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Research Article

Smart technologies and dematerialization as new opportunities for the design of more sustainable ships: Case studies in cruise vessel design

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Abstract

In the last 20 years cruise ships have increased in number and grown in size, developing oversized cruise vessels known as 'mega ships'. In the last few years, a new generation of more innovative ships, 'smart ships', have become a growing phenomenon, and may represent a more sustainable alternative to the growth of mega ships. Smart ships can produce new experiences on board and have new designs of the interiors and exteriors of ships. Through an analysis of case studies, this research highlights state of the art of smart ship design. The results provide more information on how smart technologies and new materials can help ships become more sustainable.

1. Introduction

In the past 20 years, according to the annual report of the Cruise Lines International Association (CLIA), cruise passengers from all over the world have increased from 9.6 million (2000) to about 30 million (2019). As the number of passengers has grown, the number of ships and the size of cruise ships have also increased, giving rise to the development of 'mega ships' that have capacities exceeding 120.000 GT (Gross Tonnage). Simultaneously, a growing environmental awareness has spread all over the world, affecting various economic sectors, including cruise tourism (Genç, 2016). The consequent growth of itinerary restrictions, security mandates, and health and safety risks has led the cruise industry to reflect on the concept of sustainability (Papathanassis, 2017). As a result, in the report "2020 State of the Cruise Industry Outlook", the CLIA highlighted that the most important trends in the cruise industry for the coming year will be innovation and sustainability (CLIA, 2019). In particular, the report has indicated the primary sustainable actions which must be implemented in new ships. These consist of innovative technologies and cleaner fuels: the adoption of Liquified Natural Gas (LNG), Exhaust Gas Cleaning Systems (ECGS), Advanced Wastewater Treatment Systems, Shore-Side Power, and the use of plastic-free products. In line with this initiative, Costa Cruises has launched a new generation of sustainable ships. The maiden ship, called the Costa Smeralda, was awarded the "Green Plus" international statement of sustainability. The Costa Smeralda is powered both in port and at sea by liquefied natural gas (LNG), considerably reducing the emission of toxic gases into the environment. Furthermore, the energy consumption is reduced thanks to an intelligent energy

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management system. Additionally, a policy of 100 % separation of waste on board has resulted in the reduction of food wastage and a total elimination of plastics (Costa Cruises Press Office, 2019). The main limit to its sustainable features is the oversized measure; Costa Smeralda is currently the 4th largest ship in the world (Camosse, 2018).

The 2 concepts of 'smartness' and 'sustainability' are indeed not separated, but mutually related, contrary to what appearances suggest. This has led some researchers to coin the term 'Smartainability', combining the 2 terms together into a new word (Girardi et al., 2016). By definition, smartness is a word that describes technological, economic, and social developments affected by new innovative technologies such as sensors, big data, open data, new ways of connectivity, and the exchange of information (e.g., Internet of Things, RFID, and NFC) (Gretzel et al., 2015). Sustainable development, on the other hand, is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). As described by Li and Found (2017), technology can play an important role in environmental sustainability through the following actions: simplification or replacement of mechanical components with software, enhancement of evergreen design, development of remote services to supplement or replace traditional services performed on-site, reduction of transport of physical goods, optimization of service tasks and travel routes through the use of apps, synchronization of supply chains of products and services and, finally, establishment of a shared network and database. According to a more in depth description given by the WCED (1987), sustainability is a complex concept that describes the ecological, economic, social and cultural developments of a system. In ecological terms, a sustainable cruise tourism must respect the different ecosystems of historical sea, sand, and sun tourism; in economic terms, it must enhance the welfare of destination societies, by protecting local resources and improving their conditions; in social and cultural terms, it must respect the cultural diversity of crew members and passengers (Genç, 2016).

As reported by Dewberry and Sherwin (2002), design plays an important role in sustainable development. A project initiated with sustainability in mind can influence up to 80 % of the environmental impacts produced over its life-cycle. In this perspective, Genç (2016) stated that cruise ships' interiors must be designed in a flexible form, so that they can be used for alternative activities such as conference venues, business meetings, educational tours, family reunions, and cultural events. By achieving this flexibility of space, ships can avoid having substantial monetary losses from unsold cabins and ensure that ships operate with full capacities. Design can also contribute significantly to environmental energy saving through the use of smart technologies and the reduction of material consumption. For example, Nolich et al. (2019) published an innovative research project concerning 'e-cabins', in which Internet of Things (IoT) is used for automatic and remote actions, such as opening windows and turning on/off the air conditioning system, depending on whether the passenger is in the cabin. On the same path, Świątek (2013) has proposed dematerialization in order to gain more sustainable buildings. According to this author, dematerialization can be realized at different levels: optimization, substitution, and transformation. At the first level of optimization, there is a material reduction (by size, volume, or mass). At the middle level, there is a replacement with other materials. At the highest level of transformation, there is a material replacement with a service. Studies have shown that the best result in sustainability, with a reduction in mass, energy consumption, and emission in life cycle framework, comes from a transformative approach.

As described by McCartan et al. (2015), dematerialization is a phenomenon that has been taking place for several years in the interior layout of cruise ships, where spaces have become more flexible and fluid, creating a continuous path flow path for passengers. Moreover, the reduction of material is accompanied by a trend that provides for the inclusion of natural elements inside and outside ship spaces, creating, for example, wide green courtyards with abundant plant life (e.g., Royal Caribbean Oasis and Allure of the Sea), or decks with half an acre of real grass growing on it

(e.g., Celebrity Cruises Solstice-Class). As explained by McCarten et al. (2015), this revolutionary approach to the design derives from biological sciences; the sustainability of environments is not its sole purpose but, rather, the focus is on the psychological well-being of customers by providing a restorative experience. This type of design approach is called 'biophilic design'. On the other hand, the reduction of materials has led to a simplification of many traditional decorations which characterized the interiors of passenger ships in the past. This trend has signified a passing from the original eclectic style and the following 'cosmetic design' of Farcus, which provided for an extensive use of decorative elements (Antonucci, 2009), to a more minimalist style. Elaborate decorations have been slowly replaced by LED lights and digital technologies, thus creating more flexible and lighter environments. As an example, video projections, already widely used in other tourist contexts, such as in exhibitions and art installations or in video mapping on the facades of historic buildings, can offer new immersive emotional and multisensory experiences (Piardi et al., 2012).

