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DESIGN RESEARCH IN THE DIGITAL ERA

Opportunities and implications
Notes on Doctoral Research in Design 2020

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Digital Transformation

Toward a Yacht Design 4.0
How the new manufacturing models and digital technologies [could] affect yacht design practices

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Abstract

In the field of design, Industry 4.0, Internet of Things and intelligent products are profoundly transforming not only the representation of a design project but also formal references, input data, communication strategy and the design process itself. In this scene, the doctoral research estimates the role of the new digital technologies of Industry 4.0 and the new manufacturing models in the transformation of yacht design practices. The main research results – the Yachting 4.0 Forecasting Framework and the Yacht Design 4.0 Roadmaps – came from a systematic and comprehensive study of future alternatives to answer the research questions: How could Industry 4.0 digitally-enabled technologies be better implemented in a Yacht Industry 4.0 scenario? How could these scenarios modify disciplinary approaches to the yacht design project?

The study results contain a reflection on novel yacht design practices – in particular on data input, design processes, design tools, and communication media – positioning the study achievement on a conceptual level that still needs to be pragmatically tested and verified by applied research projects both in shipyards and in design studios.

Research Framework

Toward a Yacht Design 4.0 is the result of a doctoral research process that is mainly theoretical, supported by field investigations and participatory action researches. It explores Industry 4.0 to understand its role in manufacturing transformation and in introducing challenges to the field of yacht

design. The choice of focusing on this research topic does not derive from a recognized field of study – indeed, the Yachting 4.0 topic is almost absent in the literature review[1] and in industrial practice[2] – but rather from an intuition about the need to foresee the role of new digital technologies and new manufacturing models in the transformation of the yacht design sector, in order to understand and guide the digital transformation in progress.

In the field of design, Industry 4.0, Internet of Things and intelligent products are profoundly transforming not only the representation of a design project but also formal references, input data, communication strategy and the design process itself. In the contemporary scene, a designer needs to face design requirements, which are strongly influenced by an advanced technological system characterized by connected, computational, and open-sourced digital manufacturing (Giaccardi, 2015). Manufacturing shifts from producer of objects to producer of services, and industry mixes with the lives of people, rapidly and continuously drawing useful indications from them to redefine the production itself (Frison, 2016).

However, the impact of the discussion on Industry 4.0 on the design sector is still immature, with few papers discussing the topics only from 2016. As argued by Celaschi, Di Lucchio and Imbesi (2017), looking at the impact of 4.0, "the discipline of Design seems to be absent and, therefore exempt, from taking into consideration the transition to this fourth industrial revolution as a paradigmatic change of one's role and purpose. The research on Design and Industry 4.0 is often limited to listing the challenges in terms of new technological availability without really asking the question whether and how Design itself will have to change in order to adapt, in evolutionary terms, to this near future which implies productive as well as economic and social issues."

On the other hand, yacht design is a highly complex applied sector of industrial design. Scientific fields of engineering, design, architecture, ergo-

[1] A systematic literature review was carried out during all the phases of the doctoral study to monitor the evolution of the Yacht Industry 4.0 concept in academic research. In March 2019, based on about 5,800 papers (journals and conferences) published in the field of Industry 4.0, over 480 articles include researches or applications in the maritime sector, while only thirteen are focused on the yacht industry.

[2] An international online survey was carried out between March and May 2018 with the aim of gathering information on knowledge of Industry 4.0 in the nautical field, and on the current use of digital technologies in the Yachting industry in relation to the level of end product customization. The survey results show a general lack of awareness of Industry 4.0 opportunities. In 92% of the sample, both 4.0 manufacturing models and 4.0 enabling technologies are unexplored in a systemic way, and the integration of digital data in the yacht design and production process is considerably low.

nomics and materials, with their specialized disciplinary articulations, are involved in a boat project. Besides, a marine product must have characteristics halfway between a passenger compartment and a living space that "moves even when it is still" (Spadolini, 1987). Hence, every project has to manage the diversified system of limitations imposed by the user and by the overall efficiency of the boat-system, including manufacturing techniques and process.

