DEM 5.2 Robot Cabin Creation and Validation

Demonstrator Supporting Document of the “Robot Cabin” Physical, Demonstrator, Pilot, Prototype

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DOCUMENT SHEET

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PP	Restricted to other programme participants (including the EC)	
RE	Restricted to a group specified by the consortium (including the EC)	
CO	Confidential, only for members of the consortium (including the EC)	X

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1.4	29/07/2025	Final Document	Dr. Stamatina Rassia (Author; LEDRA)

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ABBREVIATIONS

ABBREVIATION	Full Name Description
AC	Air Conditioning
AI	Artificial Intelligence
ALARP	As Low As Reasonably Practicable
CDC	Centers for Disease Control and Prevention
CDF	Collaborative Digital Framework
CLIA	Cruise Lines International Association
COVID-19	Coronavirus disease
DEM	Demonstrator
DNA	Deoxyribonucleic Acid
ERV	Energy Recovery Ventilators
ERP	Emergency Response Procedures
FSA	Formal Safety Assessment
GA	General Arrangement
GCM	Generic Communication Module
HAZID	Hazard Identification
HEPA	High Efficiency Particulate Air
HVAC	Heating Ventilation and Air Conditioning
IMO	International Maritime Organization
LOA	Length Overall in meters
LR	Lloyd's Register
MAH	Major Accident Hazard
MQTT	Message Queuing Telemetry Transport
MV	Motor Vessel (M/V): MV is a prefix interchangeable with MS in the case of Motor Ship
PA	Public Address
PBS	Phosphate buffer solutions
RNA	Ribonucleic Acid
RFID	Radio Frequency Identification
SARS	Severe Acute Respiratory Syndrome
SMS	Safety Management System
SOLAS	Safety of Life at Sea
UV	Ultraviolet
VDS	Viral Detection Sensor

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VSP	Vessel Sanitation Program
WHO	World Health Organization

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EXECUTIVE SUMMARY

The “Robot Cabin” was successfully created and integrated to serve as a demonstration and training hub for HS4U technologies. Designed and constructed by TSIKIS at the Tsikis Shipyard in close collaboration with LEDRA, the Robot Cabin is housed in an LR-certified ISO shipping container—6 meters long and openable from both its narrow and long sides—designed for deployment at a wide range of events and venues.

The Robot Cabin serves as a functional environment to prototype and showcase the HS4U solution pillars—interconnection, interoperability, and cruise ship relevant design. It was further utilized in Task T5.3 pilot testing through simulated passenger accommodation scenarios conducted at the Demo Space in the Lavrion Technological Cultural Park in May 2025. These pilots validated the sensor, actuator and system's operational capabilities and were assessed (by CAM Subcontractor) of its performance to real-world applications.

This task builds upon the foundational planning of Task T5.1, with integration activities carried out in T5.2, including technical implementation and deployment in the Lavrion Technological Cultural Park of on May 5–6, 2025. The cabin supports a plug-in model for all HS4U-developed hardware (originating in T3.1), installed in accordance with the implementation strategy of T4.3. Coordination efforts targeted the works of LEDRA, TSIKIS, ECOS, UNP, CNT and EPSILON ensured seamless testing of systems and software components in the scenario testing of May 2025.

Additionally, the Robot Cabin functioned as a training environment for crew members of the MV CELESTYAL DISCOVERY, who visited the Lavrion Demo site on May 9, 2025. This training activity was a collaborative effort between LEDRA, CEL, ABS, and EPSILON. EPSILON led the practical demonstration of the Collaborative Digital Framework (CDF) within the Robot Cabin, providing a hands-on experience. On that date collecting feedback through questionnaires completed by the crew was possible.

Lastly, the HS4U software were developed by INTRA, EPSILON and INFILI using a common-ground programming language, ensured seamless operation of the CDF. TSIKIS developed and provided all the groundwork so that the demonstration of the CDF within the Robot Cabin over the testing period of the pilots, could be made possible and LEDRA outlined this to INFILI in order for this plan to be featured clearly in the technical plans of WP4 based on the TSIKIS & LEDRA Robot Cabin ship design and further construction plans of Tasks T5.1 and T5.2.

This milestone marks a significant step in advancing HS4U’s evidence-based, interoperable maritime health technologies, offering both practical application and industry visibility.

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1. INTRODUCTION

This report presents the development, integration, and pilot implementation of the "Robot Cabin" under Task T5.2 of the HS4U project. Developed as a mobile, deployable demonstration and training unit, the Robot Cabin is a key component in validating the technological and operational pillars of the HS4U project—interconnection, interoperability, usability and impactfulness representing a cruise ship cabin.

Designed by TSIKIS and constructed at the Tsikis Shipyard, in close collaboration with LEDRA, the Robot Cabin is developed within a 6-meter LR-certified ISO shipping container. Its design—allowing opening from both narrow and long sides—ensures flexibility for deployment across various events, venues, and operational environments. This portable structure acts both as a demonstrator and an exhibition space for showcasing ship design and HS4U technologies. It serves also as a functional testing space.

The implementation of Task T5.2 builds directly upon the planning activities of Task T5.1, with particular emphasis on the integration of hardware components developed in Task T3.1 and software functionalities as defined in the technical roadmap of Task T4.3. The systems and software installation and setup activities were carried out on May 5–6, 2025, at the Lavrion Technological Cultural Park, with coordinated efforts from LEDRA, TSIKIS, ECOS, UNP, CNT and EPSILON ensuring successful testing. The transportation of the Robot Cabin to and from the demo site was covered by TSIKIS.

The Robot Cabin was subsequently used in Task T5.3 to conduct pilot testing under the passenger accommodation scenarios. These pilots validated the system's ability to support maritime health and safety operations in real-world contexts. On May 9, 2025, the Robot Cabin hosted a dedicated training session for crew members of the MV CELESTYAL DISCOVERY. This crew training exercise—led by LEDRA, CEL, ABS, and EPSILON—included a hands-on demonstration by EPSILON of the Collaborative Digital Framework (CDF) and concluded with the collection of feedback through participant questionnaires.

TSIKIS and LEDRA developed the practical method to enable the operation of the CDF developed by INTRA, EPSILON, and INFILI, in the Robot Cabin screen during the testing, crew training and the final event. In case of future events INTRA, EPSILON and INFILI will be contacted to showcase the CDF as already in all previous events, i.e. Pilot testing, crew training, and the final event.

Overall, the successful implementation of Task T5.2 represents a major milestone in the HS4U project, demonstrating the feasibility and impact of deploying interoperable, evidence-based maritime health solutions in both operational and educational contexts.

1.1 INTRODUCTION TO THE ROBOT CABIN CREATION

TSIKIS has successfully designed and constructed the "Robot Cabin" following the development of a 1:10 scale architectural model made from Plexiglas. This model was presented to the HS4U technology partners during the environmental recordings conducted in November 2024. The full-scale Robot Cabin resemble the interior dimensions of a typical Type C passenger cabin on the MV *Celestyal Discovery*, measuring 5.8 meters in length, 2.2 meters in breadth, and 2.2 meters in height, as referenced in the D5.1 report.

The Robot Cabin was constructed within a 6-meter-long, open-side, LR-certified ISO container to ensure both structural integrity and ease of transportation. To enhance flexibility for testing and demonstrations, the container was designed to open from both the narrow end—primarily used for crew training and pilot testing activities, such as those conducted in May 2025 at the Lavrion Technological and Cultural Park—and the long side, which facilitates live demonstrations at venues including the HS4U Final Event, attended by stakeholders from the shipping, tourism, navy and related sectors.

Developed through a collaborative effort between TSIKIS and LEDRA, the Robot Cabin was engineered for straightforward plug-and-play integration of HS4U technologies and was deployment at the Lavrion site. Serving as a representative ship cabin under the “Passenger Accommodation” scenario, it played a central role in WP5 activities—also within the T5.3 demonstration space—for technology testing and crew training.

The Robot Cabin has been assessed for its multiple HS4U technologies representing varying Technology Readiness Levels (TRL 5–8), including:

- The Generic Communication Module (GCM) by UNP
- Passenger Dashboard by UNP
- The Virus Detection Sensor by ECOS, GEU
- Probiotic Emitter Treatment Plant by ECOS
- Advanced smart nanomaterial coatings by CNT Lab
- The Collaborative Digital Framework (CDF) by EPSILON, integrated with INTRA’s StreamHandler and INFILI's data management tools

This modular, transportable testbed demonstrates a versatile and scalable approach for showcasing and validating innovative maritime technologies. A major milestone was reached on May 9th, 2025, when the Robot Cabin showcased the CDF in a live demonstration to the crew members of the MV *Celestyal Discovery*. At that point, the Robot Cabin made the CDF fully visible and usable by end users (crew), marking a key point in end-user engagement.

The crew training and demonstration were coordinated by LEDRA, ABS, EPSILON, and CEL, reinforcing the operational readiness and collaborative spirit of the HS4U project.

1.2 FROM "ROBOT CABIN PLANNING", CREATION AND INTEGRATION FOR DEMO-SPACE TESTING

Overview and Purpose

The integration of the "robot cabin" is designed as a portable, container-based module, which serves both as a technological demonstrator and a field-deployable pilot platform, enabling stakeholders to physically interact with the core components of the HS4U health safety ecosystem. Its mobility allows it to be transported and showcased across various venues, events, shipyards, and pilot environments, making HS4U's digital framework and innovations tangible and accessible.

This self-contained unit hosts all major HS4U-developed technological components, in other words three sensors and one actuator, and it acted as a central testbed for pilot activities under Task 5.3 making its futuristic design and construction visible as well as the CDF software operational in the public. It also acts as a demonstrator for HS4U's evidence-based strategy by making the project's outputs visible to a wider audience, including stakeholders in the tourism, maritime, shipbuilding, and blue economy sectors. One such example was the HS4U Final Event.

During the demonstration testing period from May 5 to 9, 2025, the "Robot Cabin" was deployed at the Lavrion Technological and Cultural Park by TSIKIS who arranged its transportation to the site for the purposes of integrated system validation. Within this modular space, technological solutions from ECOS, UNP, GEU, EPSILON, and CNT were directly installed and tested under the T5.1 passenger accommodation scenario, enabling real-time evaluation of system interoperability and performance.

Figure 1. The 'Robot Cabin,' deployed by TSIKIS within a white LR-certified ISO 6-meter open-side container, situated at the Lavrion Technological and Cultural Park next to the 'ROLOI' Building.

Figure 2. The 'Robot Cabin,' deployed by TSIKIS within an LR-certified ISO 6-meter open-side container, situated at the Lavrion Technological and Cultural Park next to the 'ROLOI' Building.

Figure 3

Figure 4

Figure 5

From top to bottom: Figure 3. Thodoris Tsikis (TSIKIS), designer and developer of the 'Robot Cabin' (center, Figure 4), and Stamatina Rassia (LEDRA), who coordinated the 'Robot Cabin Creation' (bottom, Figure 5)."

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Figure 6a

Figure 6b

Figure 7

The “Robot Cabin” as designed, constructed and prepared for HS4U Technology integration at TSIKIS Shipyard: From the entrance (Figure 6a, 6b) to its interior (Figure 7).

Figure 8. The “Robot Cabin” after HS4U Technology installation and during demo-space testing.