The sustainable development of the cruise sector cannot only concern the ships themselves, but must include everything connected to them, from production to circulation. For this reason, sustainable design must also include the terminals and port spaces dedicated to cruise ships. We must, therefore, also speak of "green ports", focusing on the value of energy consumption, the production of discharge, and the collection of waste while the cruise ship is stationary in port. In 2011, Genoa (Italy) powered the harbor quay, using solar panels, thereby significantly reducing CO_2 emissions (Tizzani, 2014). In the context in which cruise vessels are moving toward a more sustainable and smarter development, the question becomes: can smart technologies and dematerialization contribute to the sustainability of vessels? From a design perspective, very few authors have analyzed how new technologies are changing spaces in cruise vessels, particularly in respect to the concepts of smartness and sustainability.

2. Materials and methods

The Faculty of Design of Politecnico di Milano has been engaged in research and educational activities on cruise vessel design for several years. Recently, researchers have been focused on studying the contribution of digital technologies and smart materials in the ship sector, and how these innovative features are changing marine interiors. Focusing on the educational experience, the Interior Design bachelor's degree course in Milan has supplied many interesting case-studies in recent years; in particular, the Design Course for the academic year 2019 - 2020, held by Professor Silvia Piardi, Alessandro Villa, and Luca Mori, incorporated hands-on projects set in cruise ships such as Costa and MSC cruises.

The first step of the research involved an analysis of case studies picked from industry and educational experience, selected through the key concepts of 'smart tourism' elaborated by Navío-Marco et al. (2018): "everything connected (Internet of Things, 'smart phenomenon', wearables), convergence between the physical and digital worlds, big data and analytics, ontology and semantics, AI, robots, gamification". Next, case studies were grouped in 3 clusters, through the categories defined by Milgram and Kishino (1994) within the Reality-Virtuality Continuum: augmented (AR), merged (MR), and virtual (VR) realities. The analysis results were transferred to a diagram, created according to the following parameters: convergence vs divergence between the physical and digital worlds, and information vs entertainment purpose. Their results have shown a greater interest from the cruise industry in entertainment over information, and in virtual reality rather than augmented, while there has been very minimal interest in merged reality.

The second step investigated the level of sustainability of new 'smart ships', focusing solely on ecological aspects, and thereby postponing the study of the development of economic and social aspects to a later step. The level of sustainability was measured through a series of qualitative indicators such as energy efficiency, water management, greenhouse gas (GHG) emissions, waste management, quality of materials and products, environmental promotion and education,

environment-related entertainment, and management and monitoring. These parameters were qualitative, since they indicated the specific actions carried out by the various cruise lines and, therefore, did not measure the quantity of certain elements.

2.1 Case study analysis and discussion

Case studies were collected from March to April 2020, 3 from the didactic experience, based on the design of smart ships owned by the Costa and MSC cruise line fleets, and thirty of them selected from the following companies: AIDA Cruises, Celebrity Cruises, Costa Cruises, Crystal Cruises, Cunard Seabourn Ltd, Disney Cruise Line, Holland America Line, MSC Cruises, Norwegian Cruise Line, Oceania Cruises, Princess Cruises, and Royal Caribbean International. The selected case studies were then grouped in 3 clusters, representing the level of technological development from a sustainable perspective: zero/low, middle/high, and smart. This classification aimed to show how technology could contribute to the ecological sustainable development of cruise ships, and was an adaptation of the assistive technology continuum from low to high tech tools (Texas Assistive Technology Network, 2002) (**Figure 1**). The first cluster included case studies in which environmental impact had a zero/low technological contribution, showing the following properties: no/limited electronics, little maintenance, and provision of manual activities for users. The second cluster included case studies which had more/complex electronics, implying some/more maintenance, and provision of manual/digital activities for users. The third cluster included case studies that represented further advancement of high tech tools through the addition of smart features.

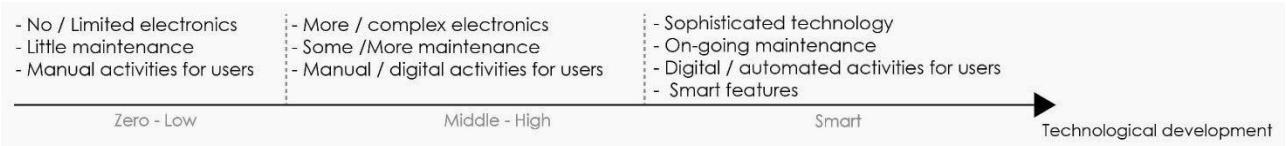

Figure 1 Criteria for the realization of three clusters in the case studies' diagram (adaptation of the AT continuum from low to high tech tools).

These clusters demonstrated that the smart features of new ships are not always directly linked to sustainable development. Therefore, technology and sustainability can be stated to travel on parallel tracks; as a consequence, some ships can be very smart from a digital and connectivity perspective, but not sustainable in a technological way. The several case studies derived from various fields of research, all related to cruise ships, from architecture and interior design to engineering and environmental technical physics.

2.2 Design of smart ships affected by zero/low technological development in ecological sustainable aspects

In analyzing the concepts of innovation and sustainability, the cruise industry has approached innovation in a more gradual way. Beginning in the 1990s, much emphasis was given to technologies related to entertainment, hence the name of 'fun ships'. On the other hand, sustainability has come into focus more recently, due to an increasing global awareness towards the protection and the enhancement of the environment, and also due to the spread of itinerary restrictions and the development of environmental regulations (Dowling and Weeden, 2017).