Nowadays, the nautical sector is facing several challenges linked to the world economic, environmental, and societal context. Furthermore, the global Yacht Industry, led by Italian production, is projected to grow by up to 11% by 2022, considering both yacht length and number of vessels under production. However, the sector is experiencing technological backwardness and is recovering from a downturn that began in 2010. The recent economic crisis has highlighted both a need for significant changes in production systems led by an afterthought of the entire yacht design process (Pollicardo, 2017). Hence, the Industry 4.0 scenario could have a disrupting impact on current yacht design processes, which are still mainly described as a process of iterative engineering refinement and incremental optimization called "yacht design spiral" (Larsson *et al.*, 1994).

Design for the Future

If future scenarios and challenges cannot be predicted with an unquestionable level of uncertainty, they can be estimated and understood to inform present actors. Due to the freshness and the "unexplored complexity" (Magruk, 2016) of the Industry 4.0 topic, and the lack of references in literature, strategic thinking to explore alternative futures – Future Studies (Bell, 1997) – is prioritized. The beginning of all industrial revolutions took place in the industry and caused a massive change in society. The opposite is true in the current industrial revolution. The beginning of the transformation process is not driven directly by the industry itself (Schuh *et al.*, 2014) but is triggered by a hyper-connected society. For the first time in history, the industrial revolution is predicted, providing opportunities to shape the future actively.

According to these considerations, the main research questions of the doctoral research are:

- How could the Industry 4.0 digitally-enabled technologies be better implemented in a Yacht Industry 4.0 scenario?
- How could the Industry 4.0 digitally-enabled technologies modify disciplinary approaches to the yacht design project? So, what are the alternative yacht design processes and tools?

The theoretical framework of the research is placed in the broader conversation on relations between the Discipline of Anticipation and Design. In this framework, the research methodology aims at pushing the boundaries of yacht design toward a possible evolution driven by digital and interconnected technologies. This vast and unexplored context of investigation compels the research to continuously shift from phenomenological exploration and interpretation (surveys and case studies) and forecasting activity (participatory scenario-building workshop), opening it up to several tangents or critical matters that may be considered for future research work.

Research Methodology

The research approach[3] is placed across the two main categories of the design research, namely Research through Design and Research for Design (Jonas, 2007). While Research for Design mainly refers to the aim of the present study, the nature of this research is close to the actual design practice. Consequently, according to Volontè *et al.*, 2015, the research output has a twofold nature: problem framing – the Yachting 4.0 Forecasting Framework – and a series of artifacts – the Yacht Design 4.0 Roadmaps – to drive the study reflection and computational strategies in Yacht Design.

The research strategy comes directly from the literature review on Future Studies, and is organized into the 6-ing phases of the *Strategic Foresight* by Hines and Bishop (2006): framing, scanning, forecasting, visioning, planning and acting. Accordingly, the research adopts methods and tools generally used in design research mixed with management research ones.

Framing and *scanning* aimed at building a robust forecasting framework through desk research and case studies analyses. The scenario-building workshop (*forecasting* and *visioning* phases) was selected as a forecasting method based on the nature of the uncertainty involved in the activity and referring to the Future Studies framework proposed by Courtney (2003). While the case study analysis was conducted with an expert mindset, the forecasting phase had a participatory mindset, involving stakeholders as co-researchers. Finally, *planning* and *acting* referred to the activity of roadmap design and retrospective analysis to ground the workshop's results in an understanding of novel yacht design approaches, processes, and tools driven by the yachting 4.0 forecasting framework.

[3] The study refers to the logical hierarchical taxonomy identified by Rampino and Colombo (2012) to give structural consistency to the term used in the research methodology.

