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Sustainability in yacht and vessel design through smart spaces: opportunities offered by digital technologies and new materiality

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Abstract. The research investigates the role of digital technologies and ICS materiality in onboard immersive spaces to reframe sustainable vessels' design. Digital technology and reactive materials have been gradually coming into the world of the pleasure maritime industry, implying new possibilities of experiences for users. Despite that, the yacht and vessel design debate lacks on sustainability perspective for these emerging technologies. In this scenario, the paper explores case studies and scenarios, analysing that through the lens of Smartainability. This study is part of a wider research conducted by the Design Department of Politecnico di Milano on the potentials of smart technologies and ICS materials on the new cruise vessels and yachts, that involves case studies analysis, interviews, scenario building, and design concept workshops. The results point out how digital technologies and ICS materials break down the barriers made up of a simple physical fitting through flexible immersive experiences. Their contribution to a sustainable development is both direct and indirect, by replacing or avoiding assembly processes and lightening the vessel itself. The research demonstrates how technologies push and design for sustainability are not distant approaches, but they rather contribute to the effectiveness of sustainable yacht and vessel design practices.

Keywords: Immersive spaces, Cruise Vessel Design, Yacht design, Digital technologies, Smartainability, Sustainable design, Merged reality, ICS materiality

1 Introduction

The great development of smart systems since '90s has significantly influenced every economic field, both leading and minor sectors, bringing industry to an actual 4th industrial revolution. The technological innovation has affected even the cruise and yachting sector, transforming cruises and vessels from “floating accommodation and catering infrastructures” to “technologically-enabled multi-experience platforms” (Papanassis, 2017) and determining so a new generation of vessels: the ‘smart ships’ and the ‘smart yachts’. Industry 4.0, Internet of Things and intelligent products are

profoundly transforming not only the design process of a nautical project (Bionda, 2020) but also the formal references, the input data, the communication strategy, and the customer experiences.

The ‘smart features’ consist of the use of digital technologies and reactive materials in on-board interaction, online check-in, radio-frequency identification (RFID) armbands, cruise-planning app, virtual balcony, nemo rooms and staterooms, high-speed internet connectivity on board, robotic technology and transformable public venues, mainly (Papathanassis, 2017). This significant passage to smart features is recent. In the cruising sector, the cruise vessel Royal Caribbean’s Quantum of seas, launched in 2014, has been defined as the first smart ship. In yachting just few future design concepts are developed while the majority of digital yacht design application lacks a whole product-service system strategy and product vision.

In the current yachting and cruising market, innovation and sustainability are reported as the primary trends for the coming years (Boat International, 2020; CLIA, 2019; CLIA, 2020a), with the recent inclusion of health safety due to the contingent pandemic emergency of covid-19. These reports reveal the advancement in cruise sector toward a sustainable development, achieved through the adoption of cutting-edge maritime environmental technologies, such as Liquefied Natural Gas (LNG), Exhaust Gas Cleaning Systems (ECGS), Advanced Wastewater Treatment Systems and Shore-Side Power. Moreover, both cruising and yachting reports indicate further sustainable solutions, consisting of battery propulsion, advanced recycling, reduced plastics, efficient lighting, solar energy and fuel cell technology.

In this framework the debate on digital onboard technology is emerging and becoming more influential in the maritime sector, but it still lacks on sustainability perspective. For this reason, the research here presented is the first approach in connecting and merging two different fields of studies that, since today, were discussed separately in the yacht and vessel design debate: digital technologies and ICS materiality for immersive interaction, and sustainability in vessel interior design.

1.1 Theoretical framework

This paper presents the state of the research on smart vessels conducted by a research team of Design Department in Politecnico di Milano on the design challenges offered by smart technologies and new classes of materials in yacht and cruise vessel sector.

