Technology and Science for the Ships of the Future
V. Crupi and V. Bucci (Eds.)

doi:10.3233/PMST250128

The Integration of AI Technologies in Modern Yacht Design Methodology

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Abstract. This paper explores the integration of artificial intelligence technologies throughout the yacht design process, enhancing both the traditional design spiral and V-model methodologies. The proposed approach begins at the requirements definition phase, where AI-powered emotion recognition and natural language processing analyse client interviews, interpreting facial expressions, tone of voice, and emotional responses to design proposals, ensuring a more precise understanding of owner preferences. The implementation of AI tools continues through various design stages, with machine learning algorithms optimising hull parameters to enhance vessel performance and onboard comfort. Generative AI accelerates the concept phase by rapidly producing and evaluating multiple design alternatives while considering complex constraints such as stability requirements, hydrodynamic performance, and spatial arrangements. This systematic integration extends beyond the design phase to the operational lifecycle of the vessel, where AI-driven comfort monitoring systems analyse passenger emotions through computer vision, automatically adjusting onboard settings including temperature, lighting ambiance and audio environments. Our findings demonstrate how this AI-enhanced approach not only reduces iteration time within the design spiral but also enhances the verification and validation phases of the V-model. The paper addresses both the benefits and current limitations of AI implementation in yacht design, proposing a framework for effective human-AI collaboration that transforms how naval architects approach luxury yacht design in the digital age.

Keywords. AI-Driven Yacht Design, Human-AI Collaboration in Naval Architecture

1. Introduction

The maritime industry is undergoing a major transformation through AI technologies, particularly in yacht design and naval architecture. Traditional design methods like the design spiral [1][2] and V-model [3] are being enhanced by AI-driven generative design, machine learning-based hydrodynamic optimisation, and intelligent autonomous systems, which improve decision-making, reduce iteration times, and enable real-time

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data analysis [4][5][6]. AI is widely adopted across maritime operations, from fleet management to navigation and safety, with the market growing from $1.47B to $4.13B in one year and an expected 23% annual growth [7]. Real-time environmental data is used to optimise routing and reduce emissions, while predictive maintenance prevents mechanical failures. SMEs drive 63% of AI innovations in the sector [8]. AI also transforms yacht design by augmenting each phase of the design spiral with automated evaluations, predictive modelling, and simulation tools. The research integrates the Theory of Embodied Cognition, especially the Motor Schema of the Mind, suggesting that cognition is grounded in physical interaction [9][10]. This leads to more intuitive human-AI collaboration in design, where sensorimotor perceptions shape the creative process—even before formal mental representations are realised. Designers interact physically with their models using gesture-based tools, haptic feedback, and virtual reality, enhancing spatial and ergonomic evaluation.

The paper proposes an AI-powered framework combining generative AI, intelligent agents, NLP, and biometric emotion recognition to better understand client needs and refine luxury yacht design. This integrated, human-centred approach advances both the quality of yacht designs and the innovation potential within naval architecture.

2. Theoretical Background

Yacht design has long been structured around iterative models such as the design spiral and the V-model, which, while effective, are time-intensive and reliant on the designer's experience. The integration of artificial intelligence is fundamentally reshaping these paradigms, introducing machine learning, computational fluid dynamics (CFD), and generative design tools that significantly enhance speed and precision in exploring design alternatives [11][12][13][14]. Our research advances this shift by introducing an AI-based, agent-driven system that transforms the vessel requirements definition phase (Figure 1) [15]. In this framework, intelligent agents [16] autonomously interact with clients, understand their preferences, and present existing market competitors for comparison. This allows clients to indicate liked or disliked features, directly influencing the configuration of their ideal vessel. These agents operate with autonomy, proactivity, reactivity, and social capabilities, collaborating within a multi-agent architecture to handle data acquisition, market analysis, and design proposal generation. A distinctive innovation lies in the use of conversational agents that adapt in real time to the client's responses, removing the need for predefined scripts and enabling more authentic, spontaneous dialogue. The system integrates facial emotion analysis and acoustic signal processing, leveraging FACS and GeMAPS [17] to detect subtle affective responses, revealing implicit preferences that would often go unnoticed in traditional interviews. The emotional and behavioural data collected dynamically informs the interaction, prompting the agent to explore relevant topics or reformulate unclear questions. Based on this enriched dataset, generative AI systems produce multiple conceptual designs, enabling rapid development of 3D models that can be iteratively refined in real time based on client feedback. This drastically accelerates early-stage design iterations.