Foresight with insight

A Case Study analysis on 4.0-enabling technologies applied in the yachting industry was carried out to reveal opportunities and trends for the scenario-building phase. Cases were identified by consulting with stakeholders – academics, naval and nautical shipyards, suppliers, yacht designers and nautical industrial associations – during international boat shows and in the yacht trade in 2017-2018. Forty projects and practices were selected within the nautical, maritime, and transportation sectors.

Case mapping mainly focused on understanding relations between industry 4.0 design principles (Herman *et al.*, 2015) and 4.0 enabling technologies, including the possible impact of the use of digital technology on yacht design and manufacturing and, more in general, to investigate the potential to scale up experiences in supporting the scenario-building activity.

After completing the desk research, cases were grouped by levels of consciousness in Industry 4.0 integration and by their influence on the disciplinary approach to the yacht design project. The resulting clusters were labelled and explored in relation to Industry 4.0 scenarios by PWC (2016)[4]. According to the PWC scenario, the forecasting framework backdrop was built as a scheme of four concentric circles divided into four sectors by the vertical and the horizontal axes. The horizontal axis separates focus on the product from focus on production, while the vertical axis marks the temporal division between before launch and after launch phases.

The resulting case study groups are labelled and described.

- Digital data gathering: projects integrating IoT and AHMI with the primary purpose of monitoring yacht assets.
- Environmental digital data analysis: projects integrating IoT, big data, simulation, and AHMI with the main purpose of gathering and analyzing field data to inform (in perspective) the design process. Vessel and marine environmental data gathering from the IoT structure are mainly used in this cluster for maintenance purposes.
- Data simulation for communication purposes: projects not informed (or partially informed) by field data integrating big data, simulation,

[4] The PWC Industry 4.0 scenario framework identifies four steps in moving from a product-oriented to a platform-focused approach: (1) Core Product, the traditional base offering, (2) Digital Augmentation, digital interfaces and channels to augment the experience and to allow a variety of interaction models, (3) Digital Service, in which digitally enabled services are added to the physical core product providing an end-to-end solution to a broader customer need, and (4) Digital ecosystem, the product is embedded in an ecosystem for co-creation and additional value capture.

VR, and AHMI. The main examples are the virtual reality in marketing strategic communication and virtual sailing testers.

- Simulation analysis and optimization: projects not informed by field data in a non-integrated ecosystem. This group encompasses simulation software to predict real world performance and tools for manufacturing process optimization.
- Optimization through integration: collaborative projects developed for the marine and yachting industry to manage design phases, value chain or offshore and sailing operation.
- Optimization through generative processes: projects involving generative design tools to optimize and self-configure the product's shape according to the manufacturing process. In this cluster, we can also find collaborative platforms for both design and additive and collaborative manufacturing.

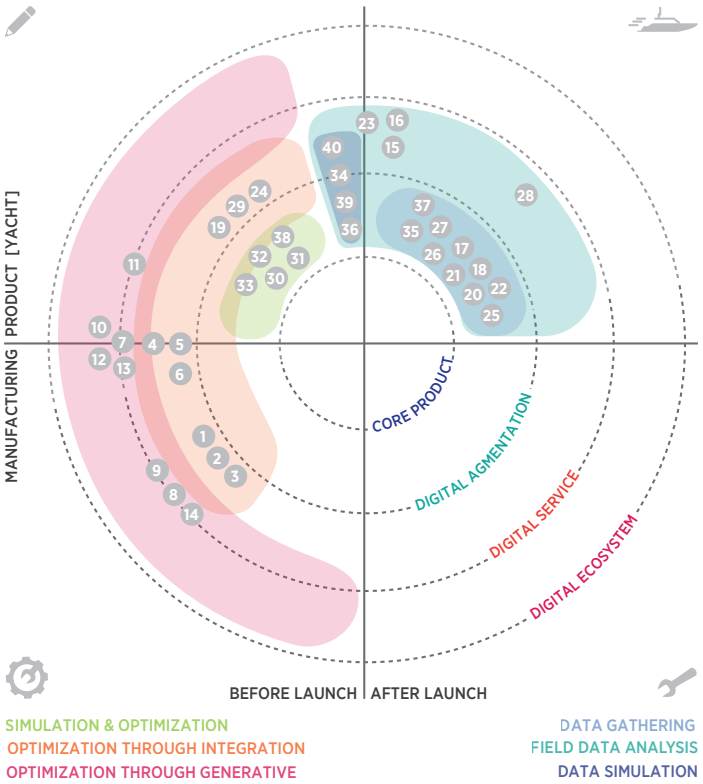

Fig. 1 – Map of case studies.