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1.3 INTEGRATION SCOPE AND COMPONENTS

The robot cabin includes sensors, actuator and software and nanomaterial coatings, as planned for integrated as part of WP5 (Led by LEDRA). The respective sensors, actuator, software and coatings were developed under WP3 and WP4 and were tested and validated as part of D5.1 over the environmental recordings onboard MV Celestyal Discovery in November 2025.

Component	Type	Partner	Purpose
Generic Communication Module (GCM)	Sensor	UNP	Environmental sensing (air quality, VOCs, CO_2, etc.)
Passenger Dashboard	Sensor + UI	UNP	Passenger health interface (symptom input, temperature)
Virus Detection Sensor (VDS)	Sensor	ECOS &GEU	Pathogen detection via HVAC air sampling
Treatment Plant: Probiotic Emitter	Actuator	ECOS	Air sanitation via probiotic dispersion
CNT Lab nanomaterial antimicrobial coatings	Material Coatings	CNT	Nanomaterial coatings for sanitization purposes
Collaborative Digital Framework (CDF)	Software	EPSILON INTRA INFILI	Real-time data visualizations and information to Captain/ Crew in Bridge

The technical implementation and mounting details were executed in accordance with the specifications jointly developed by the ship design experts at TSIKIS Shipyard and in collaboration with LEDRA. Thodoris Tsikis (TSIKIS), designer and developer of the 'Robot Cabin', and Stamatina Rassia (LEDRA), who coordinated the 'Robot Cabin Creation', played pivotal roles in creating the “Robot Cabin” and ensuring the sensors, actuator and software were ready for integration on site at the Lavrion Technological Cultural Park in May 5-6, 2025. These efforts supported the pilot use cases namely “Passenger Accommodation” of D5.1. Testing took place from May 8th, 2025, at the Lavrion Technological and Cultural Park, in conjunction with the sequential execution of all other HS4U scenario tests, as outlined in D5.1 and implemented under Task T5.3.

1.4 IMPLEMENTATION PHASES

Phase A – Preparation (Pre-T5.2)

- **Objectives**:
  - Gathered and validated all necessary components from UNP, ECOS, GEU, and CNT.
  - Finalized the robot cabin's physical space layout for installation by TSIKIS and LEDRA.
  - Confirmed visual operability of the CDF dashboard by EPSILON on the Robot Cabin screen.

Phase B – Physical Integration (T5.2): Installations of sensors, actuator in the technology ready Robot Cabin

- **Sensors/Actuator Placement**:
  - *ECOS, GEU VDS Sensor*: Mounted inside the HVAC duct or an upper compartment simulating HVAC airflow.
  - *ECOS Probiotic Emitter*: Installed near the cabin ceiling to simulate real-world dispersion into the airspace.
  - *UNP GCM Environmental Sensor*: Placed near the ceiling to monitor overall air quality metrics.
  - *UNP Passenger Dashboard*: Placed on a flat, accessible surface (e.g., table) for user interaction.
- **Mounting Approach**:
  - Devices were securely fixed to maintain consistent operation.

Phase C – Software Integration and Calibration

- **Operating with Collaborative Digital Framework (CDF) by EPSILON**:
  - The Kafka-based dual queue structure (operational metrics and sensor data) were verified.
  - Real-time data visualizations and backend integration (MongoDB and MySQL) were tested live.
- **Calibration and Validation**:
  - All sensors were calibrated based on the works of INTRA, INFILI and EPSILON.
  - Test scenarios were simulated to ensure accurate readings and full dashboard responsiveness.
  - Final assessment of Robot Cabin and infection control technologies Integration was carried out by the subcontractor of the University of Cambridge.

Figure 9. UNP Generic Communication Module (GCM)

Figure 10. UNP Fabio Querido and Diogo Inacio, operating the Generic Communication Module (sensor) to take environmental readings (top), with the Passenger Dashboard (sensor) measuring human condition parameters positioned on the cabin table.

Figure 11. UNP Passenger Dashboard (sensor)

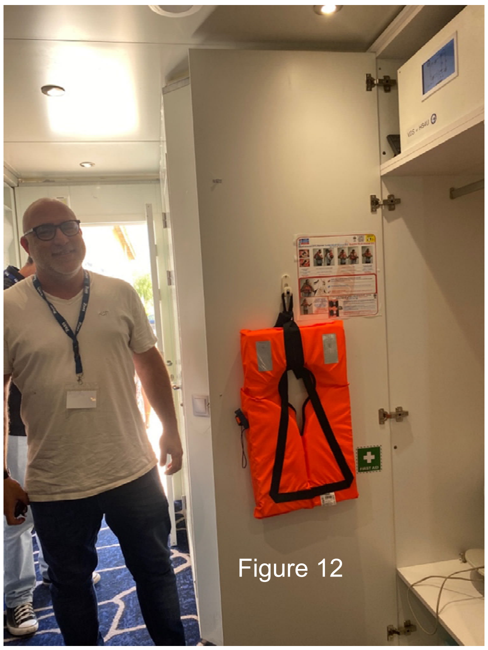

Figure 12

Figure 12. ECOS developer Pini Gross acquires data from the Virus Detection Sensor (VDS, Figure 13) during scenario testing of the “Robot Cabin” at the Lavrio Technological Cultural Park. The VDS is designed to detect airborne pathogens in real-time, enhancing autonomous response capabilities in high-risk environments by the Treatment plant: Probiotic emitter.

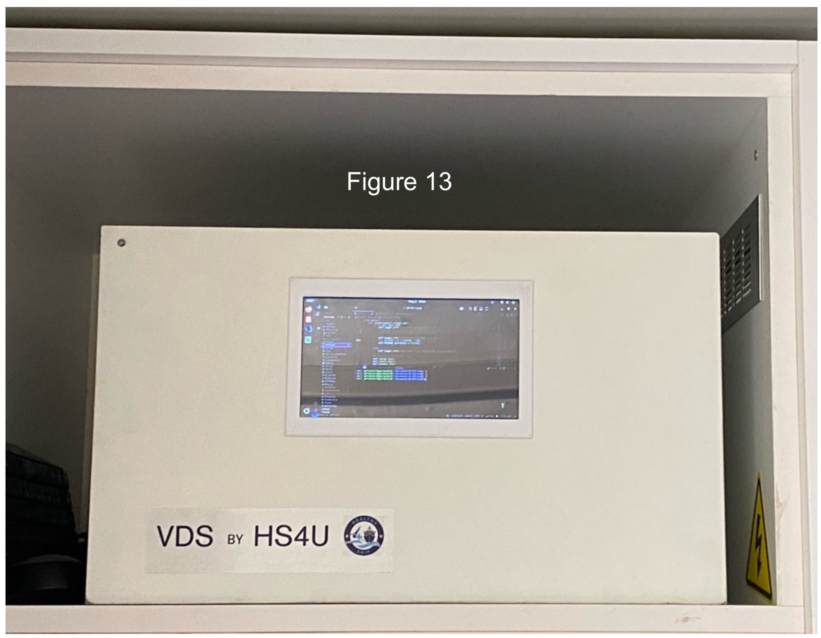

Figure 13

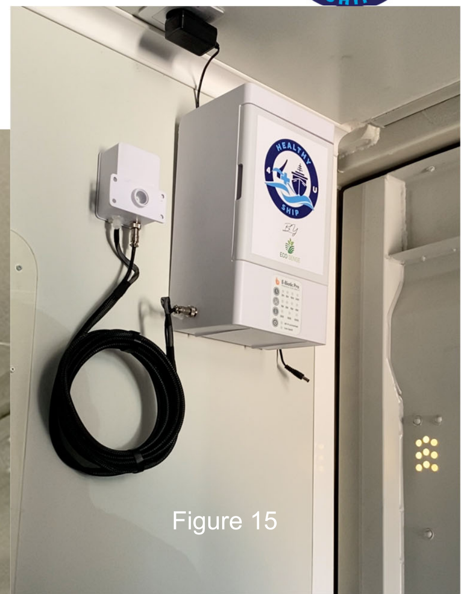

Figure 14. ECOS developers Pini Gross and Inbal Lerer testing the operation of the Treatment Plant: Probiotic Emitter (Figure 15) inside the “Robot Cabin” in real-time, advancing autonomous environmental treatment capabilities.

Figure 16

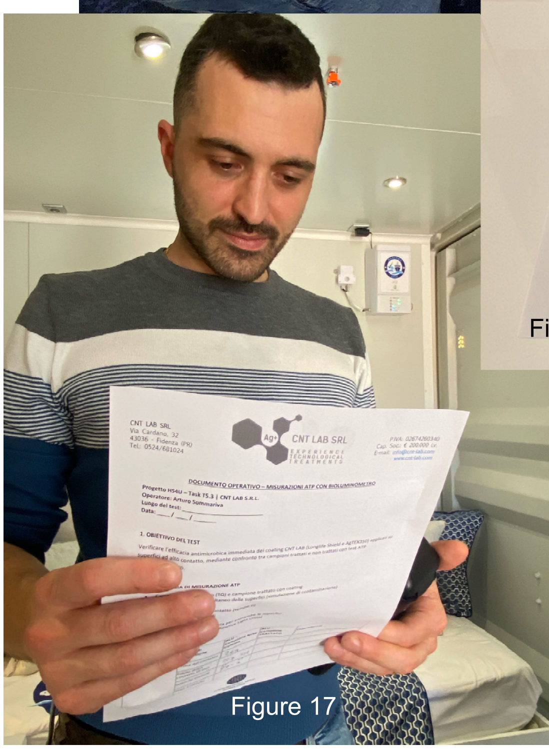

Figure 17

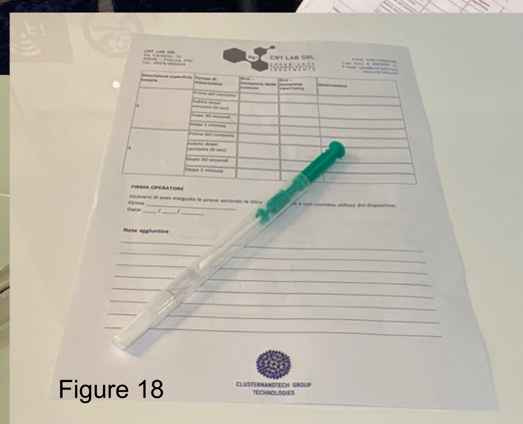

Figure 18

Figure 16. Arturo Sommariva of CNT Lab conducts sampling before and after coating application (Figure 17) inside the Robot Cabin, ensuring precise evaluation of surface treatment effectiveness (Figure 18).