Regarding technology, recent studies on smart techs have proved the high potential of them towards sustainability, through the evaluation of their direct and indirect impacts on the environment. In the report “SMART 2020: Enabling the low carbon economy in the information age.” published by Global e-Sustainability Initiative (GeSI), an association composed by over 30 leading ICT companies, ICT technologies have been estimated to reduce 15% of predicted total global emissions (five times their own footprint) for 2020 by enabling “smart motor systems,” “smart logistics,” “smart buildings,” “smart grids,” and “dematerialization” (GeSI, 2008; Hilty et al., 2014). In particular, the employment of digital technologies can supply the following environmental benefits: simplification of mechanical components or replacement of them by software, enhancement of evergreen design, the development of remote services, the reduction of

transport of physical goods, the optimization of service tasks and travel routing by using apps, the synchronization of the supply chain of product and services and the building of a shared network and database of products (Li & Found, 2017).

Looking at materials, the recent emerging of new classes of materials has determined the redefinition of the domain of design materials and materiality in the world and new materials have been recognized to have overcome the conventional smart materials, by showing further levels of intelligence: the ICS (Interactive, Connected and smart) materials. These new materials present the following features: they are able to exchange information with humans and not humans, they are linked to other entities or an external source, they are able to respond to external stimuli and they are programmable, not only through software. The ICS materials are demonstrating how technology is hybridizing all physical media, transforming also traditional materials in more interactive, connected and intelligent ones (Rognoli, 2020).

The mutual influence between smartness and sustainability has been recently stressed by a new term coined by some researchers, smartainability, aimed at estimating how much smart technologies contribute to increase energy efficiency and environmental sustainability in a city. In particular, smartainability is a methodology which, through qualitative and quantitative information, evaluates the potential benefits enabled by functionalities offered by smart technologies, according to four different dimensions: environment, economy, energy, living (Girardi & Temporelli, 2016).

As reported by Dewberry and Sherwin (2002), design can play an important role in the sustainable development, influencing up to 80% the environmental impacts of its result, intended as a product or a spatial configuration, over its life-cycle (Graedel & Allenby, 2003). Focusing on life-cycle analysis (LCA) approach, the dimension of environmental sustainability estimates the cruise sector to produce different impacts on the environment: infrastructure impacts (e.g. ship construction), operational impacts (e.g. use of energy, water and air quality pollution), distribution impacts (e.g. transfer of people to and from departure and destination points), use impacts (e.g. water consumption), waste impacts (e.g. waste for ships) (Johnson, 2002). The same impacts could be applied to the yachting sector as part of the same industry cluster.

2 Methodology

Innovation can no longer be considered as a result of occasional inspirations, but has to be managed in a systematic way, in order to keep a long-term competitiveness in the market. There are several methodologies that can stimulate systemic innovation, including the Theory of Inventive Problem Solving (TRIZ), that can help the effectiveness of the design activity and increase the performance of a technical system (Navas, 2013), and Smartainability, that evaluates the impact of smartness and sustainability in a complex system. In this research, the TRIZ approach may improve the smartainability methodology in the evaluation of sustainability of smart technologies onboard, by revealing technical contradictions and harmful effects of innovation.

The research methodology is based on a qualitative analysis of case studies aiming at answering the following research question: how can smart technologies and reactive materials onboard improve the environmental sustainability of vessels?

Case studies have been collected in a theoretical sampling (Eisenhardt, 1989) based on a cruise vessel & yacht cluster with smart features. The sampling includes 10 global cruise companies registered in CLIA (Cruise Lines International Association) (CLIA, 2020b) with the presence of smart ships (Vafeidou, 2019) and of 4 yacht companies with the presence of smart yachts, and on the domain of environmental sustainability, which regards the respect of different ecosystems such as in historical tourism, sea, sand and sun tourism (UNEP & WTO, 2005). Fourteen case studies from Cruise Industry, three from Yacht Industry, five from university courses on cruise design and three from university courses on yacht design have been collected from January 2020 to January 2021.



Fig. 1. Selection of case studies from university activities: (a) Indoors with solar leaf panels, (b) Indoors with smart floor, (c) Feel the cities, (d) Glowrious, (e) The floating forest, (f) Heckquilibrium.