Case study mapping highlights a general lack of systemic vision of Industry 4.0 technologies. Digital data from field and user engagement are not yet employed in the design phase and are only partially used in the maintenance stage. This results in a disconnection between the after launch and before launch phases at the expense of input data design quality and quantity.

Looking at the purposes in the use of 4.0 enabling technologies, low consciousness cases are generally implemented in communication strategies, while collaborative strategies lead projects with a higher level of systemic integration and self-configuring processes. In particular, new communication media are emerging in relationships within companies and the yacht's end user, besides faster and easier access to information through digital platform and self-devices. Furthermore, these new media could embed digitally-enabled services to provide an end-to-end solution to a broader customer need. In terms of design and manufacturing, horizontal integration of digital data

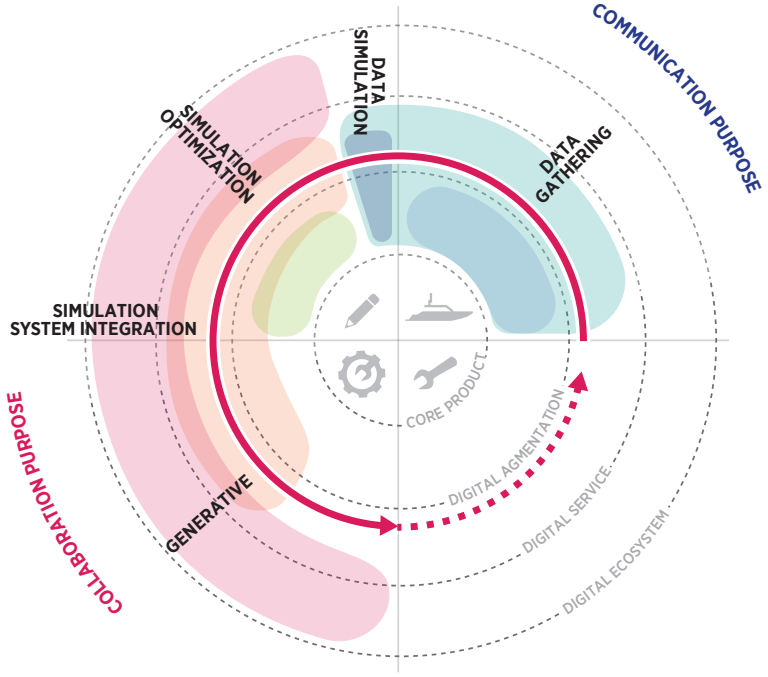

Fig. 2 – Yachting Industry 4.0 Forecasting Framework.

for simulation, optimization, and self-configuration (generative) process are arising. However, as shown in the map of case studies, the implementation in the use of collaborative platforms for optimization and generative design process does not make use of field data through the entire value chain.

The case study analysis highlights numerous unexplored opportunities in the yachting sector, and confirms the high potential of digital enabling technology in improving consciousness and interoperability during all steps of yacht design and manufacturing processes. The drivers and challenges explored for case study mapping are then summarized in the forecasting framework. The Yachting 4.0 Forecasting Framework (fig. 2, previous page) is the first research result. As a guiding backdrop for yachting 4.0 foresight activities, it is conceived as an open tool for future activities.

Yacht Industry 4.0 scenarios building workshop

A co-design scenario building workshop, the YI4.0sws, was organized and run by the Author with the aim of covering the two phases of Strategic foresight, namely *forecasting* and *visioning*. It had three objectives: (i) discuss and validate the scenario framework; (ii) explore and build alternative scenarios on yacht design 4.0, outlining drivers and criticalities; (iii) involve the specific industrial community and make it aware of the opportunities of digital technologies.