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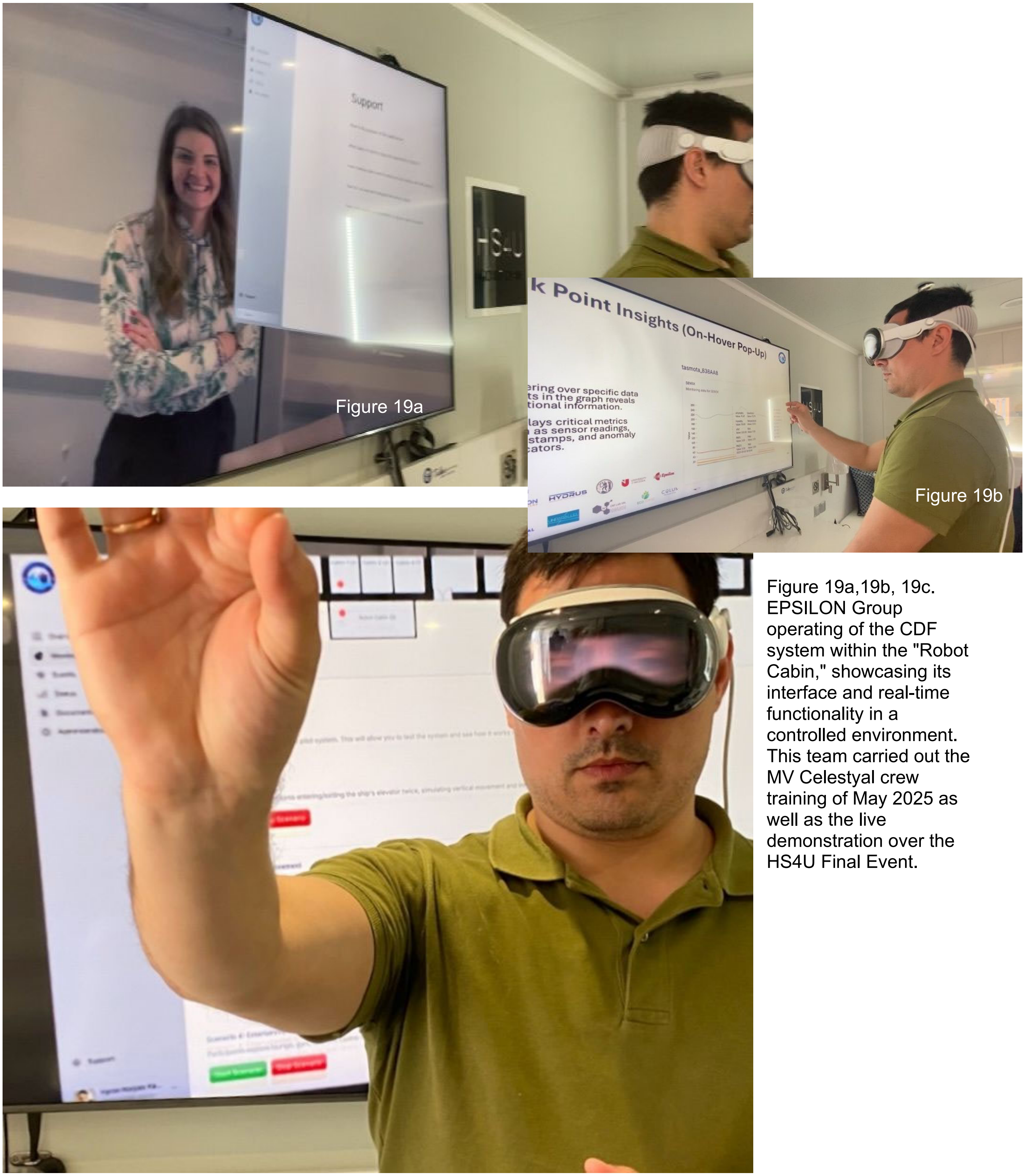

Figure 19a,19b, 19c. EPSILON Group operating of the CDF system within the "Robot Cabin," showcasing its interface and real-time functionality in a controlled environment. This team carried out the MV Celestyal crew training of May 2025 as well as the live demonstration over the HS4U Final Event.

1.5 FUNCTIONAL ROLE IN T5.3 PILOTS AND MV CELESTYAL CREW TRAINING

Following installation and activation, the “Robot Cabin” supported pilot activities under Task 5.3 by participating in the “Passenger Accommodation” scenario pilot testing held at the Lavrion Technological Cultural Park demonstration space in May 2025. The “Robot Cabin” served the following key functions:

- Functioned as a modular cabin environment for validating outbreak detection scenarios and related mitigation or management strategies.
- Enabled full end-to-end data flow, encompassing physical sensing, actuating, dashboard visualization, and integration with the Common Data Framework (CDF).
- Acted as a mobile unit for stakeholder engagement, and crew training (of MV *Celestyal Discovery* crewmembers) offering real-time demonstrations.
- Supported data-driven evaluation and practical end-user operation by crew members of MV *Celestyal* Cruises.

Feedback from the satisfaction questionnaire (Appendix 1) was collected and addressed promptly following the MV *Celestyal* crew training activities on May 9th, 2025. A total of 19 crew members participated, all of whom provided informed consent. Their responses directly contribute to WP5 assessments and inform the final evaluations under WP6. Of those surveyed, 94.7% (18 out of 19) expressed a fully positive perception of the HS4U smart system solutions, indicating strong alignment with their expectations for enhancing health and safety conditions onboard. The crew training was conducted collaboratively by LEDRA, ABS, CELESTYAL, and EPSILON.

Figure 20 & 21 MV Celestyal crew members who had just finished undergoing training on the use of the HS4U CDF system and the operations of the “Robot Cabin” on May 9, 2025.

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1.6 STRATEGIC VALUE AND VISIBILITY

The robot cabin aligns with HS4U's strategic objectives of interoperability, modularity, and public engagement. Through its visibility and transportability, it enhances the evidence-based credibility of the HS4U results and supports stakeholder engagement across diverse blue economy actors.

As of May 2025, a total of 14 stakeholders actively engaged in the pilot testing. In addition, 11 more stakeholders from the shipping industry—specifically 2 Ship Captains, 4 Ship Owners, 2 Shipyard Owners and 3 Ship Maintenance groups—visited the "Robot Cabin" at the TSIKIS Shipyard.

Over the period of July 2025 (including the HS4U Final Event), 16 additional stakeholders viewed the Robot Cabin representing the following organizations: (1) Hellenic Chamber of Shipping, (2) Hellenic Navy, (3) Union of Cruise Ship Owners, (4) Consul of Senegal, (5) LR and LR EMEA, (6) Bureau Veritas, (7) Columbia Optimum Shipmanagement, (8) Hellenic Institute of Naval Technology, (9) NTUA Naval Engineering, (10) NTUA Applied Mathematics, (11) University of the Aegean, (12) Hellenic Military Academy, (13) Four Greek national media representatives, and (14) Short-sea shipping Company Representative.

This brings the total number of stakeholders engaged to 41 as of July 2025 with 100% positive response on their satisfaction with the Robot Cabin Demonstrator for Cruise Ships. The Robot Cabin has been featured on social media, the online newspaper Piraeus365, and the national Greek radio station ERT Deutero Programma, with additional coverage possibly taking place after the submission of this supporting document of DEM5.2.

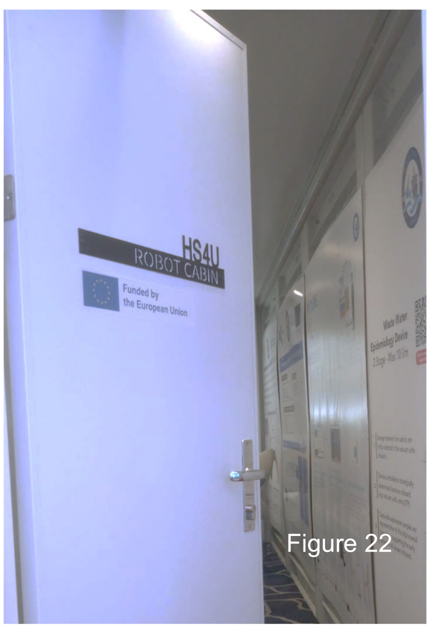

Figure 22 & 23. In support of the Final Event of the HS4U project, the "Robot Cabin" functioned as an exhibition space. This was coordinated and co-developed through the collaboration of LEDRA and TSIKIS. The operation of the CDF was made by its developers of EPSILON.

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1.7 ASSESSMENT OF ROBOT CABIN AND INFECTION CONTROL TECHNOLOGIES INTEGRATION - CELESTYAL CRUISES BY LLOYD'S REGISTER (SUBCONTRACTED BY THE UNIVERSITY OF CAMBRIDGE)

1.7.1 OVERVIEW: INFECTION CONTROL TECHNOLOGY INTEGRATION ON CELESTYAL CRUISES

A summary of the assessment of the robot cabin and the integrated infection control technologies is provided below. The full assessment, included in Appendix 2, was conducted by the University of Cambridge's subcontractor—Lloyd's Register EMEA (UK). This organization also performed the onboard *critical assessment of virus transmission mitigation systems and operations - Celestyal Cruises* of the MV CELESTYAL Discovery during the environmental recording period of Task 5.1 (November 2024). The Robot Cabin—was tested using advanced sensor and actuator-based technologies. The key goal was to achieve real-time surveillance (prevention, detection, mitigation and management) without disrupting normal ship operations.

1.7.2. TECHNOLOGIES DEPLOYED AND TESTED IN THE ROBOT CABIN

1.7.2.1. VIRAL DETECTION SYSTEM (VDS)

- Real-time air sampling using bioaerosol traps & RNA-targeted detection
- Simultaneous monitoring from 4 HVAC ducts
- Integrated alerts to the Collaborative Digital Framework (CDF)

1.7.2.2. ECOSENSE PROBIOTIC EMITTER

- Wall-mounted device dispersing Bacillus-based probiotics
- Covers up to 25,000 sq. ft. via HVAC
- Reduces surface & airborne pathogens by over 90%

1.7.2.3. CNT LAB SYNTHAG COATINGS

- LongLife Shield (transparent coating for surfaces)
- AgTEX (for textiles and porous surfaces)
- Real-life testing showed >90% microbial reduction in 60 seconds

Surface	Product	Reduction (60s)
Chair	AgTEX	98%
Elevator Button	LongLife Shield	92%
Door Handle	LongLife Shield	79%

1.7.2.4. GENERIC COMMUNICATION MODULE (GCM) & PASSENGER DASHBOARD

- Captures passenger symptoms & cabin air quality
- Allows self-check-in and live communication with onboard medical services
- Links directly to ship's central CDF platform

1.7.2.5. BIOMEDICAL RISK MODEL & WASTEWATER SAMPLING

- AI-driven risk indexing of infection spread
- Blackwater sampling to identify pathogen concentration per cabin group

1.7.3. PILOT RESULTS AND RESIDUAL RISK REDUCTION

Pilot trials showed that all high-risk scenarios from the FSA Level 1 HAZID assessment were downgraded to "allowable" or "acceptable" risk levels post-technology implementation.

Node	Max Initial Risk	Post-Mitigation Risk
Passenger Cabins (Airborne Risk)	A (Intolerable)	C (Allowable)
HVAC Contamination	A	C
Surface Transmission (Public Areas)	A/B	C

Over 50% risk reduction was achieved without changing standard procedures, proving both the feasibility and cost-effectiveness of tech-based solutions.

CONCLUSION

The robot cabin thoughtful design, construction and integration ensures visibility, portability, and impact. It forms a bridge with real-world maritime applications, amplifying the project's reach and utility. Based on the comprehensive testing outcomes and the Lloyd's Register (LR) residual risk assessment subcontracted by the University of Cambridge, the validation of the Robot Cabin within the HS4U project has been decisively affirmed. The Robot Cabin was designed and constructed by LEDRA and TSIKIS and includes the ECOS, Virus Detection System (VDS), and probiotic dispersion units (E-BIOTIC PRO), CNT antimicrobial coatings, and the UNP Passenger Dashboard and Generic Communication Module.

The operation of the Collaborative Digital Framework (CDF)—have been demonstrated over the May 9 2025 training organized jointly by LEDRA, ABS, CELESTYAL and EPSILON where the trainees were MV Celestyal Discovery crew members.

