losses, [2].

The shipbuilding process includes a series of activities from project development to the ship's delivery to the owner. All tasks and phases of the process, from design to delivery, must comply with the regulations and requirements of international maritime organizations and classification societies. The production and construction processes proceed continuously, without feedback loops, with optimized workplaces and material flows along flexible and automated production lines.

The main phases of the shipbuilding process are: preparation, processing, pre-assembly, section assembly and outfitting, assembly, launching, final outfitting, and delivery. The preparatory part of the shipbuilding process is divided into: sales, design, technological project planning, procurement, and material storage. In the preparation phase, along with technical and workshop documentation, technological documentation is also developed. This documentation is essential for the proper construction, assembly, and outfitting of the ship.

To achieve a faster, higher-quality, and more cost-efficient production process, the digital twin concept is increasingly being integrated into shipyard manufacturing systems. The digital twin is based on the principle of connecting between the physical and digital domains for simulation, monitoring and real-time data exchange. Its implementation reduces design and construction lead times, enhances production planning and process optimization, and ensures faster product delivery to the market while maintaining compliance with quality standards and market requirements. By increasing operational efficiency in the production process, achieving a higher level of automatization, and improving accuracy and quality, timely product delivery to the market is ensured along with financial profitability. The application of the digital twin concept will enable the construction of higher-quality and more sophisticated ships that currently exist only at the conceptual stage due to the lack of technological capabilities in shipyards, [3].

Virtual (VR) and augmented reality (AR) are already being applied in the shipbuilding industry, and their future is based on even more realistic, higher-quality,

and faster visualization of ship projects and all their systems, [4].

The use of virtual twins is possible across all organizational units of a shipyard, transforming a modern shipyard into the smart shipyard of the future. The main purpose of applying digital twins within a shipyard is to create simulations and analyses, connect the phases of design, construction, and operation, improve production technology, manage material and financial resources more effectively, and enable the shipowner to continuously monitor and analyze all ship systems after delivery and throughout the entire lifecycle of the ship.

This paper, which is based on master's thesis [5], analyzes the design and technological documentation of ship construction, with a focus on the implementation of 3D Experience software to create a detailed ship model at the earliest stage of the design process. This approach enables better and higher-quality design of production technology, emphasizes the potential for further development, and allows the integration of the digital model with the digital twin concept, ultimately enhancing the entire production process.

2. Documentation for Ship Construction

Ship construction documentation contains various documents that describe and define the ship's characteristics and the production process. This documentation defines the drawings required for ship construction, the bill of materials, and workshop specifications. Shipbuilding documentation is divided into three main groups: technical, technological, and material documentation.

Technological documentation describes the entire production process, including the location, method, and required time for ship construction. It is used to define the ship (dividing the ship into groups, planning pre-assembly and assembly, preparing section assemblies, and creating workload calculations for production phases), [6].

2.1. Project Technological Documentation

Project technological documentation is a subgroup of technological documentation and includes documents that define the technical characteristics of the ship project during the contractual phase. It serves as the basis for developing workshop documentation. It is divided into hull technological documentation and equipment technological documentation. Project technological documentation is prepared in accordance with client requirements, classification society rules, national and international regulations, market demands, and the shipyard's internal standards.

This documentation is used for the early definition of the production process, including calculations of necessary costs, materials, and human resources to ensure uninterrupted ship production. Smooth progress of construction requires secured financing sources and timely procurement and delivery of materials and equipment,

whose value accounts for about 80% of the total value of materials and systems installed on the ship. A well-prepared and detailed technological documentation minimizes possible errors in resource calculation and reduces the negative impact on production and the shipyard's financial stability.

The documentation defines and presents the ship's functional units, the basic characteristics of ship construction, the methods of construction and outfitting, and the procedures that must be applied during the building process.

Project technological documentation is used for:

- Developing the technological concept of ship construction;
- Dividing the ship into groups;
- Creating a technological description of the ship;
- Section planning;
- Assembly planning;
- Determining the sequence of ship assembly.

During the ordering and processing of steel materials, section pre-assembly, application of anti-corrosion protection, and section assembly, certain limitations may occur within the project technological documentation. These limitations are related to the specific characteristics and capabilities of each work area.

Minimizing possible errors in resource calculation and reducing the negative impact on production and the financial stability of the shipyard are the main advantages of using project technological documentation.

The main disadvantages are its limited applicability in workshops due to an insufficient level of detail and the dimensional constraints of plates and profiles.