Compared to traditional methods, the AI-enhanced approach introduces emotion-aware requirement analysis, automated parametric modelling for CFD, and virtual validation via digital twins and VR, as shown in Table 1. This comprehensive system transforms the designer-AI relationship into a collaborative partnership, amplifying creativity and responsiveness in the conceptual design process.

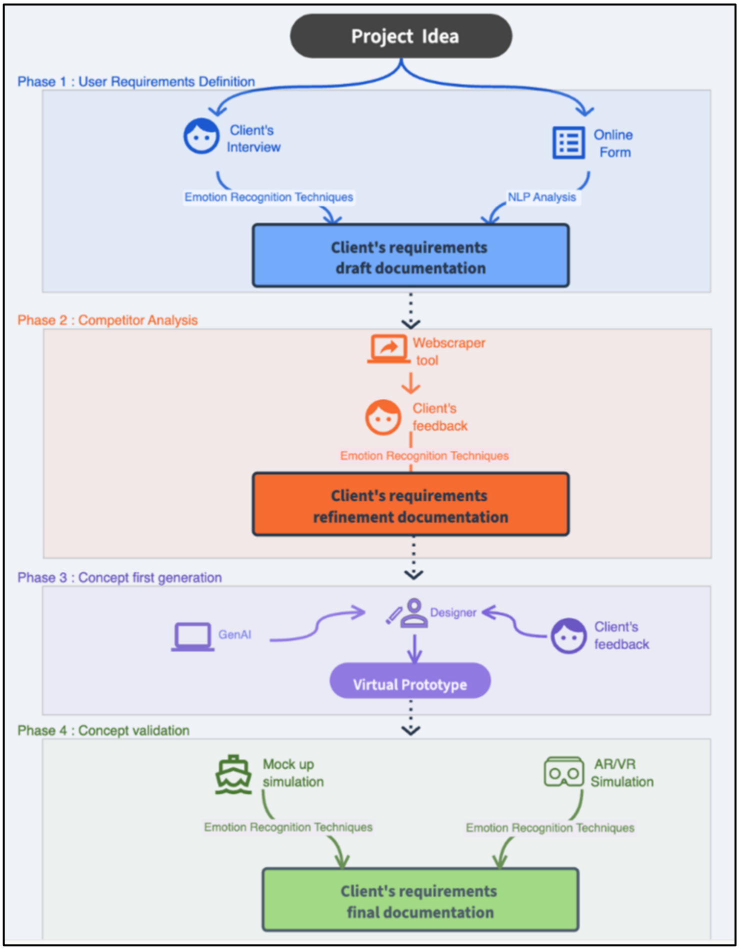

Figure 1. User Requirements Estimation: the AI Driven Approach

Table 1. Comparison between Traditional and AI-Enhanced Methodologies

Feature	Traditional V-Model	AI-Enhanced V-Model
Requirements Analysis	Based on client interviews	AI-driven sentiment & emotion recognition
Design Optimisation	Manual iterative process	Generative AI with ML constraints
CFD Simulations	Time-consuming manual setup	AI-assisted parametric modelling
Validation	Physical prototyping	Digital twin & VR-based validation

2.1. The Motor Schema of the Mind and Embodied Cognition in Naval Design

A fundamental element of our methodology is the integration of the Motor Schema of the Mind, a concept derived from embodied cognition theories. It maintains that human cognitive processes are intrinsically interconnected with bodily experience and sensorimotor interaction with the environment. In yacht design, this assumes relevance as the understanding of spaces, proportions and ergonomics derives largely from the embodied experience of both the designer and the end user. The Motor Schema of the Mind postulates that our conceptual understanding of spaces and objects is mediated by the same neural structures that control movement and sensory perception. When we imagine or design a space, we partially activate the same neural networks we would use to physically navigate that space. This process of embodied simulation is fundamental for anticipating how a user will interact with the designed environment. By integrating AI with this cognitive paradigm, we have developed interfaces that overcome the limitations of traditional two-dimensional interactions. Advanced platforms incorporating haptic feedback, immersive virtual reality (VR) simulations, and gesture-based interfaces allow designers to interact with digital models in an intuitive and multisensory manner. This approach facilitates a profound understanding of the spatial and ergonomic characteristics of the design, enabling designers to refine their decisions based on an experience that simulates real interaction with the vessel. AI further enriches this paradigm by enabling predictive simulation of how users will interact with designed spaces. Machine learning models, trained on behavioural and biometric data, can anticipate movement patterns, ergonomic preferences, and emotional responses of passengers within the confined environments of a yacht. These simulations allow for optimising the arrangement of spaces, improving accessibility, and perfecting the overall user experience proactively, even before the physical construction of the vessel.