Pilot tests conducted at the Lavrion Technological and Cultural Park, alongside previous shipboard trials on MV Celestyal's "Discovery," showed consistent and positive operational performance. Notably, all previously classified 'unacceptable' or 'intolerable' risks related to virus transmission on cruise ships were mitigated to 'acceptable' levels, achieving an over 50% reduction in overall risk. This significant decrease was accomplished through the Robot Cabin design, construction and the technological integration, without the need to alter standard ship procedures.

Furthermore, the residual risk calculations confirmed the effectiveness of the technologies in reducing severity while maintaining operational likelihoods, aligning with the ALARP (As Low As Reasonably Practicable) principle. This outcome validates not only the technical efficacy of the Robot Cabin system but also its strategic feasibility for wide-scale implementation across the passenger maritime sector.

In conclusion, the Robot Cabin has been validated as a successful proof-of-concept for integrating intelligent, automated infection control technologies into ship environments. The results strongly support its potential for enhancing public health resilience aboard cruise vessels.

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APPENDICES

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APPENDIX 1. SATISFACTION QUESTIONNAIRE: "ROBOT CABIN" DEMONSTRATOR FOR CRUISE SHIPS

D5.2 Satisfaction Questionnaire: "Robot Cabin" Demonstrator for Cruise Ships

Satisfaction Questionnaire: "Robot Cabin" Demonstrator for Cruise Ships
We would appreciate your feedback!

Please answer the following questions with a simple **Yes** or **No**.

1. According to your opinion, do the 'Robot Cabin' demonstrator solutions effectively illustrate innovative approaches for identifying and mitigating communicable disease outbreaks onboard cruise ships?

   ☐ Yes
   ☐ No

2. Do you believe that the design of the 'Robot Cabin' technologies is well-suited for application in a cruise ship environment?

   ☐ Yes
   ☐ No

3. Did the HS4U smart system solutions proposed align with your expectations for enhancing health conditions onboard?

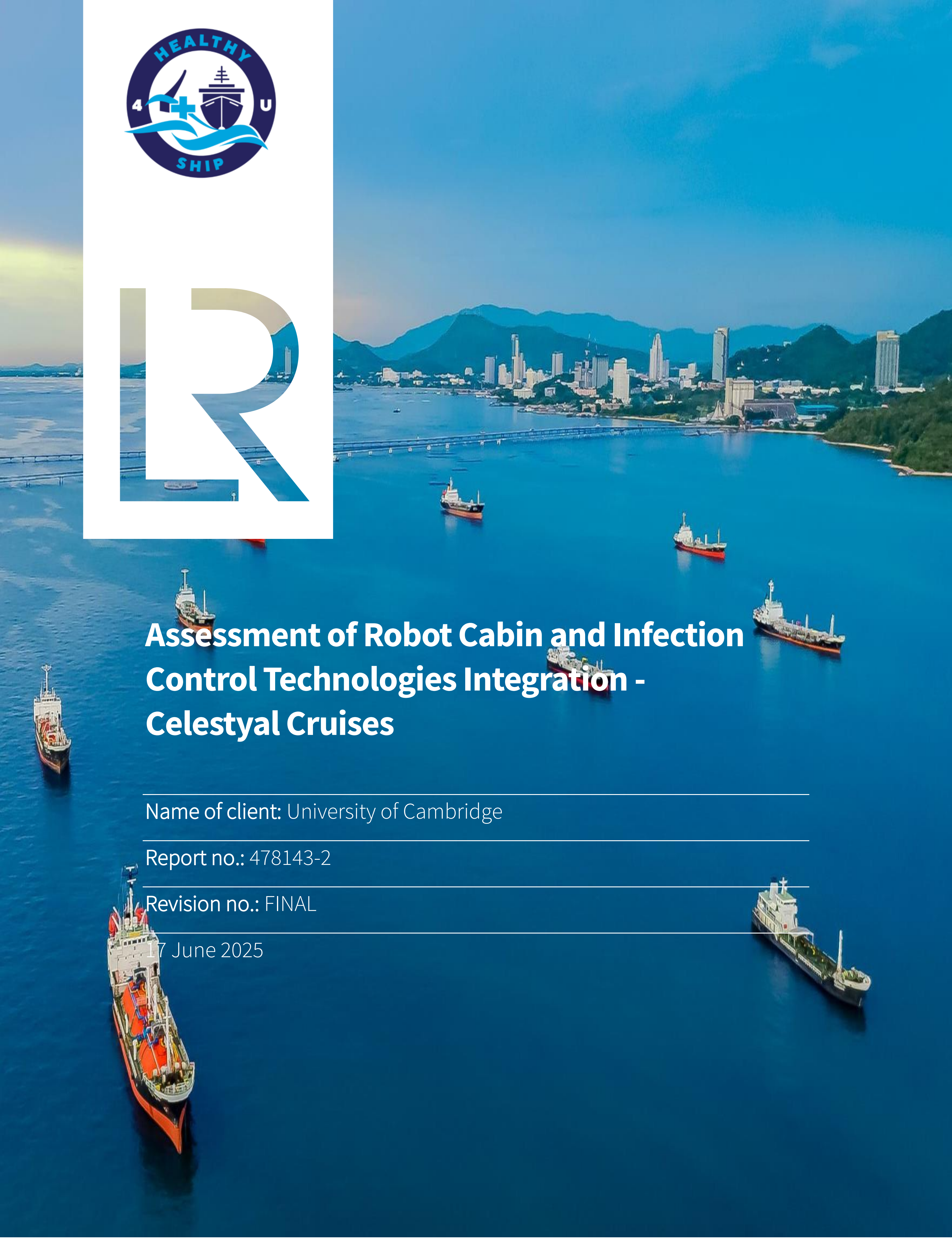
   ☐ Yes
   ☐ No

4. Do you consider the proposed solutions to be beneficial for practical, real-life applications (e.g. automation in health and safety in shipping, smart sailing, energy efficiency, use by crew members)?

   ☐ Yes
   ☐ No

Thank you for your participation!

APPENDIX 2. ASSESSMENT OF ROBOT CABIN AND INFECTION CONTROL TECHNOLOGIES INTEGRATION – MV CELESTYAL CRUISES



Assessment of Robot Cabin and Infection Control Technologies Integration - Celestyal Cruises

Name of client: University of Cambridge

Report no.: 478143-2

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Summary

Assessment of Robot Cabin and Infection Control Technologies Integration - Celestyal Cruises

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List of abbreviations

Abbreviation	Description
AC	Air Conditioning
AI	Artificial Intelligence
ALARP	As Low As Reasonably Practicable
CDF	Collaborative Digital Framework
COVID-19	Coronavirus disease
DNA	Deoxyribonucleic Acid
ERV	Energy Recovery Ventilators
ERP	Emergency Response Procedures
FSA	Formal Safety Assessment
GA	General Arrangement
GCM	Generic Communication Module
HAZID	Hazard Identification
HEPA	High Efficiency Particulate Air
HVAC	Heating Ventilation Air Conditioning
IMO	International Maritime Organisation
KPI	Key Performance Indicator
LR	Lloyd's Register
MAH	Major Accident Hazard
OPS	Onshore Power Supply
PA	Public Address
RNA	Ribonucleic Acid
RFID	Radio Frequency Identification
SARS	Severe Acute Respiratory Syndrome
SMS	Safety Management System
SOLAS	Safety of Life at Sea
UV	Ultraviolet
VDS	Virus Detection System

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Executive summary[1]

Lloyd's Register's (LR) critical assessment work in HS4U project aimed to assess the potential risk for scenarios related to virus transmission on board a passenger vessel and the proposed prevention, detection and protection systems and operations to successfully mitigate the hazards. The process followed internationally accepted Formal Risk Assessment (FSA) methodologies. The proposed mitigating equipment and systems were tested real-time onboard Celestyal's "Discovery" IMO No.9221566 a cruise vessel with a capacity of 1,266 passengers.

LR's scope included assessments together with HS4U project's stakeholders and the ship's engineering and medical teams, with all the parties completing a comprehensive review, including the onboard trials of the proposed equipment.

On receiving positive performance of the equipment and analyses tested onboard the project proceeded with the development of a full testing facility onshore, where a typical cruise accommodation cabin called 'Robot Cabin' was reconstructed to integrate all the proposed and tested technologies.

LR undertook a critical assessment of the Robot Cabin and system sensor technologies based on the operating conditions and test findings. Based on the assessment results LR updated the first phase's risk assessment to calculate the Residual Risk after the integration of the Robot Cabin and its technologies onboard Celestyal "Discovery".

The resulted Residual Risk has shown very positive results. All consequences carrying an 'unacceptable 'or 'intolerable' risk level have been mitigated to an acceptable 'allowable' risk level. This amounted to over fifty percent (50%) risk reduction which in this case has been achieved only by the application of new technologies without imposing any restrictions on standard ship procedures.

The assessment results validated that the project proposed technologies represent a significant advancement in infection control protocols and can be considered for large scale implementation in the passenger maritime sector.

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1. Introduction

HS4U is a cross-national three-year long Research and Innovation Action (01/09/2022-31/08/2025), supported by the European Union within the framework of the Horizon Europe programme. HS4U aims to develop and demonstrate holistic ship design solutions that will facilitate the early detection, prevention, and mitigation of general health conditions, pandemic crises and communicable disease outbreaks in large passenger and cruise ships by ensuring healthy ship operations and safe return to port during a health emergency.

The overall project objectives are as follows:

- Realization of use cases in a dedicated demonstrator environment.
- The creation of a Collaborative Digital Framework (CDF) for live interaction of humans and Internet of Things edge services based on co-robotics concepts and Artificial Intelligence mechanisms and models.
- Complete solutions for the training of ship's crew based on multi-player gaming, embedding realistic role-playing and context.
- The development of an evidence-based passenger behavioural model based on live experiments with passengers and crew that will allow the analysis and the visualisation of passengers' movements.
- The development of a Viral Detection Sensor (VDS) with unique characteristics that will include the online indication of pathogenic airborne spreads in indoor environments and on the air conditioner outlets.
- The development of a real-life demonstrator (robot cabin) which will effectively display the interoperability of evidence-based technologies and models developed by the HS4U team to prevent, detect, mitigate and manage virus outbreaks and spreads at an early stage.

1.1 Scope of Work

The cruise industry is a significant contributor to the global tourism sector. However, the proximity of passengers and crew onboard cruise ships raises concerns about the potential spread of infectious diseases, especially in the wake of the COVID-19 pandemic. Effective monitoring and management of health risks on passenger ships are crucial to ensure the safety and well-being of both passengers and crew members.

Lloyd's Register's (LR) critical assessment work in HS4U project aimed to assess the potential risk for scenarios related with a virus contamination and outbreak onboard a passenger vessel and the proposed prevention, detection and protection systems and operations to successfully mitigate the hazards.

During the first phase of development LR's scope of the assessment included a Risk Assessment Workshop (FSA Level 1) in the form of a HAZID study to identify potential infectious hazards, potential consequences, existing safeguard systems, calculate and qualify Risk, and establish Recommendations for additional Mitigation.

The proposed mitigating equipment/systems were tested separately onboard Celestyal's "Discovery" IMO No.9221566 a cruise vessel with a capacity 1,266 passengers registered under the Flag of Malta.

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“Discovery” was undertaking a short cruise in the Aegean and East coast of Turkey; the vessel was operating at full passenger and crew capacity.