	Context	Case study	N.	Unit of analysis	Year	
	Company	vessel		Environment affected by a sustainable action		
CRUISE INDUSTRY	Carnival Cruise Line	Spirit	01	Cabin with OceanView	2017	
	Celebrity Cruises		Celebrity Edge	02	Magic Carpet	2018
			Celebrity Solstice	03	Upper deck with solar panels	2008
				04	Upper deck with The Lawn Club	2008
				05	Indoors with motion-activated LED lights	2008
			Costa Cruises	Luminosa	06	Indoors with LED and fluorescent lighting
	Cunard Line	Queen Mary 2	07	Planetarium	2003	
	Disney Cruise Line		Dream	08	Magical Porthole	2011
			Disney Wonder	09	Oceaneer Lab	2016
	Norwegian Cruise Line	Norwegian Joy	10	Galaxy Pavilion	2017	
	Royal Caribbean		Oasis of the Seas	11	Central Park	2009
			Quantum of the Seas	12	North Star	2014
				13	Virtual balcony	2014

	TUI Cruises	Mein Schiff 3	14	Indoors with energy efficient windows	2014
UNIVERSITY (CRUISE)	Costa Cruises (fictional project 1)	Costa Smeralda (Early in the process)	15	Indoors with solar leaf panels	2019
	MSC Cruises (fictional projects 2-3-4-5)	Meraviglia (Digital Stadium)	16	Indoors with smart floor	2019
		Meraviglia (Take a walk on trash side)	17	Recycle-lab	2020
		Meraviglia (MSC Fun)	18	The tasty lab	2020
		Meraviglia (Connect to Greenline)	19	Feel the cities	2020
YACHT INDUSTRY	Ken Freivokh	M/Y Fortissimo	20	Nemo room	2014
	Arcadia Yachts	Sherpa XL	21	Roof with solar panels	2020
	Sanlorenzo Ferretti	-----	22A, 22B	Indoors with VK Design glass	2020
UNIVERSITY (YACHT)	Yacht (fictional projects 6-7-8)	Glowrious	23	Saloon with photo-luminescent smart glass	2019
		The floating forest	24	Vessel itself	2019
		Heckquilibrium	25	Yacht interior with light-emitting smart textiles	2019

Fig. 2. Case studies collection: 14 cases from Cruise Industry, 3 from Yacht Industry, 5 from university courses on cruise vessel design, 3 from university courses on yacht design.

After the data collection, a cross case analysis based on multiple cases has been conducted (Gibbert & Ruigrok, 2010) using the ‘smartainability’ approach. Case studies are then validated through the use of multiple sources of evidence (i.e. literature, archival documents, interviews and observations), the construction of a chain of evidence (i.e. research questions > data collection > data analysis > discussion > conclusions) and a review draft of case study report by key informants (i.e. cruise companies, design offices for cruise companies) (Yin, 2003).

Taking advantage from the usual comparison between cruise ships and small cities (Ward, 2019), the research proposes an analogy between smart ships and smart cities, applying the smartainability methodology. This approach allows an estimation of sustainability of smart cities thanks to innovative technologies and has the purpose to define the functionalities (services) activated by one or more enabling technologies. Functionalities create benefits that are classified in different sustainable dimensions (Environment, Economy, Energy, Living...) and are evaluated with qualitative and quantitative indicators, which express the contribution (e.g. the pollutant emissions reduction) of smart technologies compared to traditional technologies. Then a two-dimensional array is filled with functionalities and benefits, in order to check which functionalities are activated by the enabling technologies (Girardi and Temporelli, 2016).

So, based on the methodology of Smartainability, the analysis provides qualitative indicators, which estimate the impacts of smart technologies in different dimensions of environmental sustainability compared to impacts of less advanced technologies. The parameters involved in the analysis are the technological development, materials development, sustainable resource use, sustainable enablers and types of impacts on environmental sustainability.