Soon, we intend to expand this methodology by implementing immersive virtual environments that allow clients to directly explore their ideal vessel.

2.2. Multi-Domain Optimisation through AI Systems

Beyond spatial experience, AI also transforms technical aspects of yacht performance. In hydrodynamic and structural optimisation, AI uses historical and sensor data to generate efficient hull designs, validated through real-time CFD simulations [18]. Gaussian Process Regression (GPR) models trained on the Delft Systematic Yacht Hull Series (DSYHS) have significantly improved hull resistance prediction and early-stage optimisation [19]. Generative design and multi-objective optimisation enable designers to evaluate diverse configurations balancing structural integrity, efficiency, and stability. In interiors, adaptive AI systems personalise environmental settings—such as lighting and climate—based on real-time emotion recognition, setting new standards for comfort and user-centred luxury. These innovations position AI as a core partner in design, shifting the process from linear execution to an adaptive, interactive, and human-focused methodology that redefines the foundations of modern naval architecture.

3. Methodology: Implementation of the AI-Based Approach

AI integration in yacht design adopts an iterative framework that enhances traditional methods through agent-based reasoning, machine learning, and real-time user feedback. Developed at the University of Genoa, this Emotional-Enhanced Design Paradigm ensures human creativity remains central by following the *Designer-in-the-Loop* approach and is structured into four key phases for a more adaptive and user-centred design proces.:

1. *User Requirements Definition via AI-Driven Emotional Analysis:* A conversational agent interviews our potential client to understand their requirements (age, experience, type of vessel, crew, etc.).
2. *Competitive Market Analysis via AI Agents*: An agent web scrapes the internet and our internal dataset to identify possible competitors; AI-based web-scraping tools collect and structure industry data on design trends, technical specifications, and market demands. These insights are integrated into a knowledge database (308 different vessels), enabling a data-driven approach to custom yacht design**.**
3. *Generative Design and AI-Driven Concept Development:* An agent creates sketches **(**Figure **2)** according to the user's previously acquired requirements, ensuring both aesthetic harmony and spatial efficiency. These models primarily define interior layouts and material compositions, but future developments aim to incorporate engineering constraints such as stability, hydrodynamics, and structural integrity.

Figure 2. AI preliminary suggestions to the designer based on competitors and user's preferences

4. *Designer-in-the-Loop Validation and Iterative Refinement:* The designer remains the core decision-maker, using AI as a collaborative assistant rather than a replacement. The methodology aims to integrate VR-assisted prototyping and haptic feedback systems soon, allowing designers to interactively adjust form, structure, and onboard comfort settings.

3.1. Technological Infrastructure and System Architecture

Our platform is based on a distributed architecture that integrates various specialised AI modules and high-quality external services:

1. *Emotional Analysis System**:*** We currently use HumeAI APIs [20], which enable both facial expression and audio analysis. Initially, we had implemented a proprietary system based on convolutional neural networks pre-trained on EmotioNet datasets for FACS recognition, and deep learning models optimised for extracting GeMAPS acoustic parameters. However, the current results of these proprietary systems are inferior to those obtainable with specialised external platforms.
2. *Conversational Agent**:*** For this fundamental component, we have integrated ElevenLabs [21], which allows us to train the agent to collect specific information necessary for design which can quickly modify the voice and language of the interview, generate a complete transcript of the interaction, and produce audio files that can be analysed to extract information about the potential client's emotions.

3. *NLP Engine and Semantic Analysis*: This utilises a combination of multilingual transformer models and proprietary sentiment analysis algorithms adapted to the nautical domain and identifies not only explicit preference statements but also implicit nuances and revealing linguistic patterns.
4. *Generative System for Conceptual Design:* We currently rely on Midjourney [22] and PromeAi [23], which allows us to quickly create variations on images, perform inpainting, and delete or add specific details. In parallel, we are experimenting with some Hugging Face models, but the results are not yet comparable to those obtained from commercial platforms. (Figure 3).