On receiving positive performance of the equipment and analyses tested onboard the project proceeded with the development of a full testing facility onshore, where a typical cruise accommodation cabin called ‘Robot Cabin’ was reconstructed to integrate all the proposed and tested technologies.

LR objectives in this second phase (Phase II) of activities were as follows:

- Undertake a critical review of the Robot Cabin and system sensor integrated technologies based on the operating conditions and test facility findings.
- Update the results of the first phase’s risk assessment to calculate the residual risk (Level 2) after the integration of the Robot Cabin and the infection control technologies onboard Celestyal “Discovery”.
- Make recommendations for the future adoption of the project’s proposed active and passive anti-virus systems for Celestyal’s cruise ships .

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2. Passenger Vessels

2.1 General

In 2024 there were 34.6 million cruise ship passengers globally which represented a 9.3% increase compared to 2023.

The latest annual State of the Cruise Industry report [3] provides a clear indication of the high value dynamic sector driven by public increasing demand. The industry growth continues with 37.7 million cruise passengers projected in 2025 with consumers showing strong intent to cruise. The latest maritime data has shown that 82% of the cruise ships will cruise again attracting a 68% of international passengers shifting towards their first cruise.

In commercial global terms the CLIA member cruise line fleet is expected to reach 310 ocean going vessels in 2025, valued at approximately $168 billion and is currently supporting 1.6 million employees.

The sector is also driving towards higher technology and sustainability. Based on LR's data by 2028, 50% of all new cruise ships will be equipped with dual fuel engines able to run on LNG/Methanol also able to convert to bio-LNG once the production makes the fuel widely available. Further sustainability is also achieved by global cruise ports striving to provide Onshore Power Supply (OPS) and with approximately 72% of the cruise fleet expected to be able connect to these services by 2028.

EU ports recorded 395.3 million passengers in 2023 showing a 5.8% increase compared to 2023, from these more that 8 million represented cruise ship passengers.

2.2 EU Hygiene Standards

Passenger ships move from one country to another where different standards of sanitation are required. These differences have an impact on both the competent authorities of the countries and the ship companies, when trying to deal with the prevention and control of communicable diseases on board. The European Manual for Hygiene Standards on Passenger Ships [1] incorporates EU legislation hygiene standards and provides best practice guidelines for passenger ships sailing within European waters. The guidance refers to passenger hygiene environment and services, not on IMO's ship waste - regulations on garbage and sewage management which are contained in MARPOL 73/78.

The purpose of the EU manual is to collaborate with the industry and competent authorities in developing and implementing comprehensive hygiene programmes, using current legislative frameworks, in order to minimise the risk of communicable diseases. It also gives guidance on communicable disease surveillance on board ships. Compliance with the hygiene standards and best practice guidelines of the manual can help to improve and maintain:

- The hygiene level on board passenger ships sailing to or within the EU waters.
- The level of compliance with hygiene standards that are included in the existing EU legislation.
- The safety of food, water and environmental conditions for passengers and crew.

The strategy of using sophisticated means of monitoring and detection of communicable diseases on board was based on the ability to maintain the hygiene principles established by both the EU Manual, the European Centre for Decease Prevention and Control (ECDC)and IMO requirements.

It is noted that the above is also in line with the recommendations of the World Health Organisation (WHO) and the US Vessel Sanitation Program (VSP).

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2.3 Communicable Disease Surveillance

Surveillance of communicable disease on board passenger ships is an essential tool for assessing the impact of communicable diseases and to allow the early detection and management of outbreaks.

Maintaining medical logs of communicable diseases and the active monitoring of such illnesses on board assist ships in identifying outbreaks and other events of public health concern and allow them to implement control measures rapidly and consistently.

The general objectives of decease surveillance on board ships are as follows:

- To enable timely application of preventive measures through the early detection of outbreaks and other communicable disease events.
- To inform competent authorities and to assist them in case of investigation, management and follow-up.
- To collect baseline information on communicable disease by season and specific itineraries, in order to determine thresholds for outbreak detection.
- To estimate the impact of communicable diseases.
- To provide data for risk assessment.

2.4 Accommodation and public spaces

Accommodation facilities for both passengers and crew, and public spaces such as corridors, lounges, bars and restaurants, should achieve hygienic standards in terms of design, construction and cleaning. Accommodation spaces should have suitable and sufficient means of national or mechanical ventilation and have adequate natural and/or artificial lighting. Cleaning and disinfection are a key component of onboard housekeeping. An effective cleaning and disinfection protocol for all areas of the ship should be applied to reduce the risk of infection transmitted through environment sources.

2.5 Ventilation

In cruise ships, where large groups of people spend significant amounts of time, maintaining a healthy environment is a primary target of the ship's Safety Management System (SMS). Heating, ventilation, and air conditioning (HVAC) systems play a critical role in this, and advanced HVAC technology is becoming an important tool in the mitigation of virus and respiratory diseases transmission.

The following principles for hygiene related to HVAC systems onboard should be complied with at all times [1]:

- All spaces should be well ventilated.
- There should be suitable and sufficient means of natural or mechanical ventilation to all accommodation spaces.
- Ventilation systems should be constructed so that filters and other part requiring cleaning or replacement are readily accessible.
- Drains in air handling units should be regularly inspected in order to ensure that they are working properly.
- Condensate trays and sumps should be kept clean and regularly disinfected.

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It is noted, that one of the most significant advancements in current HVAC technology is the integration of smart systems. Smart HVAC systems use sensors and artificial intelligence to adjust temperature, humidity, and air quality based on real-time data. This not only improves comfort but also ensures energy efficiency by adjusting heating or cooling when necessary. The HS4U project developed these aspects further to include real time decease surveillance and mitigation in ship passenger operations.

High-end HVAC systems incorporate advanced air filtration technology, such as HEPA filters, carbon filters, and UV light systems, to remove pollutants, allergens, bacteria, and viruses from the air. This is especially important in the passenger and cruise ships market as a first stage mitigation method however it does not incorporate any means of real time virus detection leading to effective emergency control onboard the ships.

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3. Technology Demonstration

3.1 Robot Cabin

The HS4U project's proposed systems integration and operational effectiveness were pilot tested over a period of 5-9 May 2025 at the Lavrion Technological Cultural Park in Greece. Led by Le.D.R.A. Group (LEDRA) the pilot testing phase featured a newly designed and constructed smart cruise cabin prototype, the "Robot Cabin", developed in collaboration with Tsikis Shipyard in Greece.

The Robot Cabin served as the heart of the HS4U demonstrator of the interoperability of evidence-based technologies and models developed by the HS4U team to prevent, detect, mitigate and manage virus outbreaks and spreads at an early stage.

The cabin was based on a standard LR certified container of 31 m^3 capacity with internal dimensions L=5.80 m, B=2.20 m and H=2.30 m. The general arrangement of the cabin is presented in Figure 1 and Appendix 2.

Figure 1 : Robot Cabin Internal Layout

The Robot cabin was equipped and assessed using the advanced systems and software trialled onboard "Discovery" as follows:

- Unparallel Innovation, Lda: smart sensors, Passenger Dashboard and the Generic Communication Module (GCM).
- BetterAir UK & Universite Gustavè Eiffel: The Viral Detection System (VDS) enables real-time monitoring of airborne pathogens, while the integrated treatment plant includes a probiotic emitter designed to actively purify and balance the onboard environment.
- CNT LAB S.r.l.: Smart nanomaterial antimicrobial coatings.

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- Epsilon Malta Ltd, Infili Technologies SA & Netcompany-Intrasoft : The Collaborative Digital Framework (CDF) is a centralised data platform that links individual cabins with the ship's bridge, providing the captain and crew with real-time information on the location of any communicable disease outbreaks onboard.

The main technologies designed to support detection, prevention, and mitigation of airborne and surface transmitted diseases in enclosed maritime environments are presented in the following sections.

3.2 ECOSENSE System

3.2.1 Virus Detection System (VDS)

VDS is an advanced air monitoring technology engineered for the real-time detection of airborne pathogens, including viruses such as SARS-CoV-2. It operates by extracting air through a bioaerosol trap, capturing particles into a liquid medium, and analysing them using RNA-targeted detection via a sensor interface. The system is capable of sampling simultaneously from multiple HVAC ducts, significantly increasing its coverage and detection range. It provides continuous 24/7 surveillance, with automated data transmission to a central dashboard (CDF), where alerts are issued in the event of contamination. The VDS remained fully operational, with stable performance confirmed during testing. It is installed, integrated with the CDF system, and functioning as intended, supporting proactive pathogen monitoring and contributing to onboard health security.

- Installation Status: Fully installed and operational.
- Functionality: Provides real-time airborne pathogen monitoring using RNA detection via liquid bioaerosol sampling.
- Detection Radius: Covers 4 HVAC ducts simultaneously, extending its surveillance range across key ventilation points.
- Dashboard: Provides live status updates, alerts in case of contamination, and maintenance notifications.
- Communication: Full integration with the CDF system.

The VDS interface displays all operational stages of the system, including bioaerosol sampling, heating, and detection. System status, alerts, and contamination notifications are clearly visualized for effective monitoring and rapid response (Ref. Figure 2).

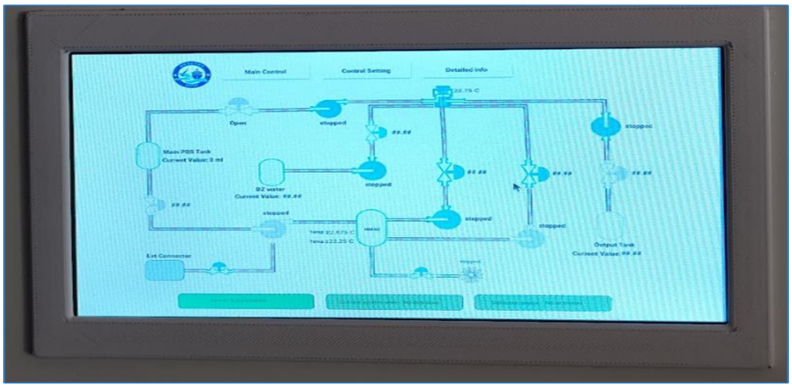

Figure 2 : VDS System Dashboard, Real-Time Monitoring and Status Overview

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Figure 3 : CDF Dashboard interface showing real-time map of the demo space

Figure 4 : VDS device installed in the Robot Cabin

3.2.2 Probiotic Emitter (E-BIOTIC PRO)

Maintaining clean indoor air and surface aboard cruise ships is particularly challenging due to their enclosed environments and high foot traffic. Passenger ship areas such as cabins, fitness rooms, theatres, and dining spaces can accumulate biological contaminants like bacteria, mold, allergens, and viruses. While conventional air purifiers typically address only airborne pollutants, they overlook pathogens residing on surfaces, inside HVAC systems, and on shared objects. The ECOS Dispersion System offers a comprehensive solution by releasing beneficial probiotics through the ship's HVAC network. This approach promotes a balanced microbial environment, targeting both the air and surrounding surfaces to improve overall hygiene and safety.

The ECOS system disperses a scientifically designed probiotic formula, offering:

- Reduction of Harmful Pathogens: Probiotics outcompete harmful microbes, reducing their presence.
- Allergen Neutralization: Mitigates common irritants like pollen and dust mites.

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- Organic Material Breakdown: Disrupts microbial growth by eliminating nutrient sources, fostering cleaner spaces.