The design and technological documentation for the hull and equipment are prepared separately to simplify the process and ensure a clearer presentation. The interconnection between the hull and equipment documentation must be maintained throughout all stages of the design and construction process.

2.2. Basic Phases of Project Technological Documentation

The concept design, preliminary design, and contract design form the basic phases of project technological documentation.

The concept design is divided into two phases. In the first phase, the basic data about the ship are determined, calculation data are collected, and a conceptual sketch of the ship is created. In the second phase, the data from the first phase are supplemented to produce the ship's technical description.

The preliminary design contains the basic ship data, calculation results, a short description, a brief technical overview, the ship's general arrangement plan, and the general arrangement of the engine room.

The contract design is divided into two phases. The first phase takes place before

the contract is signed and includes the basic ship data, calculation results, a technical description, and contractual documentation. The second phase follows after the contract has been signed and is used for developing or refining the ship's hull form, ordering model testing, and modifying the geometry of specific hull components.

2.3. Basic Ship Construction Technology

Basic ship construction technology defines the ship's construction strategy. It must comply with the shipowner's requirements and the shipyard's technological capabilities. The documentation describes shipbuilding technology based on general and specific data related to construction, outfitting, and hull painting. The main goal is to increase technological efficiency and reduce costs.

The basic construction technology is developed based on the technical description, the general arrangement of the engine room, and the basic section plan. It includes: section planning, assembly technology, space outfitting plan, welding technology, anti-corrosion protection, and assembly and inspection networks.

Ship construction technology design is divided into conceptual, preliminary, and contractual stages, along with accompanying documentation. It is a process that evolves and improves throughout the entire design and construction period. It is specific to each shipyard and is created to ensure maximum utilization of the shipyard's resources, which directly affects profitability. It serves to define the location, method, time, and materials for ship construction and outfitting. It is primarily used for optimizing construction, calculating workshop load capacities and costs, and predicting potential production issues.

The methodology of ship construction based on technological units is a systematic and structured approach that includes all phases from design to construction, within which the types and categories of technological units are defined. Each technological unit contains information about dimensions, element composition, weight, and center of gravity.

The types of technological unit:

- Functional (SFI – System Function Identification), where the ship is divided into main groups, groups, and subgroups; and
- Technological, where the ship is precisely divided into spatial units and the required works within them.

3. Digital ship model

A digital twin is a virtual representation of a physical product or process that enables real-time measurement, understanding, and monitoring of all data and performance of the physical model. By using a digital twin, virtual simulations of intended scenarios can be performed in real time. Each digital twin collects and processes information

about the physical model, allows necessary changes to be implemented in real time, and provides insight into the effectiveness and quality of those changes, [7].

A digital twin uses collected data to analyze the past, monitor the present, and predict the future, effectively providing answers to “what-if” scenarios.

This technology relies on smart devices. A variety of sensors, scanners, and cameras are strategically installed on the physical model to continuously collect data, which is then transferred to the virtual environment for analysis. All operations and changes occur in real time, involving the seamless transmission of large volumes of data.

The tree elements of a digital twin

1. Real- world entity or process;
2. Virtual representation;
3. Data that connects the two.

Continuous monitoring and real-time data updates allow every change in the physical model to be tracked throughout the entire product lifecycle, creating a seamless feedback loop in the virtual environment, [8].

The digital twin has a main role at the industrial digital transformation, connecting the entire product lifecycle with manufacturing. By enabling collaboration and coordination across teams and users, digital twin drive more efficient processes, higher-quality outcomes, and smarter project execution.

3.1. Digital Twin in Shipbuilding

The digital twin is an invaluable tool for the future and success of shipyards in the global market.

During the project development phase, the digital twin is used for simulations, testing, and optimization to reduce errors, increase efficiency, and produce the highest-quality ship design possible. Performance is digitally represented, then analyzed and refined until the best possible performance is increase for the specific ship being designed. In addition to improving performance and increasing efficiency, the digital twin is also used in design to simulate potential issues and prevent unnecessary costs and problems.

In ship structure design, the digital twin provides precise, fast, and efficient analysis of all structural elements. By integrating comprehensive data on materials, operating conditions, and structural loads, it enhances simulations and numerical analyses, allowing optimization of component layout and dimensions. Potential structural weaknesses can be detected early, enabling proactive design adjustments, predicting changes under varying load conditions, and minimizing the need for physical material testing. This ensures a stronger, safer, and higher-quality ship structure.

The digital twin enables optimization of structural element arrangement and dimensions, prediction of structural changes under varying load conditions, and reduces

the need for physical material testing. Early detection of potentially weaker areas allows for timely design of a high-quality structure.