Figure 3. Different proposals for the interior design in a yacht

5. *Rapid 3D Model Generation:* We have integrated Meshy [24], an AI platform that enables the transformation of sketches, drawings, or photographs into detailed 3D models. The platform also supports exporting in formats compatible with major nautical CAD software, facilitating the workflow from conception to technical development (Figure 4).

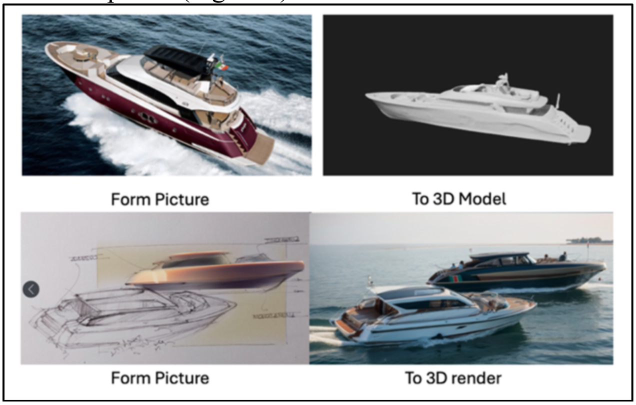

Figure 4. AI-Transformation from sketch to 3D Model, from sketch to render

3.2. Preliminary Validation and Experimental Plan

The system is currently in a preliminary validation phase, with pilot tests conducted on two university professors and two volunteer students. Early results are promising: the time needed for initial requirements definition has been reduced by 47%, the accuracy of capturing client preferences has improved, and the diversity of design solutions has increased by 215%. A full experimental protocol is in preparation and will involve five professional naval designers (with 5–25 years of experience), five prospective clients with varying nautical expertise, and twenty students from the Naval Nautical Design and Naval Engineering programmes at the Polo Marconi, University of Genoa. This study will compare traditional and AI-assisted design methods using two real-world cases and a combination of quantitative and qualitative evaluation metrics to assess the overall impact of the AI-enhanced process.

3.3. Ethical Considerations in Data Collection

All data collected during the preliminary testing adhered to strict privacy protocols, with full anonymisation and informed consent obtained from all participants. Recordings and biometric data are used exclusively for research and are not shared with third parties. Ethical approval for the upcoming experimental phase has been granted by the University Ethics Committee, and similar safeguards will be in place, ensuring compliance with institutional ethics and European data protection regulations [25]. Future research will also address potential biases in emotion recognition and consider the cultural variability of emotional expression.

4. Conclusions and Future Perspectives

This research marks a significant methodological leap in the integration of artificial intelligence into nautical design, surpassing traditional models such as the design spiral and V-model. The preliminary results demonstrate three major contributions. Firstly, the adoption of AI has accelerated decision-making and design processes, reducing the time required to define design requirements by 47% and increasing the diversity of topological solutions by 215%. Unlike conventional approaches, which optimise parameters sequentially, the AI-driven method enables simultaneous optimisation, allowing designers to explore a wider range of solutions more efficiently.

Secondly, the study introduces cognitive-emotional integration into naval design by applying the Motor Schema of the Mind. This approach aligns computational capabilities with embodied human experience, using emotion recognition and biometric analysis to reveal clients' implicit preferences. This enables designers to address not only measurable technical criteria but also more subtle experiential and emotional needs that traditional methods struggle to capture.

Thirdly, the research outlines a roadmap for the evolution of nautical design practices. Future developments will focus on integrating AI with CAD software for unified simulations that account for hydrodynamic, structural, and ergonomic factors; applying the full methodology to real-world projects for enhanced validation; and making the tools accessible to mid-sized design studios through a modular system architecture. In this vision, AI is no longer a passive automation tool but an active creative partner, with the designer remaining central to the process. The goal is to raise the qualitative standards of yacht design by combining technical excellence with deeper sensitivity to the emotional and sensory experiences of users. Further research will expand the predictive power of AI by incorporating broader datasets and developing immersive virtual environments that allow clients to experience yachts early in the design phase, optimising iterative validation and refinement.

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