  - Installation Status: Wall-mounted within the HVAC-connected Robot Cabin.
  - Functionality: Continuously emits beneficial Bacillus-based probiotics through the cabin air system.
  - Disinfection Radius: protect large areas up to 25,000 sq. ft. area coverage when connected to HVAC with measurable biotic presence on all surface types.
  - Power Consumption: 15W during operation.
  - Performance: Demonstrated uniform spatial distribution of probiotics throughout the cabin, reaching difficult areas (vents, under seats, corners).
  - Maintenance: Refillable liquid container; probiotic bottle requires replacement once per month.

Figure 5 : The probiotic device

3.3 CNT LAB Srl Coatings

Experimental tests were carried out to validate the antimicrobial effectiveness of two formulations based on the patented SynthAg technology: the transparent coating "LongLife Shield" and the textile treatment "AgTEX". The tests were conducted in real-life conditions on high-touch surfaces representative of cruise ship environments. The methodology was based on microbial load detection using a professional bioluminometer, with measurements taken before and after product application. Results showed a significant microbial load reduction within 60 seconds, with average performance exceeding 90% reduction. The predefined KPIs were fully achieved, confirming the potential of these formulations for rapid and sustainable sanitation in maritime environments.

The objective of the test was to assess the in-situ antimicrobial efficacy of two solutions developed within the HS4U project. Testing was conducted inside the Robot Cabin and in the Demo Space at the Lavrion Technological and Cultural Park (Greece), simulating realistic biological contamination scenarios on frequently touched surfaces.

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3.3.1 Tested Products

1. LongLife Shield

   - Transparent coating containing SynthAg
   - Designed for surfaces treatment
2. AgTEX
   - Liquid solution containing SynthAg
   - Designed for application on textiles and other porous surfaces

SynthAg is a patented nanostructured colloidal silver technology in which Ag^{+} ions are stabilized by polar polymers, forming high-bioavailability clusters. This structural configuration enables enhanced antimicrobial activity while minimizing cytotoxicity, making the technology particularly suitable for applications in in the maritime sector and other fields requiring high levels of hygiene and microbiological control.

3.3.2 Tests and Results

The testing procedure was structured as follows:

- Surface preparation: A selection of different surface types was carried out to represent those commonly encountered in daily use aboard cruise ships.

- Controlled contamination: Each surface was deliberately contacted by unwashed hands to simulate the natural transfer of microbial load through human interaction.

- Initial measurement: The baseline microbial load was quantified using a professional grade bioluminometer equipped with specific ATP (adenosine triphosphate) detection swabs.

- Treatment application: The tested antimicrobial products were applied directly to the contaminated surfaces in accordance with the usage protocol.

- Post-treatment measurements: Follow-up measurements were performed at 30 seconds and 60 seconds after application to evaluate the progressive reduction in microbial load.

While consistent with the original testing framework, minor procedural adaptations were implemented. The coating was properly applied, and to better replicate real-life contamination scenarios, multiple individuals made contact with the surfaces. Bioluminescent analysis was conducted immediately following contamination, with subsequent measurements taken at 30-second and 60-second intervals to track microbial reduction over time.

Results were measures using the following instrumentation:

- Professional Bioluminometer: A portable device employing bioluminescence technology to detect the presence of ATP on surfaces.

- ATP (adenosine triphosphate) is a biomolecule universally present in living cells and serves as a reliable quantitative indicator of microbial contamination.

Test results are expressed in RLU (Relative Light Units), with lower RLU values corresponding to a reduced level of surface contamination. The test results are shown in Table 1.

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Table 1: Antimicrobial Coatings Test Results

Surface	Product	RLU Initial	RLU 30s	RLU 60s	Reduction 30s	Reduction 60s
Elevator Button	LongLife Shield	264	99	20	63%	92%
Robot Cabin Chair	AgTEX	2637	298	43	89%	98%
Handrail 2	LongLife Shield	2144	431	240	80%	89%
Floor	AgTEX	692	281	71	59%	90%
Handrail 1	LongLife Shield	2799	337	240	88%	91%
Door Handle	LongLife Shield	400	133	84	67%	79%
Stainless Steel Handle	LongLife Shield	320	118	19	63%	94%

3.3.3 Analysis of Results

Overall Antimicrobial Efficacy

Both tested formulations exhibited notable antimicrobial activity under the experimental conditions. A time-dependent reduction in microbial load was observed across all treated surfaces, with more pronounced effects recorded at 60 seconds post-application compared to the 30-second interval.

Product-specific Performance

LongLife Shield

- Average reduction at 30s: **69%**
- Average reduction at 60s: **89%**
- Best performance: **94%** reduction after 60s (stainless steel handle)

AgTEX

- Average reduction at 30s: **74%**
- Average reduction at 60s: **94%**
- Best performance: **98%** reduction after 60s (robot cabin chair)

All results showed consistent trends, with progressive microbial reduction over time and reliable performance across various surface types.

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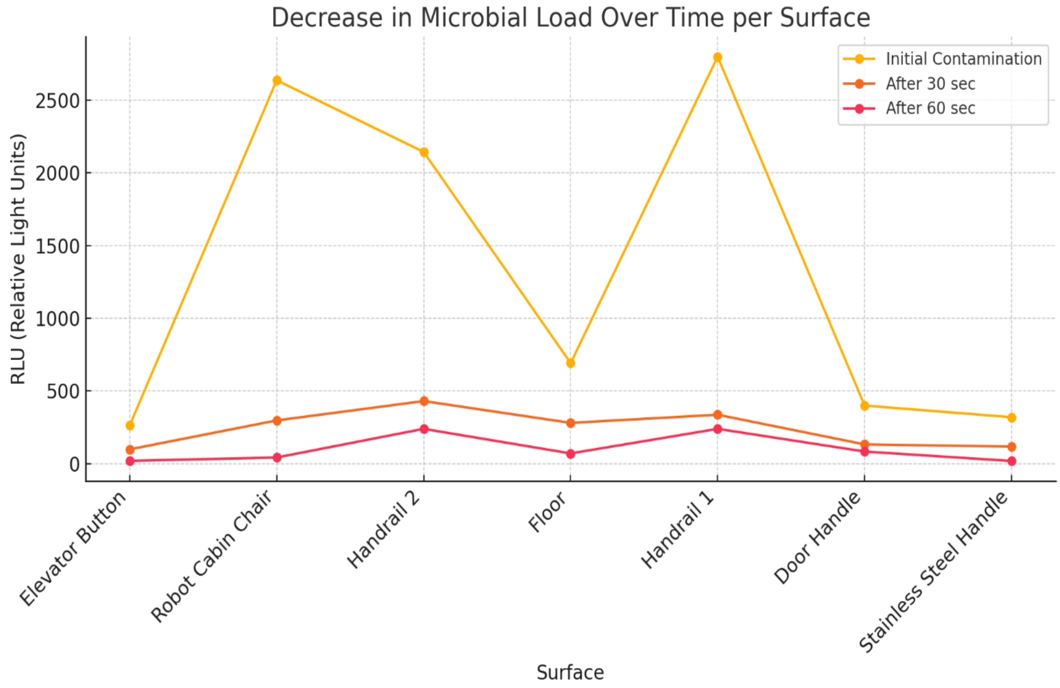

Figure 6 : Antimicrobial Results Over Time

3.4 Generic Communication Module and Dashboard

3.4.1 Description

The Generic Communication Module (GCM) is a multi-sensor management board designed by Unparallel. It supports the holistic integration of a wide range of sensor types with real-time measurements.

The Passenger Dashboard is a user-friendly interface to analyse early symptoms and prevent disease spread. Passengers can input their symptoms, and the system uses GCM sensors to indicate air quality parameters. It provides recommendations for precautions or calling a doctor ensuring quick and informed medical decisions to maintain health and safety.

The purpose of the system is to collect health and well-being data (e.g., Environmental and air quality, Light, Motion sensor and Sound Level Meter) deployed in the spaces to improve well-being and prevent diseases.

3.4.2 Deployment

The system was used in connection with VDS and successfully tested in the following areas in Lavrion facility which were modelled on “Discovery” general arrangement.

- Robot Cabin
- Access corridors , entrance gangways at the check-in or check-out of the cruise
- Public areas, gym, restaurant, lounges.

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3.5 Biomedical Model

3.5.1 Description

Biomedical Model with Inputs of Infrastructural Components and Human Interaction for Risk Assessment of Disease Transmission.

This component is used as an assessment tool in the Collaborative Digital Framework (CDF).

The biomedical model, developed by UTH, includes an AI algorithm that can assess the risk of short-term disease transmission within indoor areas of the ship. This assessment is based on a set of inputs provided by smart sensors and the ship information system. This algorithm outputs a risk index that is classified as low, medium or high, signifying the severity of the situation. Simulations of short-term disease transmission are also used complementary to the AI algorithm to increase the confidence of the system.

3.5.2 Deployment

The software has been used in all the monitored areas:

- Private areas such as cabins.
- Public areas such as restaurants, bars, toilets etc.

3.6 Sewage Automatic Sampling Device

3.6.1 Description

The RWO sampling device addresses the complexities of detecting viruses in wastewater, particularly targeting SARS-CoV-2, however it can be extended to include different type of pathogens. This technology is proposed for the ship's engine rooms, enabling centralised wastewater sampling and serving multiple cabins and other shared areas. RWO was not tested at Lavrion, the device was already successfully tested onboard "Discovery" during the phase I stage of the project, and it has been recommended for installation onboard the cruise ship.

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4. Residual Risk Assessment

4.1 Methodology

The success of the critical assessment process is based on the effective implementation of a formal risk assessment methodology. The risk assessment enables critical evaluation of mitigating factors identifying any omissions and/or errors in the implementation of technology or procedures which usually result in higher risk of failures.

The process and methodology were based on guidance from the following sources :

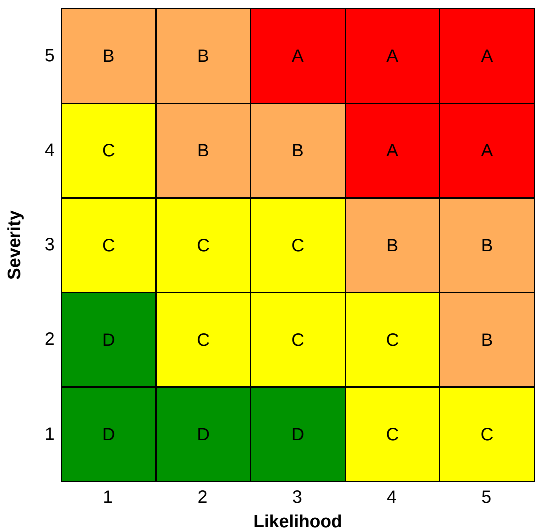
- BS ISO 31000: 2009, Risk Management – Principles and Guidelines
- BS ISO 31010: 2010, Risk Management – Risk Assessment Techniques

Following the FSA level 1 [2], the VDS detector, probiotic emitter, GCM and antimicrobial coating were placed and operated inside the Robot Cabin and Lavrion test facility areas designed to model passenger areas onboard "Discovery". The systems mitigation ability was verified, and appropriate responses were raised to the Risk Assessment recommendations of level 1.

The HAZID software PHA-Pro was used to record the assessment findings, recommendations and qualify the residual risk levels. Refer to Section 5.2 and Appendix 1.