Technological development				
Low	Middle - High		Smart	
Materials development				
Inactive	Reactive		Proactive	
Sustainable resource use				
Infrastructure impacts	Operational impacts	Distribution impacts	Use impacts	Waste impacts
Sustainable enablers				
Education & promotion about environment		Entertainment about environment		
Types of impacts on sustainability				
Direct impact		Indirect impact		

Fig. 3. Parameters for the case studies analysis.

The category of technological development differentiates the contribution of technology towards sustainability depending on that being low, medium or high. In this sense, the technology continuum developed by the Texas Assistive Technology Network (2002) best explains this classification from a Design for Disassembly (DfD) perspective, indicating the degree of complexity of electronic component assembly, according to low, middle, high tech. The category of materials development distinguishes classes of materials according to their degree of interactivity, smartness, and connectivity, and to their technological and systemic complexity. The ‘ICS materials map’ expressed by the Material Experience Lab (Parisi et al., 2018) best explains this classification by indicating three categories: inactive, reactive and proactive. The categories of sustainable resource use and sustainable enablers, adapted from the sustainable taxonomy of Townsend (2015), identify possible sustainability effects of a technological system. In particular, the taxonomy distinguishes technologies which have a more sustainable use of natural resources, from those ones support the sustainability objectives through financing, education, regulation and component technologies. The sustainable resource use category includes the different impacts produced by the cruise sector on the environment: infrastructure, operational, distribution, use and waste impact (Johnson, 2002). The sustainable enabler category involves: education & promotion about environment, entertainment about environment. The classification of the types of impacts on sustainability is focused on ICT technologies and distinguish two main kinds of impact of ICT: direct and indirect (GeSI, 2008). The direct impact is referred to the life cycle of ICT components and evaluates, for example, the emissions caused by producing them and supplying them with power, whereas the indirect impact of ICT is linked to the concept of dematerialization and estimates, for example, the emissions avoided by using a smart solution (Hilty et al., 2014).

Categories from the data analysis have been compared in a cross-case pattern, in order to examine the relationships among the several classifications and to evaluate the specific contribution of smart technologies and materials onboard toward environmental sustainability (Fig. 4).