During ship construction, the digital twin is used to simulate and optimize the production process, from material procurement to delivery. It facilitates information collection, order tracking, monitoring of material flow, and production supervision. Optimizing production lines increases speed, efficiency, and product quality. Feedback loops in the production process, errors, waste, and poor resource allocation can lead to financial losses and delays, all of these problems can be solved through the application of a digital twin. Its integration enables the construction of safer and more efficient ships.

In ship operation, the digital twin supports problem detection, maintenance, and system optimization. It identifies potential risk and critical systems, allowing preventive actions before issues occur, ensuring compliance with safety regulations. Simulations help predict the impact of weather and navigation conditions, while improvements in digital twins focus on prevention and timely correction of all ship systems for safer and more efficient operation.

The use of digital twins is becoming increasingly common and is expected to be a standard tool across many fields. In shipbuilding digital twins enable lifecycle optimization from design to shipbreaking yard. Applications cover design, procurement, production, outfitting, delivery, and testing, allowing comprehensive monitoring and continuous improvement of shipyard operations.

Figure 1 shows the detailed digital ship model developed in this study, forming the basis for the real digital twin. This model was used for production technology design. Further development into a full digital twin focuses on production improvement and increased efficiency. This work primarily considers the digital twin concept in terms of improving production process efficiency. The following section briefly describes hull modeling in the 3D Experience software.

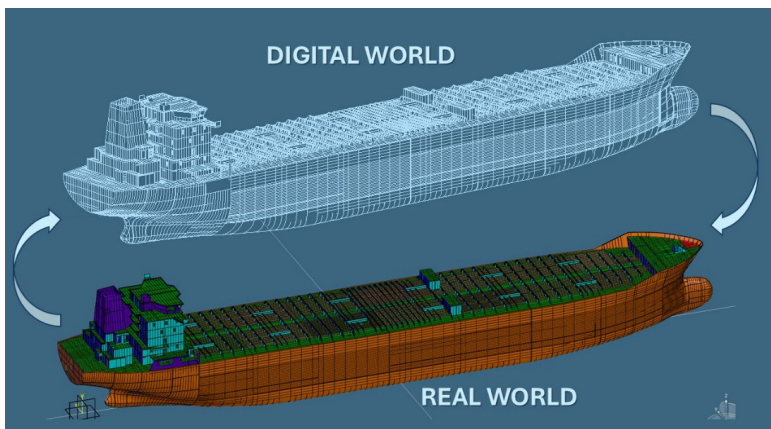


Figure 1. The lifecycle of a ship model using a digital twin

3.2. Modeling in 3D Experience Software

One of the first steps in designing a new ship is the analysis of existing ship projects based on similar ships that have been built in the selected shipyard, or on available information about ships constructed in other shipyards. These analyses are performed to provide a solid foundation for the design of a new vessel, ensuring full alignment with the client's specifications and requirements.

In this project, a 3D model of the ship was created using the 3D Experience software, based on the available documentation from the "3. Maj" Shipyard in Rijeka, [6].

The 3D Experience software platform, developed by Dassault Systèmes, includes applications such as Catia, Enovia, and Simulia. This integrated system connects the entire process from design to production. The application of this software ensures better collaboration between all participants involved in shipbuilding through a connected digital system.

The ship model was created in 3D Experience software in the Catia SFD (Structure Functional Design) application. The model includes the basic structural elements of the ship's hull, superstructure, and funnel.

The structural elements used in the model include the keel, center girder, inner bottom plate, frame, deck girder, bottom longitudinals, double-bottom side girders, bracket knees, side longitudinals, side stiffeners, deck stringers, deck longitudinals, and hatch coamings. Brackets and other details that belong to the Detail Design phase were not modeled; however, their weight was estimated and added as an additional 10% (based on experience) to the total calculated ship weight.

The modeling concept is based on dividing the ship into ring-shaped sections, with the hull divided into 12 ring sections. The aft ring section is divided into the main deck, decks, and bulkheads within its compartment. The engine room ring section is divided into the double bottom with tanks, decks, and bulkheads throughout the engine room area. The cargo hold ring sections are divided into groups: double bottom, double hull (P.S.), double hull (STB.), corrugated bulkheads, cargo area stringers, and the main deck. The basic divisions of each ring are subdivided according to the type of structural elements they contain. All modeled elements correspond to the technical drawings and components specified in the project documentation.

An example of the methodology for dividing the cross-section into groups and sections, applied in this study, is shown in Figure 2.