4.2 Risk Qualification

To qualitatively rank the risks (both current and residual), impacting on maritime operations a Risk Assessment Matrix has been adopted and is presented in Figure 1. The matrix has been integrated in PHA-Pro programme and risks have been qualified in the assessment worksheet (Appendix 1) based on the following data.



Risk	Description	Ranking
A	INTOLERABLE/UNACCEPTABLE: Risk cannot be tolerated or justified unless there are exceptional reasons for the activity to take place. Control measures to be introduced to drive risk downwards.	5
B	TOLERABLE / UNDESIRABLE: Risk may be tolerated but shall only be accepted without further action when risk reduction is impractical. In general, further actions are necessary.	4
C	TOLERABLE/ALLOWABLE: Risk is tolerable once demonstrated that the residual risk has been reduced as low as reasonably practical, with regards to safety, security and environmental issues.	3
D	TOLERABLE /ACCEPTABLE: Risk is sufficiently low that may be tolerated according to the ship's standard operating procedures.	2
U	UNCLASSIFIED: Interim condition when risk is not yet categorized or is recorded but it is not deemed an equipment safety issue.	1

Figure 7 - Risk Assessment Matrix

The orange, yellow and green areas of Risk Assessment Matrix represent the range where the risks are tolerable if they are As Low As Reasonably Practicable (ALARP). This is achieved if the cost of risk reduction would greatly exceed the safety improvements gained. The greater the risk, the greater the disproportion between cost and benefit which is required before an improvement becomes impractical. The red shaded region represents the range where risks are high and intolerable and would be required to be reduced by design or technology upgrading activities.

Risks have been calculated based on their severity and likelihood of their occurrence. Residual risks have been calculated on the reduction of their consequence (severity) due to the successful implementation of mitigation solutions. The following explanatory Tables 2 and 3 apply.

Table 2 - Severity Definitions

Severity	Ranking	Personnel PER	Public PUB	Environment ENV	Asset / Property AST	Business Interruption BUI	Media MED
5	5	Multiple fatalities	Single fatality	Extensive, persistent, or irreversible damage to ecosystem function	Total or extensive damage to on-site equipment requiring complete replacement and significant (in excess of US$50 MM). Extensive damage to off-site property (in excess US$ 1MM) Dwelling(s) off-site damage and uninhabitable	Disruption to dependent operations for more than 1 year	International media attention. Severe adverse public reaction threatening facility operations.
4	4	Single fatality	Serious illness - Impairment to several persons. Hospitalization > 24 hrs. Delayed recovery	Widespread moderate-long term ecosystem damage	Major damage to onsite equipment repaired within 4 to 12 months. requiring significant capital expenditure (US$25MM to US$50 MM). Major damage to offsite property (up to US &1MM) Dwelling off-site damage uninhabitable.	Disruption to dependent operations for 3 to 12 months	National media attention Moderate public concern / reaction

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Severity	Ranking	Personnel PER	Public PUB	Environment ENV	Asset / Property AST	Business Interruption BUI	Media MED
3	3	Serious illness - impairment to several persons. Hospitalization > 24 hrs. Delayed recovery	Medical illness. Impairment treatment with rapid recovery. Hospitalization < 24 hrs.	Short term damage impairing local ecosystem	On-site equipment damage repaired within 7 to 120 days with loss of production, requiring capital expenditure (US$10 MM to US $25 MM)	Disruption to dependent operations for 70 to 90 days	State media attention. Adverse public reaction
2	2	Medical treatment illness with rapid recovery. Hospitalization < 24 hrs.	First aid treatment	Minor biological effects across limited area onsite	On-site damage repaired within 7 days with loss of production, requiring capital expenditure (US$ 1MM to US $ 10MM)	Disruption to dependent operations for less than 7 days	Local media attention. Possible adverse public reaction
1	1	First aid treatment	No effect	On-site release immediately contained and readily cleaned up with onsite or locally available technology	On-site equipment damage repaired within 24 hours, without loss of production, requiring capital expenditure (less than US$ 1MM)	Disruption to dependent operations for less than one day	No effect

Table 3 – Likelihood of occurrence

Likelihood	Description
5	Likely to be experienced often in the life of an item, greater than 1×10^{-1} / yr
4	Likely to be experienced more than once in the life of an item; less than 1×10^{-1} / yr but greater than 1×10^{-2} / yr
3	Unlikely, but reasonably expected to occur in the life of an item; less than 1×10^{-2} / yr but greater than 1×10^{-3} / yr
2	Unlikely to be experienced, but credible to occur in the life of an item; less than 1×10^{-3} / yr but greater than 1×10^{-4} / yr
1	Extremely unlikely to be experienced but not physically impossible; less than 1×10^{-4} / yr

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5. Conclusions and Recommendations

5.1 Pilot Testing

The testing of HS4U technologies in the Robot Cabin and Lavrion facility has demonstrated strong operational reliability, technical robustness and the practical effectiveness of these systems in real-world maritime conditions. The VDS operated continuously throughout the test and, the Probiotic Emitter delivered a steady dispersion of beneficial microorganisms into the cabin environment, forming a protective layer on both air and surface levels. The application of the SynthAg resulted in antimicrobial performance across all surfaces used in the cruise ship environment. This biologically based approach provided an eco-friendly and sustainable alternative to traditional disinfection methods.

The following Key Performance Indicators (KPIs) have been recorded associated with the HS4U smart system solutions tested at Robot Cabin and the Lavrion demo facility :

- Detection of airborne transmittable diseases was evaluated via VDS. Although no active airborne events were recorded during the Robot Cabin test, the VDS maintained continuous surveillance. The VDS and Probiotic system worked in parallel, maintaining monitoring and protective functions simultaneously.

- The Probiotic Emitter demonstrated up to 90% expected reduction in surface-transmitted disease cases, based on the combined environmental results and validated trials. It also shortened mitigation response time, achieving effective biotic coverage.

- The VDS in the Robot Cabin successfully sent automated data reports to the CDF, the system is designed to trigger alerts in case of positive detection. All system equipment VDS/Emitter remained stable and communicated effectively with the CDF.

- The field trials validated the antimicrobial efficacy of the SynthAg active ingredient in both tested formulations. A significant reduction in microbial load was observed within the first 30 seconds after product application. A microbial reduction >90% was obtained in cases of high initial contamination.

- The formulations proved effective across a broad spectrum of material types, including metal, wood, and textile surfaces with performance consistently improved over time, with maximal results at 60 seconds of application.

- The sewage Automatic Sampling Device RWO was not tested at Lavrion, the device was already successfully tested onboard “Discovery”, and it has been recommended for installation onboard the cruise ship.

Human Element interaction with the environment and other elements of the HS4U systems was tested during a dedicated crew training session with Celestyal Cruises, where crew members tested the technologies and managed the information outputs. Based on the issued questionnaire responses, over 94% of the “Discovery” participating crew members expressed a positive view of the operability and systems effectiveness, reflecting strong alignment with future adoption by the cruise industry.

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5.2 Residual Risk Calculation

Using the positive test results of the HS4U technologies the project proceeded in addressing the recommendations raised by the FSA level 1 [2] with suitable mitigating systems from the proposed HS4U technologies.

Based on the testing facility's area, the following FSA level 1 [2] basic area 'nodes' were re- assessed, and the Residual Risk was calculated.

- Node 1 – Passenger and Crew Accommodation
- Node 2 – Passenger Embarkation and Movements Onboard
- Node 3 – Passenger Common Facilities

The following explanatory notes apply:

- The calculated risk ranking does not relate to the recommendation it always relates to the consequence of the hazard.
- The safeguards are what means (systems/processes) exist now on the ship to mitigate such consequence and therefore reduce the risk.
- In HS4U project stage (FSA 1) except some disinfection process and a small medical facility there is nothing now onboard the ship to mitigate the risk from virus contamination and outbreak.
- Residual risk, in the context of risk management, refers to the risk that remains after mitigation efforts have been put in place. If mitigation reduces the consequences of a risk event but does not affect its likelihood, the residual risk will have a lower impact but the same probability of occurring.

The project addressed all FSA recommendations with the provision and implementation of HS4U technology as the main mitigation means, supported by hygiene processes in compliance to EU Manual [1]. The residual risk has been re-calculated and the combined Worksheet, presenting both the current risk and the Residual Risk after implementation of the HS4U Project technology solutions is presented in Appendix 1.

The summary of the recommendations, the project's responses with mitigation measures together with the current and the Residual Risk rankings are presented in Table 4.

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Table 4: Recommendations and Risk Ranking

Recommendations	Responsibility	Implementation	Maximum Current Risk Ranking	Maximum Residual Risk Ranking
1. Install VDS real-time air sampling devices in HVAC units to detect pathogen aerosols.	LEDRA/ BetterAir UK & Universite Gustavè Eiffel	VDS installed and operated successfully inside Robot Cabin and covered 4 HVAC ducts simultaneously. Real-time detection, enabling timely isolation and response measures	A	C
2. Deploy an ECOS BA device to actively disperse probiotics via the HVAC system, inhibiting pathogen growth and reducing airborne risks.	LEDRA/ BetterAir UK & Universite Gustavè Eiffel	Probiotic dispersion using E-BIOTIC PRO incorporated and successfully tested in cabin.	A	C
3. Ship operations to verify that HVAC system serving the cabins area (total number of cabins may be on 2 decks) can be maintained operational without cross circulation of air flow to other HVAC systems.	CELESTYAL	HVAC can be operated without cross circulation of air flow to other HVAC systems.	A	C
4. Ship to employ UV air sterilization inside all return air ducts to ensure that the system sterilizes air constantly with the AC is on.	CELESTYAL	UV air sterilization is operational.	A	C
5. Install VDS real-time air sampling devices in HVAC units	LEDRA/ BetterAir UK & Universite Gustavè Eiffel	VDS installed and operated successfully inside Robot Cabin and covered 4 HVAC ducts simultaneously.	C	C
6. Operations to inspect and replace HVAC filters to maintain efficiency and minimize microbial retention.	CELESTYAL	Undertaken under standard maintenance compliance with EUMS Manual of Hygiene [1].	C	C
7. Deploy ECOS BA probiotic devices for continuous probiotic dispersion, creating an antimicrobial barrier in air circulation pathways.	LEDRA/ BetterAir UK & Universite Gustavè Eiffel	Probiotic dispersion using E-BIOTIC PRO incorporated and successfully tested in cabin and other areas in Lavrion facility.	C	C
8. Integrate airflow sensors and real-time monitoring to ensure even air distribution throughout the vessel	CELESTYAL	This is not the case for "Discovery" as AC flow is automatically adjusted on temperature level inside the area.	C	C
9. Ship to introduce method of passenger self-testing in cabins to minimise prolonged undetected occupancy and transmission spread. Adoption of Passenger Dashboard will provide the early self-checking of every passenger feeling unwell, measure body temperature and video call the medical facility onboard.	LEDRA/ UNPARALLEL	GCM Passenger dashboard was installed and successfully tested inside the cabin. System connected on CDF.	A	C
10. Deploy an ECOS BA device to actively disperse probiotics via the HVAC, inhibiting pathogen grow and minimise contact contamination from surfaces.	LEDRA/ BetterAir UK & Universite Gustavè Eiffel / CTNLAB	Probiotic dispersion using E-BIOTIC PRO incorporated and successfully tested wall mounted in cabin and other areas in Lavrion facility. CNT LAB's transparent coating "LongLife Shield" and the textile treatment "AgTEX and successfully tested in cabin and other areas in Lavrion facility.	C	C
11. Ship Operations to introduce early passenger screening at terminal reception by thermal Imaging and fever detection	CELESTYAL	Only adopted during virus epidemic.	B	C
12. Introduce electronic entry by passenger cabin room pass or use of RFID sensors to improve early identification of infected user.	CELESTYAL	Not currently tested or adopted. VDS technology will be used.	B	C
13. Deploy ECOS BA probiotic devices for continuous probiotic dispersion, creating an antimicrobial barrier in air circulation pathways.	LEDRA/ BetterAir UK & Universite Gustavè Eiffel	Probiotic dispersion using E-BIOTIC PRO incorporated and successfully tested in areas in Lavrion facility.	B	C
14. Incorporate VDS technology which provide real-time detection and alarm enabling timely isolation and response measures.	LEDRA/ BetterAir UK & Universite Gustavè Eiffel	VDS installed and operated successfully inside Robot Cabin and covered 4 HVAC ducts simultaneously.	B	C