From a design perspective, there are various fields in the ecological sustainable development realm with zero/low technological impact that can be examined. As highlighted in the diagram of case studies (**Figure 2**), these include energy efficiency, the use of eco-friendly materials and products, environmental-related promotion and education, and environmentally-related entertainment.

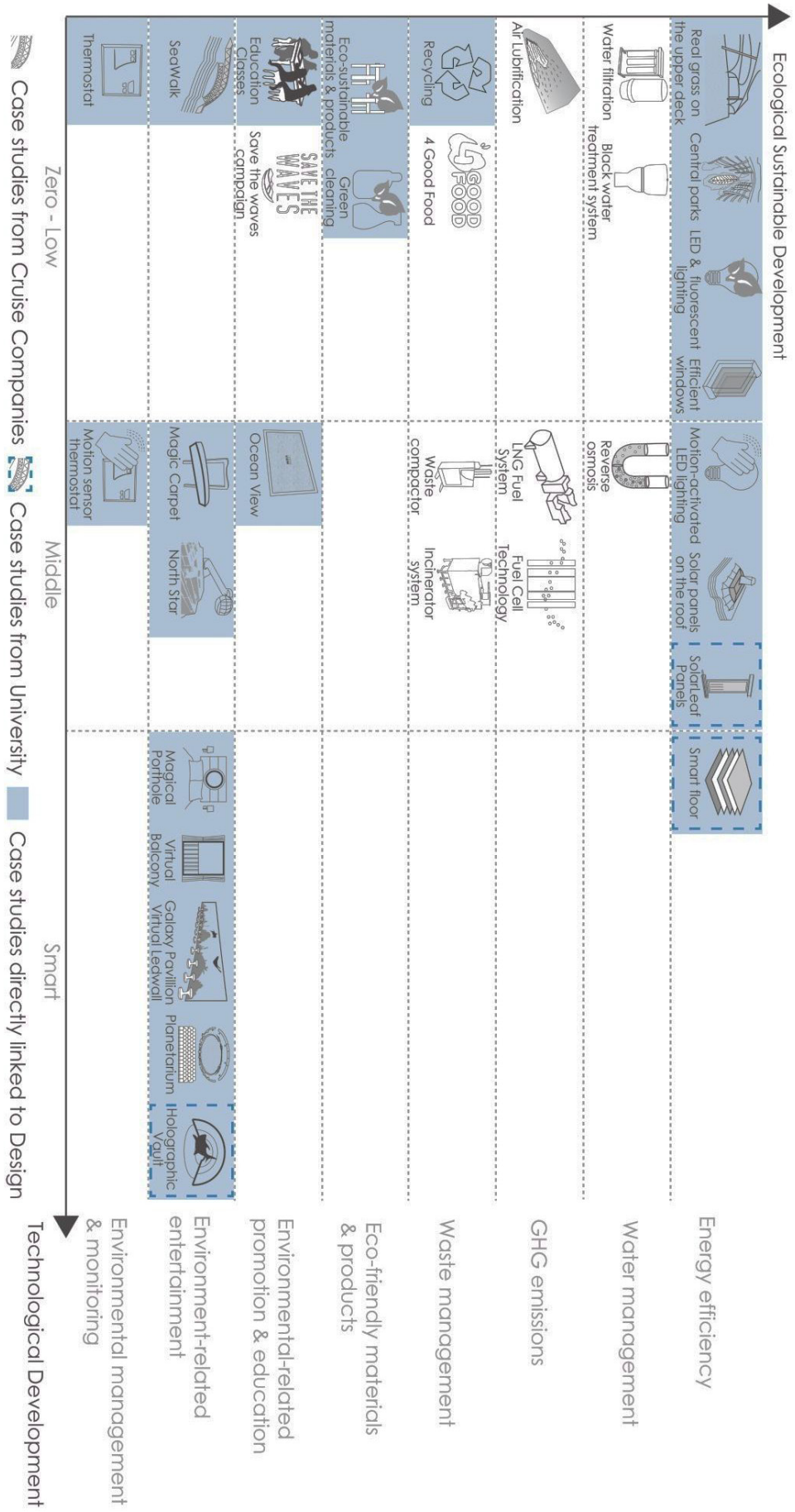

Figure 2 Case studies' diagram from cruising sector: Classification based on ecological sustainable development vs technological development.

Looking at energy efficiency, LED and fluorescent lighting can supply better energy efficiency in comparison to halogen lighting (saving over 20 % percent of power), with a better chromatic and color temperature variety, as wonderfully shown by the architect Joseph Farcus on the Costa Luminosa ship (Antonucci, 2009). Real grass on the upper deck of the Celebrity Cruises Solstice ship, or a courtyard garden with more than 10,000 live plants and flowers, like the 'Central Park' on the Royal Caribbean's Oasis-class ships (Kramer, 2020), can give many benefits. A green roof can improve storm water management, reduce heat demand, increase urban plant life and wildlife habitats, enhance air and water quality, decrease energy consumption costs, decrease noise pollution, provide greater spaces for recreational activities, and increase the aesthetic value of environments (Shafique, 2018). Energy efficient windows on cruise ships are triple glazed, aiming at cutting solar radiation and reducing the need to cool cabins with fans and ventilation (Nurmi, 2017). Furthermore, Royal Caribbean Cruises are equipped with tinted windows which allow natural light to enter the ship and reduce both the amount of solar heat that comes through and the amount of air conditioning needed to cool shipboard spaces (Royal Caribbean Cruises Ltd., 2014).