To achieve the intended research objectives, the workshop involved experts in the yacht design field. Specifically, participants in the scenario-building workshop were yacht designers and draftsmen in the yard and shipyard project, and production managers, yacht industrial association managers, experts in digital transformation and policymakers. A specific set of tools, the YI4.0sws Toolkit, was created to support the strategic conversation among participants, and to assist the development in progress of alternative scenarios.

The workshop was focused on Yacht Design practices, but a systemic view of the whole yachting sector was fostered. The activity was divided into four main phases: a general introduction on purpose and forecasting framework, structured brainstorming, a free envisioning session, and a scenario-building session exploring the gap between current and future technology. Though free envisioning and scenario exploration activities were described as a consecutive sequence, the two stages were often conducted in parallel in an iterative conversation among challenges and opportunities.

The workshop resulted in the creation of three visions and three Roadmaps towards Yacht Design 4.0.

Roadmaps to Yacht Design 4.0

The roadmaps were developed according to the three clusters of yacht product and production (Pollicardo, 2017): top of the line – encompassing a high level of product customization and looking toward the larger segment of super- and mega-yachts –, model-based – product with a lower value in terms of customization and an engineered production process – and semi-custom – model-based production with a high level of flexibility and customization of the core product. Furthermore, the roadmaps created in the YI4.0sws take into account contemporary challenges in the yachting sector as described by Camper & Nicholsons and Wealth-X (2017) and explored in the *framing* phase of this study. These challenges are recognized when creating a product-service value system and when enhancing customization and product flexibility.

Top of the line roadmap to digital product-service ecosystem

The first roadmap takes the peculiarity of the specific cluster's sector into account and proposes a journey toward a digital product-service ecosystem in which field data are transmitted seamlessly and in two ways between the yacht and its digital twin. Furthermore, personalized service and yacht components are designed based on field data gathered on a knowledge management platform. The first roadmap step is the digital augmentation of both the design project, i.e., 3D model of the yacht, and the product, i.e., the yacht itself. Yacht design modelling becomes parametric[5], while sensors and remote control networks are placed onboard, transforming the vessel into a connected object. User experience data are recorded on a knowledge management platform. Coupled with the use of big data analysis, the digital platform allows the development of onboard personalized service, including optimized and automated routing, maintenance and marina service, and legal insurance services, component and digital assets optimization and customization.

In this scenario, yacht design processes maintain their character of an iterative cycle of refinement steps. With the use of parametric design tools, which allow to generate a living digital model according to a predefined

[5] The relations between project dimensions are not directly drafted on a digital continuum space anymore (as in a CAD direct modelling tool) but depend on various parameters. This process is generally described as predictive modelling, as opposed to direct modelling, in which the descriptive modelling process converges manufacturing rationale and material proprieties (Oxman, 2006).

relational structure, the sequence of simulation and optimization steps are integrated into a unique analytical process on geometrical models.

In this contest, the living digital twin is managed by parametric design technologies and optimized by the result of the digital experience platform analysis. This scenario provides an integrated tool powered by real-time field data in which the designer can define the generic properties of a geometrical structure within a user-defined framework. Moreover, the design platform could allow multiple evaluative analyses and support collaboration among the various design and engineering teams involved in the yacht design process.

Finally, the digital twin, enriched by field data gathered on the digital platform, could be visualized through virtual reality digital devices both for augmented customer experience and manufacturing/maintenance purposes. The representation highlights not only the yacht feature and control gateways but also information on how the yacht, the systems, and the components operate throughout the whole life cycle.

Model-based roadmap to co-modular digital ecosystem

The second roadmap reflects on the recent debate on mass production and on the challenging shift to mass personalization. The move from mass production to mass personalization has been struggling worldwide in the industrial sector since the early ’90s, and is extensively discussed in theory and applications. However, the integrated use of Industry 4.0-enabling technologies seems to offer a solution to the dilemma between the economies of scale and scope triggered by the concept of mass customization (Brettel *et al.*, 2014).