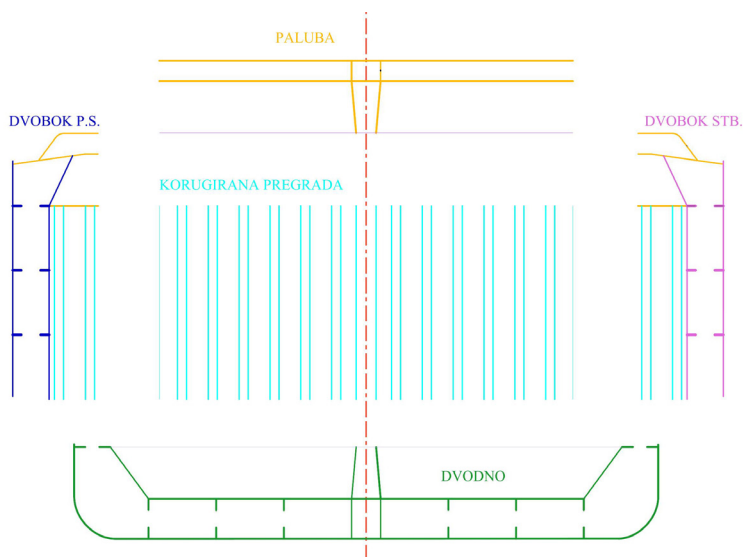


Figure 2. Cross section divided into groups and sections

The ship model, created using the software 3D Experience, is shown in Figure 3.

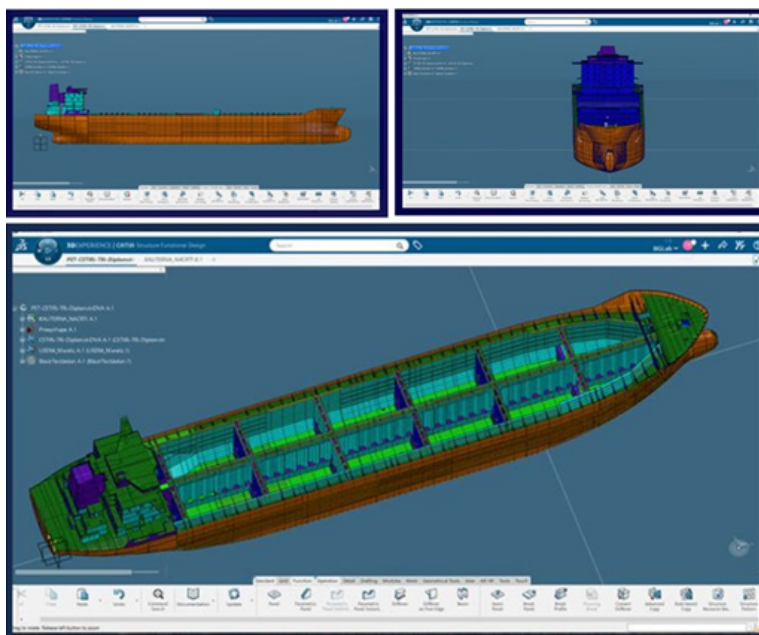


Figure 3. Ship model in 3D Experience

A comparison of the dimensions of a similar ship and the ship model, is shown in Figure 4