As regards waste management, cruise companies have recently become very active in recycling and in food waste management. Recycling is defined as "the act of processing used materials into new products for further use" (Collins English Dictionary, 2020), and involves 3 main steps: the collection of recyclable materials, the recycling process, which turns the old products in new ones, and the purchasing of recycled products (All-recycling-facts, 2020). Cruise companies have shown a greater interest in more technological solutions with incinerator systems, rather than recycling, despite the fact that there are popular electronic recycling systems emerging on the market, including the SmartBin, the Dream Machine, and the WeRecycle bin, which represent smarter solutions (Mozo-Reyes et al., 2016). In regard to food waste management, in 2016, Costa Cruises adopted the '4GOODFOOD' program, in collaboration with several partners, including Fondazione Banco Alimentare ONLUS, Cittadinanzattiva, the Slow Food Foundation for Biodiversity, Università degli Studi di Scienze Gastronomiche di Pollenzo, and Winnow. This initiative resulted in a 50 % reduction in food waste in 11 months (i.e., the saving of 1,189 metric tons of CO_2, which is equivalent to the emissions of 231 motor vehicles in a year) (The Medi Telegraph, 2018).

In regard to eco-friendly materials and products, various actions depend on the environmental impact of the product life cycle. Life Cycle Assessment (LCA) is "a method used to evaluate the environmental impact of a product through its life cycle encompassing extraction and processing of the raw materials, manufacturing, distribution, use, recycling, and final disposal" (Ilgin and Gupta, 2010). Moreover, the choice of furnishings having adequate material certifications can provide a guarantee of eco-compatibility and improve the quality of the internal environments, through improvements in thermal, acoustic, luminous, and ventilation comforts. As stated by Bighignoli (2020), certifications in material can supply many advantages, such as the optimization of production processes with a reduction of costs for the company, a clear communication of the environmental performances related to a product/services, and an enhancement of the corporate brand by adopting a policy of transparency towards stakeholders. According to data supplied by Bighignoli (2020), the main certifications in material are EPD, GreenGuard, FSC, LEED, ECOLABEL, PEFC and carbon footprint. The 'FSC' mark certifies the eco-sustainable origin of paper and wood. The 'PEFC' mark is a certification system based on the mutual recognition of national forest management schemes. 'LEED' is a certification program that can be applied to any type of building and promotes a sustainability-oriented approach. 'Ecolabel' is a European brand used to certify the reduced environmental impact of products or services offered by companies that have obtained their use. 'GreenGuard' is an American product certification that establishes some standards for measuring the emissions of materials and products that are used inside buildings. Finally, the 'carbon footprint' indicates the "measure of the impact that human activities have on

the environment in terms of the amount of greenhouse gases produced, measured in units of carbon dioxide".

In regard to environment-related promotion and education, Disney Cruise Line applies a responsible environmental education model for its members and employees, as well as for business partners and customers around the world (Manoiu and Antonescu, 2017). As part of this program, both adults and children can attend environmental programs, such as 'Youth Activities', 'Safety Smart Goes Green', and 'Summer Eco-Camps', which are held in classrooms on board or outdoors on the ashore excursions (Disney Cruise Line, 2018). Other educational programs on the environment are carried out by Costa Cruises and Paul Gauguin Cruises. For instance, since 2015, Costa Cruises has participated in Project Whalesafe, for the protection of whales, and have organized on board programs including educational videos and kids' activities, while on Paul Gauguin cruise ships, cruisers are educated on conservation and nature discovery via lectures (from conservationists, scientists, and oceanographers) and a "Stewards of Nature" hands-on kids' program (Garay and Paloti, 2020).

As regards environment-related entertainment, every cruise ship is now equipped with balconies which offer splendid views. For example, the SeaWalk, a 20 meters long enclosed glass hallway, located on the uppermost deck of the ship, allows customers to enjoy a breath-taking 360 degree views of the ocean from an altitude of 40 meters above sea level (Kosciolek, 2020). These spaces offer customers the opportunity to know and better appreciate the surrounding natural environment.

Looking at environmental management and monitoring, the interiors of most cruise ships are equipped with electronic thermostats which allow passengers to control and regulate the temperature and humidity in cabins, thus adjusting by themselves the supply of heating and cooling and ensuring adequate thermal comfort with less energy waste.

2.3 Design of smart vessel ships affected by middle/high technological development in ecological sustainable aspects

The second cluster groups the case studies affected by a middle/high technological level within the world of cruises, although many of them can be identifiable with other fields of application, from which they are probably derived; the most striking example is the use of solar panels on the roof, which derives from the world of civil construction. Furthermore, this cluster demonstrates how technology can bring a greater level of sustainability, guaranteed by a greater performance in energy efficiency, environmental control, and group communication.

In regard to energy efficiency, motion-activated LED lights are now very common in cabins (Ward, 2019) and permit the reduction of electricity consumption of up to 35 - 45 % most of the time, and even up to 75 % in few cases, since many people, especially children, have the bad habit of forgetting to turn off the lights when they leave the room (Sarkisian, 2017). In addition, in 2008, Celebrity Cruises installed 216 photovoltaic panels on 5 areas of the Solstice ship, obtaining the primacy of a cruise ship equipped with solar panels on board (Millar, 2012). However, as reported by Millar (2012), the large number of solar panels has to be compared to the actual demand for energy of such massive ship. Indeed, the Solstice ship, recognized at its launch as the largest cruise ship in the world, was not fully powered by solar panels, which could cumulatively provide enough energy just to operate the elevators, or 7,000 LED bulbs. This result shows that a technological contribution must be accompanied by a reduction in mass and, more generally, by a process of dematerialization, in order to guarantee a real contribution to the sustainable development of cruise ships. As an alternative to solar panels, in 2013, the 'Solar Leaf Panel' made its appearance in Hamburg (Germany) for the International Building Exhibition (IBA); this was the world´s first bio-reactive system that could generate renewable energy from algal biomass and solar thermal heat. The panel is composed of 4 glass layers, among which there is a mixture of water, air, and microalgae, and generates a renewable energy from solar light, converting it into electric and

thermic power (Mora, 2014). The university project "Early in the Process. Cues for a sustainable design process" (**Figure 3**) has proposed an adoption of this system on the façade of Costa Smeralda, conferring a greener aesthetic profile to the cruise ship (Bighignoli, 2020).