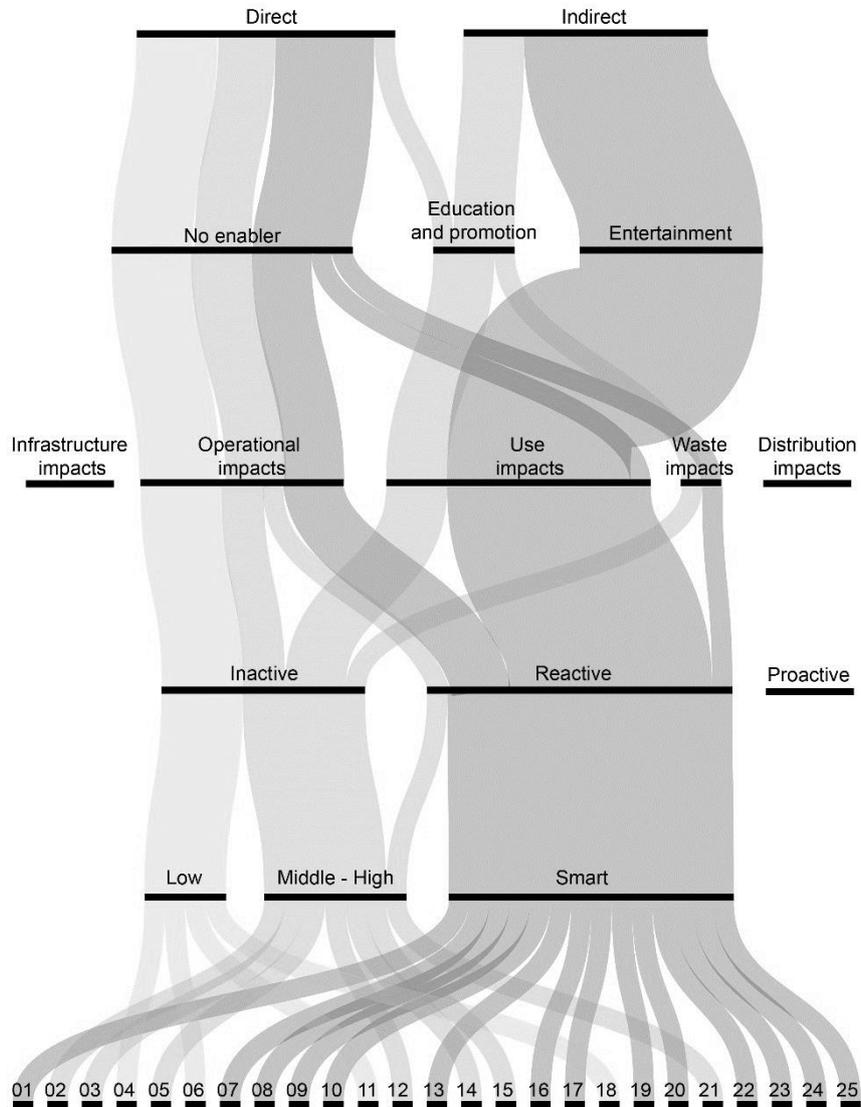


Fig. 4. Diagram of case studies analysed for the relationship smartness and environmental sustainability.

3 Findings and discussion

Case studies show a variety of applications of sustainable solutions. The cases' collection demonstrates that the cruise sector is experimenting more than the yachting sector with the sensorial dimension of smart technologies and reactive materials improving sustainability impact onboard.

Cruise and yacht lines express a diversified commitment to sustainable development with low, medium and smart technological content. Smart technologies are proved to contribute to sustainable development, by a direct impact, in relation to the evaluation of life cycle components, or by an indirect impact, by replacing or avoiding processes and productions that cause harmful emissions or consume non-renewable energy (GeSI, 2008). Even in this case studies analysis, companies have shown a focused interest on smart technologies related to the entertainment field, which represents the main source of economic income for the cruise and yacht business.

Case studies with low technologies show a coherent behaviour through the several parameters of analysis, revealing a strong connection between low tech and inactive materials, no property of sustainable enablers and just a direct impact on environment. Regarding the cruise and yacht sectors, these cases show a focused sustainable resource use on the operational impacts.

Case studies with middle-high technologies show a more varied behaviour through the several parameters of analysis, except for the strong connection between middle-high technology and inactive materials. As regards the sustainable resource use, they reveal to generate operational, use and waste impacts. Unlike the previous cluster of cases, they can be either sustainable enablers, in relation to environmental education and promotion, or not, and they can have either a direct or an indirect impact.

Case studies with smart technologies show an almost coherent behaviour through the several parameters of analysis, revealing a concentration of impacts in some areas. They display a strong connection between smart tech and reactive materials, a focused action on the use impacts with little interventions on operational and waste impacts and a more marked link with the indirect impact.

Blank gaps in the clusters indicate that there are other potential areas to explore, either through independent research or by drawing from other disciplines such as civil architecture (e.g., solar leaf panels or smart floors). Compared to reactive material, proactive materials are more advanced in the programming of every stage of fabrication and use, but they are not yet applied in cruise and yacht sector. Indeed, these materials can play an important role in sustainability at different stages of product life. The research has involved the environmental impacts of on-board activities, so excluding the infrastructure and distribution impacts, which are categories referred to on-land operations by cruise and yacht companies. In particular, the infrastructure impacts represent those ones caused by the construction of harbours and terminals for passengers, whereas the distribution impacts are those ones caused by the movement of tourists and goods for the supply of cruise ships (Tizzani, 2014). A more complete understanding of the environmental sustainability of cruise ships should include all the categories of impacts expressed by the life-cycle analysis (LCA) approach and specific tools by the TRIZ approach, which can reveal the degree of ideality and the contradictions of the smart system onboard.