In this context, the model-based roadmap envisions a journey toward an integrated modular digital ecosystem, in which the yacht product, design, and production processes consist of integrated (design-production-product) subsystems with few interdependent aspects serving as module links. Subsystems are then grouped in a unique platform by flexible combinations. In the future scenario, field data and customer needs could optimize the single modules via the virtual management platform.

A sequence of four steps divides the design process of the co-modular digital ecosystem scenario. (i) Definition of a pre-set of general conditions and parameters mirroring the first cycle of the yacht design spiral aiming at establishing the interdependent logical structure of the yacht based on configuration variables and on yacht design principle and constraints. (ii) Variant-based generation of subsystems according to market and trend research. This step also involves the definition of module links and the rational cor-

relation of subsystems. (iii) Variant optimization by field data from product performance (sailing and user experience), from the production process and from supply chain management. (iv) Variant selection, final product visualization, and evaluation by customers through virtual reality. In this case, the collaborative design process involves customers in flexible customization.

In this scenario, the design process is supported by a parametric tool involving generation and management of digital representations of physical, functional, and production proprieties of subsystems and of their rational/ construction links.

Semi-custom roadmap to generative-integrated ecosystem

The third roadmap proposes a journey in which virtual data from user experience and field measurements could inform the design phase during generative processes for higher optimization and personalization of project development. Indeed, the semi-custom sector features model-based products with a high level of flexibility and customization, in some cases already coupled with digital technology in design and production processes. The roadmap focuses on the generative design process. As argued by Kolarevic (2004), in the generative process, computational analytical techniques based on the finite element method are used to explore formal complexity and to accurately drive shape-forming processes. In this process, designers interact with the generative structures, their limits, and input, defining the grammar of shapes.

In this scenario, the previous parametric design process is shifting toward a computational process model of digital design (Oxman, 2006) under the impact of a new generation of associative algorithms. The linked and iterative cycles of design, analysis, simulation and optimization of the yacht design spiral do not describe the new paradigm of the yacht design process anymore. Furthermore, generative processes could take into account the "making level" of 4.0, enabling technology additive manufacturing and collaborative robotics.

Computational strategies in the yacht design process

The definition of the Yacht Design 4.0 Roadmaps was, in itself, a design matter. Underpinned by all the qualitative data and knowledge collected from case studies and by the co-design visioning activity, roadmaps are a synthesis of research results.

In the roadmaps, the journey toward a computational morphology system affects not only the design practice with the use of novel design tools but also the input data, the design process, and the communication media between designers and customers, and designers and manufacturing site.

As also suggested by the yachting 4.0 forecasting framework, 4.0-enabling technologies are driving the yacht design process toward a more digitally conscious and virtually collaborative environment.

The roadmaps highlight three different approaches to the yacht design process driven by digital and computational modeling tools: Digital yacht design spiral, Digital yacht module optimization cycle, and Generative yacht design tangle. At first, in the roadmap toward a digital product-service ecosystem, the yacht design process maintains its characteristic of an iterative cycle of refinement steps fed by real-time digital data. In the digital yacht module optimization cycle, the digital focus shifts to the logical structure in relations between elements and junction constraints.