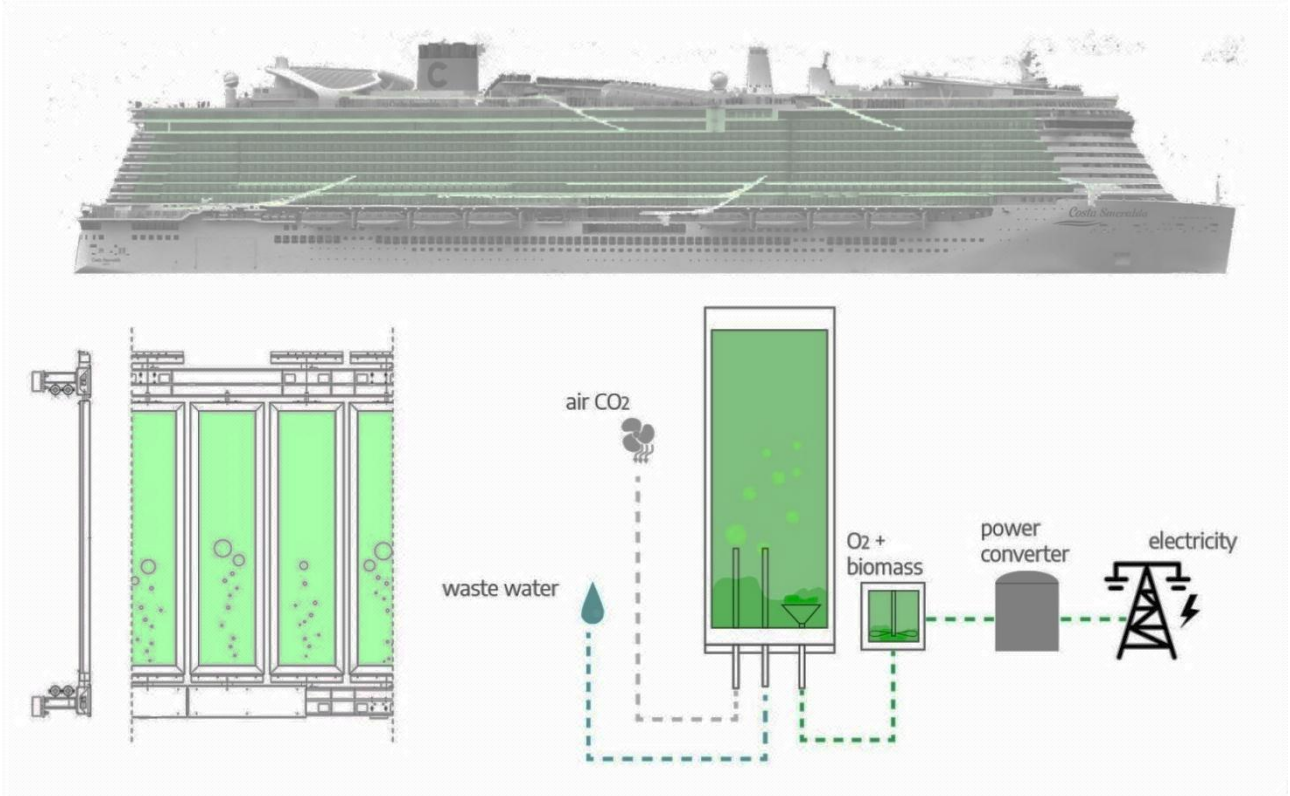

Figure 3 Selection of case studies from university activities: Costa Smeralda students' master's degree thesis "Early in the process. Cues for a sustainable design process".

Although, apparently, fuel systems do not have a direct connection with the design field, LNG deserves particular attention, as it represents an ecological fuel that is revolutionizing the civil sector and, lately, the maritime one. By definition, LNG (liquefied natural gas) is "a natural gas which is changed into liquid by making it very cold so it can be more easily transported" (Cambridge Business English Dictionary, 2020); in the liquid state, the volume reduction is about $1/600^{th}$ the volume of the gaseous state, so that it can be transported using cargo ships or transport trucks instead of pipelines, reducing a lot the transportation costs (Mokhatab et al., 2019). Moreover, nowadays, it represents the cleanest fossil fuel because, compared to traditional heavy fuel oils, it generates the following GHG emissions: a 25 % reduction in carbon dioxide (CO_2) emissions, a 90 % reduction in nitrogen oxide (NOx) emissions, and a 100 % reduction in sulfur (SO2) and fine particle emissions (Elengy, 2019). Focusing on the naval sector, AIDAnova in 2018 and Costa Smeralda in 2019 have been the first LNG-powered cruise ships in the world (Saltzman, 2019), paving the way for new more ecological ships. In 2019, most cruise companies had at least one LNG-powered ship on order; 10 for Carnival Corporation (Carnival Cruise Line, Princess Cruises, AIDA Cruises, P&O Cruises), 2 for TUI cruises, 3 for Disney Cruise Line, 2 for MSC Cruises, 2 for Royal Caribbean, and so on (Cruise Fever, 2019). Indirectly, the LNG system influences design from different perspectives; with regards to the exteriors, an additional funnel changes the profile of the ship, and openings for refueling are positioned on the side while, regarding the interiors, the passage of new pipes through the decks conditions the spaces that is met along the way, and the ending pipe needs a ventilation space around it (Bighignoli, 2020).

Looking at environment-related promotion and education, since 2017, Carnival Corporation has launched 'OceanView', the first digital streaming channel in the world from a travel provider, through which customers can see a video collection with shots of panoramas of ocean stretches or natural sites on land that might be visited along the trip (Newswire, 2017).

In regard to environment-related entertainment, there are the 'Magic Carpet' on the Celebrity Edge and the 'North Star' on Quantum-class ships, which have allowed passengers to enjoy breath-taking views from the ships. The Magic Carpet is an large orange elevator, and includes 4 functionalities, namely comfortable seating, a full bar, a space for live music performances, and a throughway for passengers when it is located at sea level (Saltzman, 2020). The North Star is a glass observation capsule rotating up, down, and out over the side of the ship thanks to a giant mechanical arm (Silverstein, 2016).