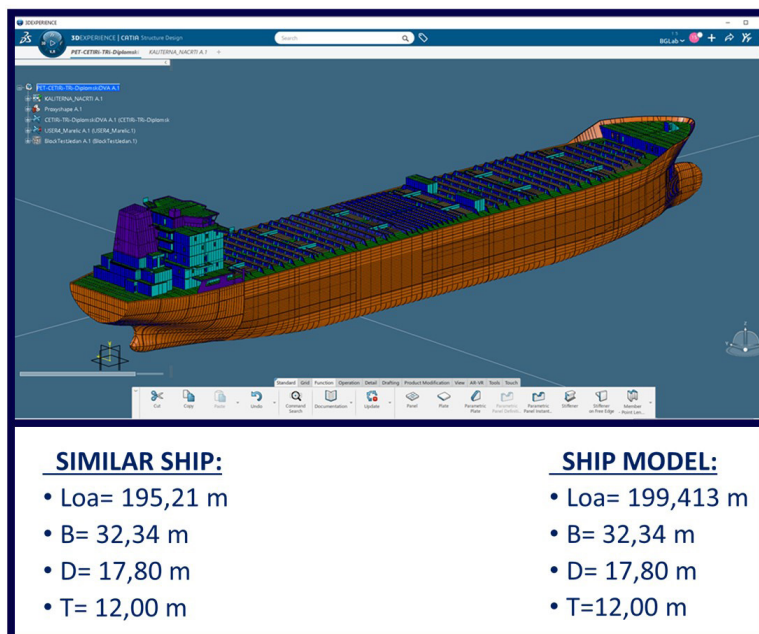


Figure 4. Main dimension of similar ship and ship model

4. Technological subdivision of the Modeled Ship

By dividing the modeled ship into technological units, it becomes possible to equip and paint closed volumetric sections at an early stage. The subdivision into technological units was carried out to meet the established requirements as closely as possible. Some selected units represent a compromise between technical demands and the technological capabilities of the shipyard. Technological units are represented as ring-shaped sections, while the division into sections and structural elements is presented both in tabular and drawing form. The subdivision of technological units includes a list of all units of the ship spaces and the division of each space with the characteristic units of each particular area. For each subdivided unit, its mass and center of gravity were determined. The standard plate length in the robust area of the parallel midship sections is 10,200 mm, with some exceptions within specific groups. Plates in the stern and bow areas are shorter due to the curvature and finer shape of the hull in these regions.

4.1. Division of the ship into ring sections

The ship was divided into ring the 12 ring sections, is showed on Figure 5.

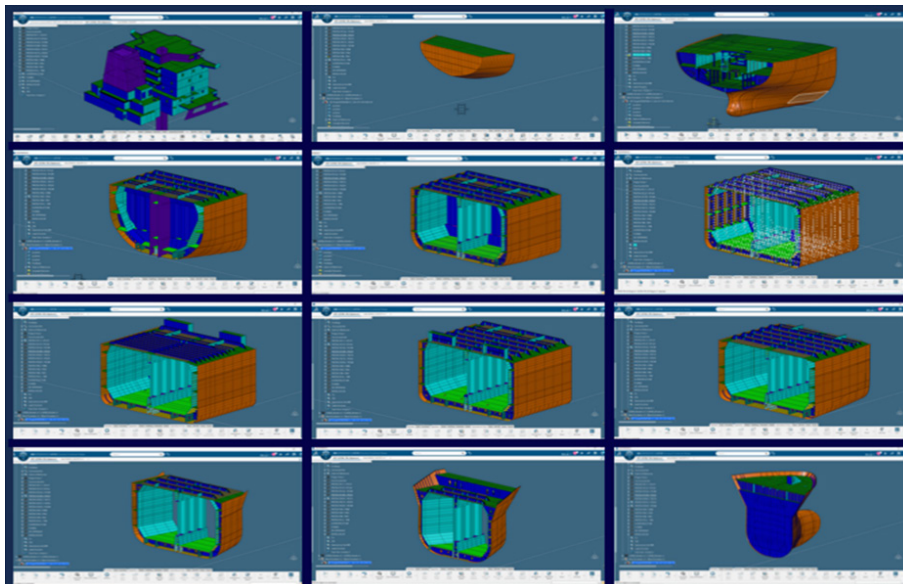


Figure 5. The ship was divided into ring sections.

4.2. Division of the Ship into Groups

The ship was divided based on the lifting capacity of the crane located on the slipway (300 t), as well as the technological capabilities of the shipyard. According to the ship's length, width, and height characteristics, the hull was divided into 12 ring sections consisting of 62 technological units. Each group consists of several sections that together form a technological whole.

Characteristics of Hull Division Along the Cargo Hold Length:

- ◇ The double bottom (gr. 3410), double side (gr. 3450), and deck groups (gr. 3480) cover two plate lengths (except for the first and last rings); the cutting line is positioned along the frame line;
- ◇ The basic plate length is 10,200 mm, with a cutting step of +200 mm from the frame, and outside the intersection of corrugated bulkheads;
- ◇ Corrugated bulkheads were divided following the structural cutting line, with a shift toward the bow up to the first half-wave of the corrugation.

Characteristics of Hull Division by Width and Height of the Cargo Hold:

- ◇ The double bottom groups consist of the double bottom, lower side tanks, longitudinal and transverse stools;
- ◇ The double side groups consist of deck parts, upper transverse stools, and parts of the transverse corrugated bulkheads; the cutting line is aligned with the frame line;
- ◇ The deck groups consist of upper longitudinal and transverse stools;
- ◇ The bulkhead groups consist of longitudinal and transverse corrugated bulkheads.