Low tech	Middle-High tech	Smart tech
<ul style="list-style-type: none"> - Inactive materials; - Operational and waste impact; - No enabler; - Direct impact. 	<ul style="list-style-type: none"> - Inactive and reactive materials; - Operational, use and waste impact; - No enabler / enabler for educational and entertainment purposes; - Direct and indirect impact. 	<ul style="list-style-type: none"> - Reactive materials; - Operational and use impact; - No enabler or enabler for educational and entertainment purposes; - Indirect impact mostly.

Fig. 5. Resulting concepts from the analysis of case studies related to smartness and environmental sustainability.

Future design concepts and university workshop projects prove the effectiveness of digital technologies and new materiality in creating sustainable immersive spaces, increasing their impact on the overall naval architecture. Despite this, case studies from the contemporary pleasure maritime industry are few and isolated. New design experiences and research should include industry participation to leverage the impact of these preliminary results. Furthermore, the sustainable development of the yacht and cruise sector cannot only concern the vessel themselves, but must include everything connected to them, from production to cruising. For this reason, the proposed approach should include marine and port design. Vessel companies already express a growing interest in the research, specifically focusing on digital technology and ICS materials for entertainment purposes and fun-ship design. The discussion on how smart technologies can contribute to sustainable development is arising, impacting on goods and non-renewable energy consumption in maritime assembly processes, sailing energy efficiency, GHG emissions, and waste management.

Taking into account the TRIZ approach, any technical system tends to ideality. Specifically, the ideality of a system is the ratio between useful effects and harmful effects (i.e. system costs increase, space occupied, noise produced...) and can be increased in several ways: eliminating auxiliary functions, eliminating some elements of the system, considering self-service possibilities, replacing elements or the whole system, changing the operating principle on which the system is based, use of resources. Moreover, the TRIZ approach aims to remove technical contradictions, by considering which parameters deriving from innovation deteriorate other existing parameters of the technological system (Kaplan, 1996; Terninko et al., 1998). By the inclusion of the harmful effects and the removal of technical contradictions, the smartainability approach would supply a more complete evaluation of sustainability of the smart system onboard.

4 Conclusions

Though the design discipline is central in cruise vessel design, the scientific literature in the sector is generally developed with an engineering approach. Indeed, most of the scientific articles are focused on naval architecture, structural engineering and technical materials. This research lays on the ground of spatial design, with the integration of

theoretical frameworks from different disciplines, and aims at shifting the boundaries of cruise vessel design toward the specialized area of interior, driven by a technological innovation and a sustainable process. It is a first approach in connecting and merging two different fields of studies that, since today, were discussed separately in the yacht and vessel design debate: digital technologies and ICS materiality for immersive interaction, and sustainability in vessel interior design.

The methodological approach of the present research represents a step ahead in the research of cruise vessel design. The research demonstrates that the smartainability approach could overcome the boundaries of the original field of study, smart city, to be a tools for other contexts affected by smart innovation, such as the cruise and yacht one.

The smartainability approach highlight as the sustainable development of the yacht and cruise sector cannot only concern the vessel themselves, but must include everything connected to them, from production to cruising. For this reason, a further development on how digital technology onboard could impact on the marina/port infrastructure and tourism distribution (tourists and goods for the supply of cruise ships) is recommended. A more complete understanding of impact of digitalization on sustainability can be explore linking the smartainability approach with the existing TRIZ tools. As argued by Jones and Harrison (2000) tools such as the 40 principles, SU field analysis, 76 standards or the separation principles, could help generate new solutions to problems encountered in sustainable design expecially evolving towards ideality, where environmental impacts are unveiled or absent in the first design concept definition.

Lastly, the evolution of technologies implies opportunities and, at the same time, the appearance of critical factors, such as the management of personal data and the development of a responsible technological innovation.

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