As regards environmental management and monitoring, new cruise ships use motion sensor thermostats which recognize if a cabin is occupied by passengers or not and automatically set the desired options; of course, they can also be manually programmed by passengers themselves.

2.4 Design of smart vessel ships affected by smart technological development in ecological sustainable aspects

Smart technologies are emerging more and more in the naval sector, radically changing the structure and shape of the interiors of cruise ships. In recent years, the concept of smartness has often been linked to the theme of sustainability, not due to a semantic affinity, but for society's common interest in innovation and sustainable development. As a consequence, an example of smart technology may or may not be sustainable, depending on the size of its own environmental footprint and on its environmental impact in the process (Hilty et al., 2014). By analyzing, in depth, the potential of smart technologies, in 2008, the GeSI (Global e-Sustainability Initiative), an organization representing around 40 of the world's leading Information and Communications Technology (ICT) companies, 12 global businesses, and multiple international organizations, published a report in which it presented 5 major opportunities for smart solutions to reduce emissions: dematerialization, smart motor systems, smart logistics, smart buildings, and smart grids. Applying these opportunities in subsequent years globally, the research estimated the possibility for 2020 of reducing 7.8 GtCO2e (gigatons of equivalent carbon dioxide) from 51.9 GtCO2e of BaU (Business-as-Usual) total emissions (GeSI, 2008). How is all this possible? The GeSI studies answered this question by demonstrating that smart solutions can provide better energy efficiency in a particular production and produce less consumption in the process or can avoid an activity that would have taken place otherwise and would have caused emissions. A simple example is given by virtual meetings, during which the electricity consumption has a lower impact than the emissions caused by the transportation used by speakers to reach the meeting place in a physical setting (Hilty et al., 2014).

In regard to energy efficiency, there is only 1 case study concerning educational activities: in the project "Digital Stadium", from MSC Meraviglia workshop (**Figure 4**), students introduced the 'smart floor', a "raised floor with high added value that converts, by piezoelectric effect, the kinetic energy of the steps into clean electrical energy", moreover, made with recycled materials (Veranu, 2016).

Figure 4 Selection of case studies from university activities: MSC Meraviglia students' project "Digital Stadium".

Looking at environment-related entertainment, there are several case studies from the industry: Disney Dream's Magical Porthole and Quantum of the Seas's 'virtual balconies', that are HD screens simulating views and sounds from outside; Norwegian Cruise Line's Galaxy Pavilion Wonderwall, an LED wall with an interactive 3D animation of an ocean floor (Clarke, 2019); and Cunard's Queen Mary 2 planetarium, an auditorium with a dome-like screen, offering constellation viewing and lectures on astronomy (Kosciolek, 2018). Also able to be added is a case study concerning educational activities, derived from a project called 'MSC Meraviglia, Promenade Redesign', which proposed a more technological variation of the MSC's 'Galleria Meraviglia'(**Figure 5**), turning a curved LED wall into a curved holographic display based on AR technologies.

Figure 5 Selection of case studies from university activities: MSC Meraviglia students' project "Promenade Redesign".

3. Results and discussion

The existing case studies in the cruise ship sector show a variety of applications of sustainable solutions, more than half of which are directly linked to design, referring to both the product and the spatial configuration. However, as displayed by the diagram (**Figure 2**), they also show a concentration of interventions on certain areas of sustainable development, neglecting by far other categories which are equally important and effective in their contribution. In addition, cruise lines express a greater commitment to sustainable development with low or medium technological content, almost completely ignoring the potential offered by smart technologies.

As reported in the GeSI study (2008), smart technologies can greatly contribute to sustainable development, both directly and indirectly, by replacing or avoiding processes and productions that cause harmful emissions or consume non-renewable energy. Actually, cruise companies have shown a focused interest on the development of smart technologies related to the entertainment field, which represents the main source of economic income for the cruise business. Blank gaps in the smart cluster indicate that there are many 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).

In this paper, industry case studies were selected from among at least 20 cruise lines, considering the most important globally in order to provide results over the widest possible spectrum, while university case studies were selected within 2 courses, the Interior Design course at Politecnico di Milano and the Yacht and Cruising Vessel Design course at the University of Genoa. Design activity in the university courses, driven by the research activity on the topic, can inspire cruise companies towards greater awareness of the emerging issues in industrial development.

4. Conclusions

The state of the art of ecological sustainable development in the cruise sector shows a general approach toward environmental issues, such as energy efficiency, water management, GHG emissions, and waste management. Even if cruise companies usually express great interest in developing technologies for entertainment, they have also recently been interested in some environmental-related ones.

The main trend for new sustainable cruise ships seems to be the improvement of energy efficiency, obtained by the application of innovative solutions, aiming at providing energy saving and pollution reduction. The development of national and international environmental protection and shipping regulations is driving the cruise sector toward more sustainable actions, encouraging it in the reduction of polluting agents and GHG emissions. Moreover, these actions grant economic benefits and an improvement of public image for cruise companies, since they have often been associated with poor environmental and employment practices (Hall et al., 2017). Following this trend, Politecnico di Milano has planned to study further possible applications of smart technologies in sustainable actions, demonstrating how technologies and ecology are not distant concepts to each other, but rather as both contributing to the effectiveness of sustainable development strategies.

Looking at this scenario, design can play an important role at different levels of technological development, as shown by the diagram's results (**Figure 2**), and at different stages of product life (raw material extraction, manufacturing and processing, transportation, usage and retail, and waste disposal), as underlined by the innovative Life Cycle Assessment (LCA) method. Indeed, LCA provides a more complete measurement of the sustainable level of a system by assessing the environmental impacts of a product, process, or service all along the duration of its life and, in this way, affecting designers' choices from the conceptual phase to the detailed one (Keoleian, 1993). In addition, an interesting factor is given by the inclusion of passengers' behavior (e.g., recycling, food waste management, or environmental programs) and of technological devices in order to achieve a more sustainable development of cruise ships.