Characteristics of Assembly Units in the Cargo Hold:

- ◇ The double bottom is marked as one group, consisting of two VT sections extending from side to side in one plate-length line, with transverse and longitudinal stools;
- ◇ The double sides are marked as one group, consisting of four VT sections (2xP.S., 2xSTB.), deck parts, the upper transverse stool, and the transverse corrugated bulkhead;
- ◇ Two double-side sections were combined into one large unit across the full group length in the parallel midship section;
- ◇ The deck is marked as one group, consisting of two assembly units, except for group 3480, where two deck sections were merged after anti-corrosion protection and outfitting with the loading ramp before assembly on the slipway;
- ◇ The corrugated bulkheads consist of two groups of two-dimensional sections longitudinal and transverse bulkheads, where the corrugation intersection is included in the longitudinal bulkhead section.

Other ship spaces were divided according to the standard integrated subdivision system. All technological units were listed, and a document titled "List of Technological Groups and Assembly Units" was prepared.

The division of the ship into technological groups, assembly units, and their respective lengths is shown in Table 1.

weights of the technological groups, an assembly plan was created in accordance with the 300-ton lifting capacity of the selected crane. The weights are expressed in metric tons (t), the Centers of Gravity are represented as CoG values in meters (m), and the material list is provided as a Bill of Materials (BOM).

Within the *SFD* and *GSD* modules, the necessary elements for performing the weight and center of gravity analyses were created, [5]. To carry out the measurement process, the model must first be positioned and aligned to the coordinate system, after which a rectangle of the required dimensions is created in the *Sketch* environment depending on the analyzed section. The generated rectangle defines the boundaries of the selected section, which is then converted into a solid volume using the “*Extrude Volume*” command. The limits of this solid are defined according to the dimensions of the corresponding section. For each generated volume, a weight and center of gravity analysis was performed using the “*Block Test*” tool. The software automatically performs the analysis of the selected volume through a dedicated script, and exports the results into a .txt output file.

Ship model showing calculated weights and centers of gravity for each ring, including all technological groups, is shown on Figure 7.

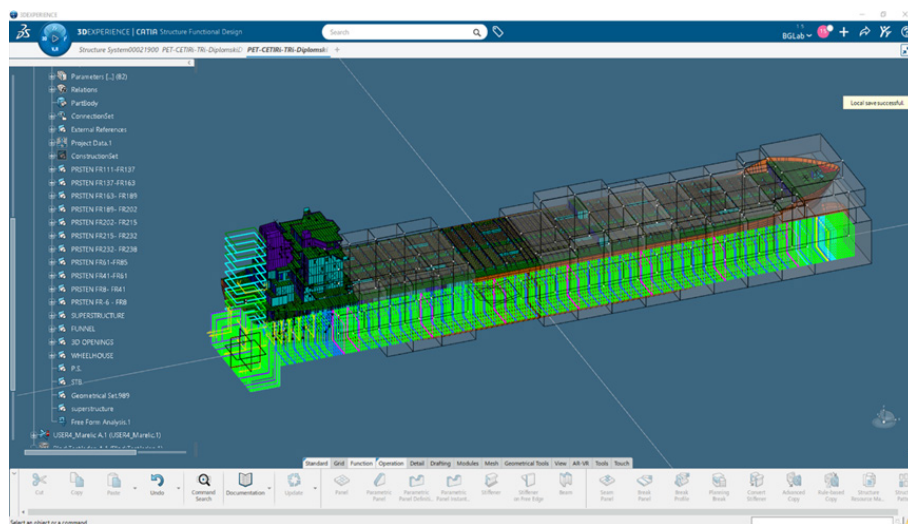


Figure 7. Ship model with calculated weights and centers of gravity

The analysis was carried out for every section within each ring of the 3D model ship. The total calculated weight of the ship model amounted to 13,605 tons.