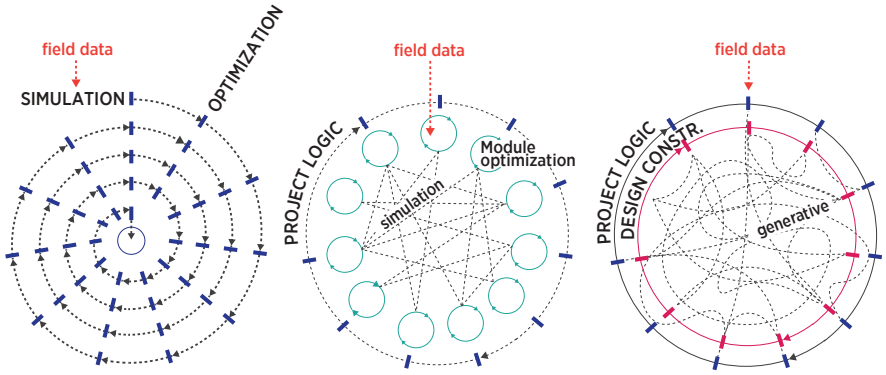

Fig. 3 – Approaches to the yacht design process driven by digital and computational modelling tools: (a) Digital yacht design spiral, (b) Digital yacht module optimization cycle, (c) Generative yacht design tangle.

Although the parametric and modular approach has increased the interoperability of systems and flexibility among geometrical relations, the exploration of yacht design alternatives is still limited by the manual operation of designers in varying individual parameters. In the generative yacht design tangle, instead, digital focus is on the creative process itself. An artificial intelligence is asked to explore the design space semi-autonomously to disclose options based on predefined generative rules, relations, and principles. In this journey, the designer enters the generative structures of the yacht

model, defines the project requirements and the grammar of shapes and, finally, evaluates the generative results.

Research evidence highlights three central possible and future shifts in yacht design practices.

- Input data are moving from analogue to digital, reframing the focus of the designer practice from measured data to inferred data. The Internet of Things will enable access to more extensive data. In parallel to analogue data, yacht designers could make use of a large amount of direct data measured by sensors and smart devices. In the roadmaps, digital data from production processes and intelligent vessels become the new fuel for design empowerment and customer involvement only if they can be fully understood within a qualitative context framework of previous analogue yacht design knowledge.
- The use of parametric and generative design tools is shifting "digital doing" from digital drafting to digital logic. When focusing on the design process, moving from direct modelling to parametric design and, then, to generative yacht design could fragment the dichotomy between creative thinking and the digital draft of vessel shapes. This focus on the reasoning level of the design process is highlighted in the purposes of generative and computational design processes (Rossi and Buratti, 2018): "creating responsive objects able to react to external stimuli by modifying the formal shapes while conserving the morphogenesis logic".
- The digital twin is modifying the approach to communication media toward a more collaborative media strategy. In the journey depicted in the roadmaps, it acts as a medium by virtually replacing the paper draft and drawing and project renders. As a shadow of projects embedding all physical and digital assets, the digital twin could also be used as a co-design tool between yacht designers and engineers, as well to involve customers or manufacturing teams and supply chains in project definition.

Conclusions and criticalities

Toward a Yacht Design 4.0 is an exploratory study of the topic of Industry 4.0 in the yachting field. Strategic thinking to explore alternative futures was prioritized, due to the freshness and the unexplored complexity of the Industry 4.0 topic in yacht design practices. For this reason, the research outcome

was placed at a conceptual level. Hence, the results of the doctoral study still need to be pragmatically tested and verified by applied research projects both in shipyards and in design studios.

Although the research achieved its objectives, there are some limitations and criticalities, which should be discussed. First of all, the research focused on the level of yacht design processes, also exploring the manufacturing and sailing process as directly connected with the digital integration of 4.0, and not on the product level and its aesthetics. Second, though a case study analysis was carried out with an international point of view, the co-design workshop was conducted with a focus on the Italian Yacht Industry. The specific characteristics of semi-custom and custom production of Italian yacht craftsmanship fit a journey toward more personalized products but lacked a vision of the opportunity of mass market production. Furthermore, the co-design workshop was a unique experience that could only be reiterated to get more informed results.

Finally, workshop discussions point out numerous criticalities at different levels that should be considered for future study in the field: (i) the emerging role of digital yacht designers and the new skills necessary to face the digital transformation; (ii) the design of specific tools for yacht design co-creation; (iii) the release of data used and data protection; (iii) the challenges on cybersecurity in maritime sectors.

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