As anticipated in the introduction, this research has analyzed the sustainable development of cruise ships only from an ecological point of view, leaving out the economic and social aspects, which would require additional studies. The new epidemiological emergency of Covid-19 raises other research questions, at least in the transition phase towards a post-vaccine time. In light of the new social distancing regulations, interior design must question itself on new forms of more rarefied entertainment with new proxemics. As happened after various disasters of the past, even in this case, the cruise sector will have to make a great effort from the point of view of communication design to regain the trust of customers and modify ships to make passenger travel completely safe.

References

All-recycling-facts. (2020). *The recycling process*. All-Recycling-Facts.com. Retrieved from http://www.all-recycling-facts.com/recycling-process.html

Antonucci, R. (2009). In the clouds of Joseph Farcus: The phenomenology of going to sea in the era of supermodernity. *Design Issues, 25*(4), 36-50. doi:10.1162/desi.2009.25.4.36

Bighignoli, S. (2020). *Early in the process. Cues for a sustainable Design process*. [Master thesis in design navale e nautico]. Università degli Studi di Genova - Politecnico di Milano - Polo Universitario della Spezia.

Cambridge Business English Dictionary. (2020). *LNG definition*. Retrieved from https://dictionary.cambridge.org/dictionary/english/lng

Camosse, J. (2018). *Five biggest cruise ships in the world in 2019*. The Muster Station. Retrieved from https://themusterstation.com/largest-cruise-ships

Clarke, P. (2019*). Norwegian Joy's Unique Onboard Activities*. TravelPulse. Retrieved from https://www.travelpulse.com/news/cruise/norwegian-joys-unique-onboard-activities.html

Collins English Dictionary. (2020). *Recycling definition*.

Costa Cruises Press Office. (2019). *The debut of Costa Smeralda, Costa Cruises' new ship powered by LNG*. Carnival Corporation & Plc. Retrieved from https://www.carnivalplc.com/news-releases/news-release-details/debut-costa-smeralda-costa-cruises-new-ship-powered-lng

Cruise Fever. (2019). *Why More LNG-Powered Cruise Ships Are Being Built | Hellenic Shipping News Worldwide*. Www.Hellenicshippingnews.Com. Retrieved from https://www.hellenicshippingnews.com/why-more-lng-powered-cruise-ships-are-being-built

Cruise Lines International Association (CLIA). (2019). *2020 State of the Cruise Industry Outlook*. Retrieved from https://cruising.org/-/media/research-updates/research/state-of-the-cruise-industry.pdf

Dewberry, E., & Sherwin, C. (2002). Visioning sustainability through design. *Greener Management International, 37*, 125-138. doi:10.9774/GLEAF.3062.2002.sp.00011

Disney Cruise Line. (2018). *Environmental overview*. Disney Cruise Line News. Retrieved from https://dclnews.com/fact-sheets/2018/10/03/environmental-fact-sheet

Dowling, R., & Weeden, C. (2017). *Cruise ship tourism*. CABI. Retrieved from https://www.cabi.org/cabebooks/ebook/20173010814

Elengy. (2019). *LNG: An efficient and clean energy*. Www.Elengy.Com. Retrieved from https://www.elengy.com/en/lng/lng-an-energy-of-the-future.html

Garay, E., & Paloti, M. (2020). *Green cruising*. Cruise Critic. Retrieved from https://www.cruisecritic.co.uk/articles.cfm?ID=528

Genç, R. (2016). Sustainability in cruise ship management. *International Journal of Social Science Studies, 4*(6), 76-83. doi:10.11114/ijsss.v4i6.1601

GeSI. (2008). *SMART 2020: Enabling the low carbon economy in the information age*. Retrieved from https://gesi.org/public/research/smart-2020-enabling-the-low-carbon-economy-in-the-information-age

Girardi, P., & Temporelli, A. (2016). *Smartainability: A Methodology for Assessing the Sustainability of the Smart City*. *Energy Procedia, 111*, 810-816. doi:10.1016/j.egypro.2017.03.243

Gretzel, U., Sigala, M., Xiang, Z., & Koo, C. (2015). *Smart tourism: Foundations and developments*. *Electronic Markets, 25*(3), 179-188. doi:10.1007/s12525-015-0196-8

Hall, C. M., Wood, H., & Wilson, S. (2017). *Environmental Reporting in the Cruise Industry. Cruise Ship Tourism*. CABI. doi:10.1079/9781780646084.0000

Hilty, L., Aebischer, B., & Rizzoli, A. E. (2014). Modeling and evaluating the sustainability of smart solutions. *Environmental Modelling & Software, 56*, 1-5. doi:10.1016/j.envsoft.2014.04.001

Ilgin, M. A., & Gupta, S. M. (2010). Environmentally conscious manufacturing and product recovery (ECMPRO): A review of the state of the art. *Journal of Environmental Management, 91*(3), 563-591. doi:10.1016/j.jenvman.2009.09.037

Keoleian, G. A. (1993). The application of life cycle assessment to design. *Environmental Life Cycle Assessment and Its Applications, 1*(3), 143-149. doi:10.1016/0959-6526(93)90004-U

Kosciolek, A. (2018). *Planetarium on Cunard's Queen Mary 2 Cruise Ship*. Cruise Critic. Retrieved from https://www.cruisecritic.co.uk/articles.cfm?ID=3424

Kosciolek, A. (2020). *SeaWalk on Princess Cruises*. Www.Cruisecritic.Co.Uk. Retrieved from https://www.cruisecritic.co.uk/articles.cfm?ID=2707

Kramer, G. (2020). *Central Park on Royal Caribbean Cruises*. Cruise Critic. Retrieved from https://www.cruisecritic.co.uk/articles.cfm?ID=668

Li, A. Q., & Found, P. (2017). Towards Sustainability: PSS, Digital Technology and Value Co-creation. *Procedia CIRP, 64*, 79-84. doi:10.1016/j.procir.2017.05.002

Manoiu, V. M., & Antonescu, M. A. (2017). Disney cruise line environmental management. Part I: Environmental policy and waste management on cruise itineraries. *Papers of Geographic Seminar, 45*, 89-108. doi:10.15551/lsgdc.v45i0.08

McCartan, S., Thompson, T., Brossa, A., & Mori, L. (2015). *Design-driven innovation: A new design meaning for superyachts as a less egocentric user experience*. 18. Retrieved from https://pureportal.coventry.ac.uk/en/publications/design-driven-innovation-a-new-design-meaning-for-superyachts-as--2

Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems, E77*, 1321-1329.