Table 2 presents the calculated weights and centers of gravity

N.A.	GRUPA	NAZIV GRUPE	PROJEKCIJSKA RAVNINA	Tilna y ₀	Center of gravity point		
					CoGx	CoGy	CoGz
PROJEKCIJA 1 - 01NA							
1	1210	OPREMA STATNA OD R. 0 DO R.13	V701	61.824	7204,907	47,641	8623,376
2	1210	OPREMA PA OD R. 4 DO R.4	V701	220,276	342,749	224,862	12746,247
3	1210	OPREMA PA OD R. 4 DO R.4	V701	61.824	397,699	730,847	12049,409
4	1210	OPREMA PA OD R. 4 DO R.4	V701	61.904	1064,611	-1704,208	12049,368
5	1210	OPREMA PA OD R. 4 DO R.4	V701	207,862	704,693	133,425	10654,274
6	1210	OPREMA PA OD R. 4 DO R.4	V701	23,649	---	---	---
PROJEKCIJA 2 - 02NA							
7	2110	OPREMA U STRANICIMA OD R.01 DO R.11	V701	181,649	2037,233	-43,399	1208,238
8	2111	OPREMA OD R.10 DO R.20	V701	61,748	18089,015	-478,261	1248,054
9	2210	OPREMA OD R.21 DO R.41	V701	200,276	20093,736	13368,979	12746,493
10	2220	OPREMA OD R.41 DO R.41	V701	174,726	23966,999	-13391,108	12464,248
11	2230	OPREMA NA R.41	V701	200,205	2037,239	124,643	12709,023
12	2310	OPREMA OD R.10 DO R.20	V701	61,209	18064,126	762,734	6898,133
13	2310	L. PLATFORMA OD R.0 DO R.01	V701	120,776	12100,000	754,885	4764,200
14	2310	L. PLATFORMA OD R.0 DO R.01	V701	1,000	4364,489	-3,700	12744,203
15	2340	L. PLATFORMA OD R.0 DO R.01	V701	131,646	12066,268	8055,704	12465,744
16	2310	L. PLATFORMA OD R.0 DO R.01	V701	23,000	12092,220	-6824,720	12464,771
17	2310	L. PLATFORMA OD R.0 DO R.01	V701	43,000	12154,857	-182,854	12705,567
18	2340	OPREMA PALUBA OD R.0 DO R.01	V701	207,860	12066,264	8054,613	10682,401
19	2310	L. PLATFORMA OD R.0 DO R.01	V701	104,679	12064,761	-1087,047	10470,688
PROJEKCIJA 3 - 03NA							
20	3100	OPREMA PALUBA OD R.01 DO R.01	V701	61,938	83443,233	1,344	14093,764
21	3100	OPREMA PALUBA OD R.01 DO R.01	V701	74,600	61887,143	6,883	14053,548
22	3100	OPREMA PALUBA OD R.01 DO R.01	V701	200,420	34234,974	12074,264	12746,009
23	3100	OPREMA PALUBA OD R.01 DO R.01	V701	43,790	42766,267	12462,764	12049,493
24	3100	OPREMA PALUBA OD R.01 DO R.01	V701	61,880	54851,839	-14044,848	12049,368
25	3100	OPREMA PALUBA OD R.01 DO R.01	V701	67,328	42922,440	-14489,893	12434,348
26	3100	OPREMA PALUBA OD R.01 DO R.01	V701	44,970	10464,711	12,073	12394,442
27	3100	OPREMA PALUBA OD R.01 DO R.01	V701	43,680	10394,288	6617,389	12324,761
28	3100	OPREMA PALUBA OD R.01 DO R.01	V701	43,680	10394,288	6617,387	12324,761
29	3100	OPREMA PALUBA OD R.01 DO R.01	V701	43,790	10374,010	-8424,334	12354,137
30	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
31	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
32	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
33	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
34	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
35	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
36	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
37	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
38	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
39	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
40	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
41	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
42	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
43	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
44	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
45	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
46	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
47	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
48	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
49	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
50	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
51	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
52	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
53	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
54	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
55	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
56	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
57	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
58	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
59	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
60	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
61	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
62	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
63	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
64	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
65	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
66	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
67	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
68	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
69	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
70	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
71	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
72	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
73	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
74	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
75	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
76	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
77	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
78	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
79	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
80	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
81	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
82	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
83	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
84	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
85	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
86	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
87	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
88	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
89	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
90	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
91	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
92	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
93	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
94	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
95	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
96	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
97	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
98	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
99	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
100	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
101	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
102	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
103	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
104	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
105	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
106	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137
107	3100	OPREMA PALUBA OD R.01 DO R.01	V701	124,510	10374,010	-8424,334	12354,137

ensure precise assembly, geodetic reference points (benchmarks) are installed along the slipway.

Ship assembly represents a crucial stage of the project technological documentation. The assembly sequence plan defines and designates all ship sections. The sequence of assembly is illustrated in the assembly drawing, which also determines the order of material and equipment procurement, the sequence of production and section assembly, as well as the storage locations and handling capacities for large sections based on the available transport systems.

Plan of ship assembly, is shown on Figure 9.

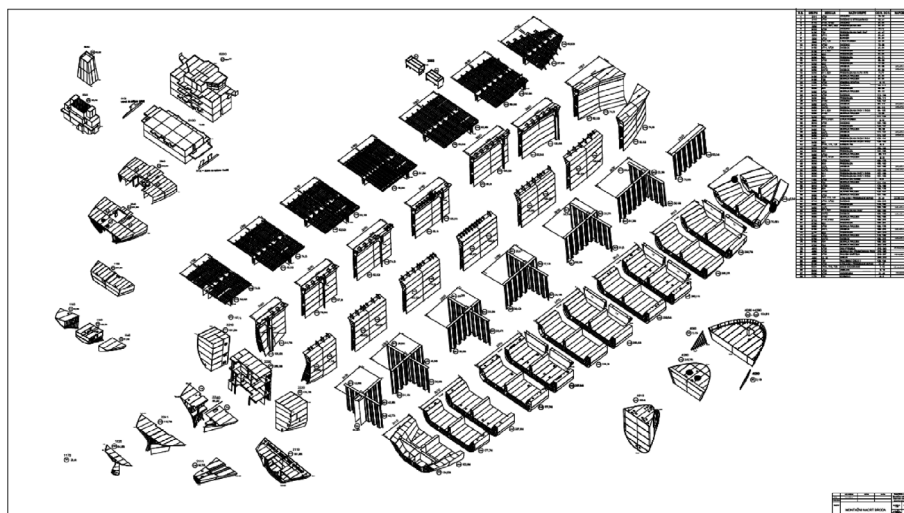


Figure 9. Plan of ship assembly

6. Conclusion

Modern shipyards are based on block construction design, which significantly shortens and integrates the processes of fabrication, assembly, outfitting, and painting. This approach is achieved through the division of the ship into technological units, although such division alone does not resolve all issues related to the formation and completion of units.

The key requirements for a successful technological subdivision of the ship are structural, technological, and production related. The implementation of 3D modeling software in the initial stages of design allows for more precise, efficient, and optimized technological planning. By achieving the maximum integration of IHOP (Integrated Hull Outfitting and Painting), DFP (Design for Production), and PWBS (Product Work

Breakdown Structure) principles within both the design and construction processes, shipyards improve coordination and reduce rework.

Creating a 3D ship model, as presented in this paper, provides insight into the ship structure and outfitting prior to construction, allowing for early identification of potential design or dimensional errors. The technological subdivision of the 3D model also enables a preliminary calculation of weights and centers of gravity for individual sections. This results in lower overall costs, reduced material waste, fewer labor hours, and a faster and more coherent design and production process. Continuous improvement in design, procurement, quality control, production preparation, and construction methods, together with the timely creation of a 3D model, are essential for achieving these objectives.

Furthermore, developing 3D ship model towards the digital twin aims to monitor, implement, and optimize all processes throughout the ship life cycle. The implementation of the digital twin concept within the shipbuilding process provides capability to perform simulations and optimizations from the design phase to ship operation, where automated and sensor-equipped ship systems are continuously monitored in real time. Therefore, the continuation of this research is based on a detailed ship model developed as a foundation for early-stage production technology design, serving as a basis for further development of the digital twin. All data and information collected during the processes within the digital twin will be used to enhance technology design, making the production process ultimately more efficient, advanced, and cost-effective.

Acknowledgements

This research is supported by funds from the supporting research at the University of Rijeka for the project “Ship design and production integration based on digital twin concept” (*uniri-iskusni-tehnic-23-80*).

References

1. Hadjina, M.: “Metodologija gradnje plovnih objekata“, predavanja, Tehnički fakultet Rijeka, Rijeka, 2022.
2. Storch, at all “ Ship production“ Cornell Cornellmaritime press, Centerville, Maryland, 1995.
3. DNV, “Digital twins in maritime: Applications and benefits,” 2021.
4. Nuwan Sri Madusanka, at al. Digital Twin in the Maritime Domain: A Review and Emerging Trends. JMSE. Vol 11. Issue 5. <https://doi.org/10.3390/jmse11051021>. 2023.
5. Kaliterna I.: „Ship production documentation“, master thesis, mentors Hadjina / Bolf. Tehnički fakultet Rijeka, 2025.
6. Dokumentacija broda tipa tanker, Brodogradilište 3. Maj
7. F. Mauro, A.A. Kana. Digital twin for ship life-cycle: A critical systematic review. Ocean Engineering. Vol. 269, <https://doi.org/10.1016/j.oceaneng.2022.113479>. 2023.
8. Material www.siemens.com/ DigitalTwin
9. Furlan, Z.; i dr.:“Tehnologija gradnje broskog trupa“, Školska knjiga, Zagreb,1986.