Millar, A. (2012). *Solar power: Here comes the sun*. Verdict Cruise. Retrieved from https://www.worldcruise-network.com/features/featuresolar-power-here-comes-the-sun

Mokhatab, S., Poe, W. A., & Mak, J. Y. (2019). *Handbook of natural gas transmission and processing. Principles and practices*. In Mokhatab, S., Poe, W. A., & Mak, J. Y. (Eds.). Gulf Professional Publishing. doi: 10.1016/B978-0-12-815817-3.00001-0

Mora, V. (2014). SolarLeaf. Algae bio-reactive facade. *More than Green*. Retrieved from http://www.morethangreen.es/en/solarleaf-solar-leaf-algae-bio-reactive-facade

Mozo-Reyes, E., Jambeck, J. R., Reeves, P., & Johnsen, K. (2016). Will they recycle? Design and implementation of eco-feedback technology to promote on-the-go recycling in a university environment. *Resources, Conservation and Recycling, 114*, 72-79. doi:10.1016/j.resconrec.2016.06.024

Navío-Marco, J., Ruiz-Gómez, L. M., & Sevilla-Sevilla, C. (2018). Progress in information technology and tourism management: 30 years on and 20 years after the internet - Revisiting Buhalis & Law's landmark study about eTourism. *Tourism Management, 69*, 460-470. doi:10.1016/j.tourman.2018.06.002

Newswire, M. P. (2017). *Carnival corporation launches OceanView - World's first digital streaming travel channel for land and sea*. Multivu. Retrieved from https://www.multivu.com/players/English/8180951-carnival-corporation-streaming-channel-oceanview

Nolich, M., Spoladore, D., Carciotti, S., Buqi, R., & Sacco, M. (2019). Cabin as a Home: A Novel Comfort Optimization Framework for IoT Equipped Smart Environments and Applications on Cruise Ships. *Sensors, 19*(5), 1060. doi:10.3390/s19051060

Nurmi, M. (2017). *Improving the energy efficiency of a cruise ship stateroom*. Aalto University, School of Engineering. Retrieved from https://aaltodoc.aalto.fi:443/handle/123456789/26163

Papathanassis, A. (2017). Cruise tourism management: State of the art. *Tourism Review, 72*(1), 104-119. doi:10.1108/TR-01-2017-0003

Piardi, S., Pasina, I., & Tieghi, S. (2012). *Reflections on the sidelines of a shipwreck*. In Proceedings of the 17th International Conference on Ships and Shipping Research. Centro Congressi Università di Napoli Federico II.

Royal Caribbean Cruises Ltd. (2014). *Energy efficiency*. Https://Www.Rclcorporate.Com. Retrieved from https://www.rclcorporate.com/environment/ship-design-technology/energy-efficiency

Saltzman, D. (2019). *Launch of Costa's First LNG-Powered Cruise Ship Delayed*. Retrieved from https://www.cruisecritic.co.uk/news/4682

Saltzman, D. (2020). *Celebrity Cruises' Magic Carpet on Celebrity Edge*. Cruise Critic. Retrieved from https://www.cruisecritic.co.uk/articles.cfm?ID=3453

Sarkisian, E. (2017). *Benefits of using motion-sensor light switches*. The Eco Guide. Retrieved from https://theecoguide.org/benefits-using-motion-sensor-light-switches

Shafique, M., Kim, R., & Rafiq, M. (2018). Green roof benefits, opportunities and challenges: A review. *Renewable and Sustainable Energy Reviews, 90*, 757-773. doi:10.1016/j.rser.2018.04.006

Silverstein, E. (2016). *North Star on Royal Caribbean Cruises*. Cruise Critic. Retrieved from https://www.cruisecritic.co.uk/articles.cfm?ID=2459

Special Education Information Center (SPEDTex). (2020). Assistive Technology Consideration. Retrieved from https://www.texasprojectfirst.org/node/155

Świątek, L. (2013). Dematerialization in architecture as an imperative of sustainable building. *Sustainable Building and Refurbishment for Next Generations*, 6. Retrieved from http://www.cesb.cz/cesb13/proceedings/5_tools/CESB13_1299.pdf

Texas Assistive Technology Network. (2002). *Considering assistive technology in the development of the IEP: A training module in the Assistive Technology in Texas Schools Series*. Center for Technology in Education & Technology and Media Division.

The Medi Telegraph. (2018). *Costa Cruises to halve food waste on board its ships thanks to the "4 Good Food" project*. Retrieved from https://www.themeditelegraph.com/en/shipping/2018/02/05/news/costa-cruises-to-halve-food-waste-on-board-its-ships-thanks-to-the-4-good-food-project-1.38085411

Tizzani, G. (2014). *La sostenibilità ambientale nel settore crocieristico*. (Master's Degree Thesis). Università degli studi di Genova.

Veranu. (2016). *Smart energy floor*. Retrieved from http://www.veranu.eu

Ward, D. (2019). *Berlitz Cruising & Cruise Ships 2020*. Retrieved from https://www.ibs.it/berlitz-cruising-cruise-ships-2020-libro-inglese-douglas-ward/e/9781785731389

World Commission for Environment and Development (WCED). (1987). *Report of the World Commission on Environment and Development: Our Common Future*. Oxford University Press. Retrieved from http://www.un-documents.net/our-common-future.pdf