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Recommendations	Responsibility	Implementation	Maximum Current Risk Ranking	Maximum Residual Risk Ranking
15. Operations to adopt touch surface sanitation using antimicrobial coatings especially in stairs banisters, door handles and lift surfaces.	LEDRA/ CNTLAB	CNT LAB's transparent coating "LongLife Shield" and the textile treatment "AgTEX and successfully tested in cabin and other areas in Lavrion facility.	B	C
16. Use devices to verify the effectiveness of staggered schedules and timed entry systems to reduce overcrowding.	CELESTYAL	Boarding and disembarking time controls by entry number and passenger deck/room numbers.	A	C
17. Deploy VDS devices to monitor bioaerosol levels in HVAC components and detect contamination early.	LEDRA/ BetterAir UK & Universite Gustavȅ Eiffel	VDS installed and operated successfully, covered 4 HVAC ducts simultaneously. Real-time detection, enabling timely isolation and response measures.	A	C
18. Air purification using probiotics and surface sanitization using antimicrobial coatings.	LEDRA/ BetterAir UK & Universite Gustavȅ Eiffel	Probiotic dispersion using E-BIOTIC PRO incorporated and successfully tested in areas in Lavrion facility.	A	C
19. Operations to consider surface sanitation by introducing antimicrobial coatings in changing rooms surface counters, benches, railings and handles which provide long term pathogen elimination.	LEDRA/ CNTLAB	CNT LAB's transparent coating "LongLife Shield" and the textile treatment "AgTEX and successfully tested in similar areas at Lavrion facility.	A	C
20. Ship Operations to introduce screening outside the gym, pool areas.	CELESTYAL	Only adopted during virus epidemic periods.	A	C
21. Depending on the size of facility electronic entry by passenger cabin room pass or use of RFID sensors will improve early identification of infected user.	CELESTYAL	Not currently tested or adopted.	A	C
22. Install VDS real-time air sampling devices in HVAC units to detect pathogen aerosols.	LEDRA/ BetterAir UK & Universite Gustavȅ Eiffel	VDS installed and operated successfully inside Robot Cabin and Lavrion testing facility covering 4 HVAC ducts simultaneously.	A	C
23. Operations to follow timely reporting procedures on antibacterial cleaning in order to improve frequency during peak usage times.	CELESTYAL	Undertaken under ongoing hygiene maintenance in compliance with EUMS Manual of Hygiene [1].	C	C
24. Improve sanitation by introducing air purification with probiotics.	LEDRA/ BetterAir UK & Universite Gustavȅ Eiffel	Probiotic dispersion using E-BIOTIC PRO incorporated and successfully tested in areas in Lavrion facility.	B	C
25. Improve surface sanitation by antimicrobial coatings especially on lavatory doors/handles.	LEDRA/ CNTLAB	CNT LAB's transparent coating "LongLife Shield" and the textile treatment "AgTEX and successfully tested in similar areas at Lavrion facility.	A	C
26. Operations to adopt wastewater management using black water samplers with the ability to inform whether a pathogen is present or not and with which intensity at the point of sampling. Samples should be collected from many different sources including cabins and public spaces.	LEDRA/ BetterAir UK & Universite Gustavȅ Eiffel	The RWO sampling device has been successfully tested in wastewater onboard "Discovery".	A	C
27. Deploy VDS devices to monitor bioaerosol levels in HVAC components and detect contamination early.	LEDRA/ BetterAir UK & Universite Gustavȅ Eiffel	VDS installed and operated successfully inside Robot Cabin and Lavrion testing facility covering 4 HVAC ducts simultaneously.	A	C
28. Operations to consider introducing thermal Imaging and fever detection in access corridors serving entertainment functions, restaurants, public toilets, and in general in areas where due narrow spaces detection can be efficient.	CELESTYAL	Not currently tested or adopted.	A	C

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It is noted that at FSA Level1 the identified consequences were conservative (worst case event). Based on the hazard severity on the passengers the 'worst case' consequence was established to be a single fatality (as per reported maritime cases during COVID-19), refer to Table 1; such scenario is deemed possible to take place more than once in the lifecycle of the ship operation, refer to Table 2.

The resulted Residual Risk has shown very positive results. All consequences carrying an 'unacceptable 'or 'intolerable' risk level have been mitigated to an acceptable 'allowable' risk level (Ref. Figure 7). This amounts to over fifty percent (50%) risk reduction, which in this case was only made achievable by the application of new technologies.

The comparison between current and Residual Risk due to the mitigation of consequences is graphically represented in Figures 8 and 9.

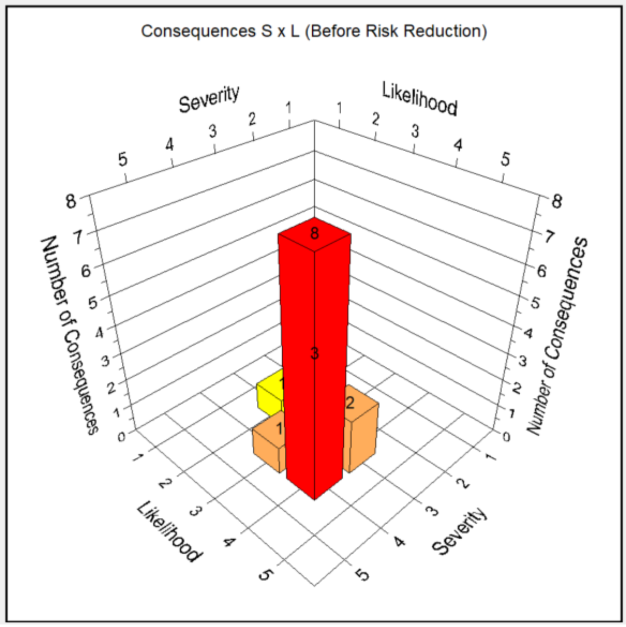

Figure 8: Current Risk Consequences

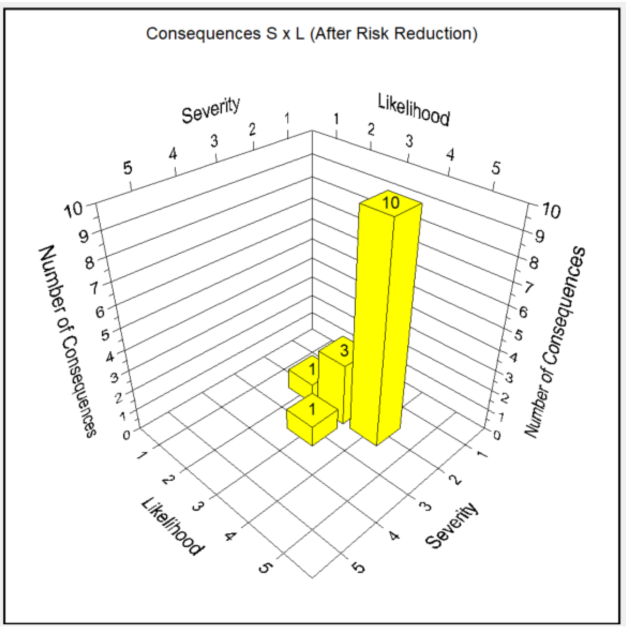

Figure 9: Residual Risk Consequences

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The moving of the severity of the hazard consequences to lower levels has noticeably reduced risk although the likelihood of hazards occurring has remained at the same levels.

The mitigation is considered particularly successful as it does not depend on any additional procedures affecting the existing standard operating procedures (SOPs) onboard the ship but is based on human passenger interaction with intelligent systems on autonomous care.

5.3 Cabin Integration

One of the main critical assessment findings is the requirement of a fully integrated detection system with strategically positioned sensors able to provide continuous real time monitoring and alarms at the onset of a pathogenic decease contamination.

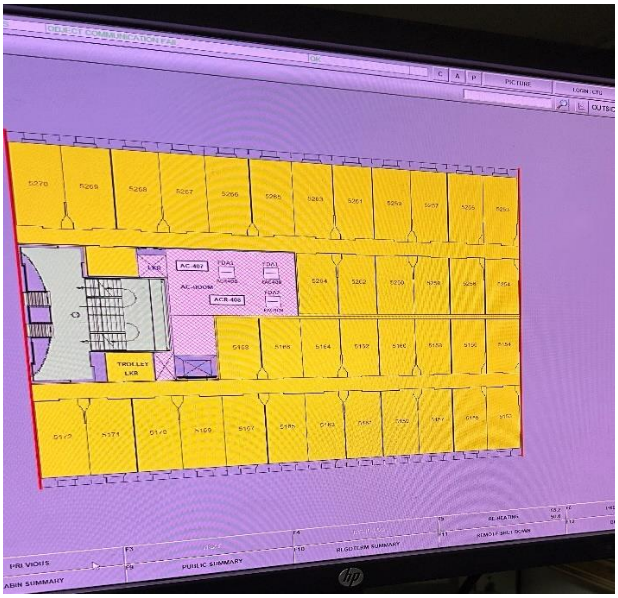

Figure 10: Cabins and HVAC Systems Arrangement

The HS4U project's Robot Cabin serves as the single cabin unit incorporating all latest technologies mitigating and managing virus outbreaks. As the proposed cabins are supported by VDS and probiotic protection covering 4 HVAC ducts simultaneously a strategic number of robot cabins on every deck could be able to provide a sufficient conversion solution onboard an existing cruise ship. Each proposed detector runs on a low 3W power supply and ship operations will be able to support the extra number of detectors from the main electricity board.

The relative low cost of such conversion would succeed high safety benefits gained in line with the ALARP principle.

The pilot activities presented a tangible result in how health resilience is embedded into maritime design. By merging traditional ship operations with intelligent systems and autonomous care, HS4U project has provided valuable input in transforming cruise ships into health-secure environments.

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6. References

[1] European Manual for Hygiene Standards and Communicable Disease Surveillance on Passenger Ships (April 2016)

[2] Critical Assessment of Virus Transmission Mitigation Systems and Operations – Celestyal Cruises, by Lloyd's Register, February 2025

[3] The 2025 State of the Cruise Industry Report by Cruise Lines International Association (CLIA)

[4] Field Validation Report- Antibacterial Effectiveness, CNT LAB Srl, 8 May 2025

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[6] Advice for cruise ship operators for preparedness and response to an outbreak of COVID-19

[7] Cruise Ship Compendium of Best Practices for Customs (March 2023)

[8] Guidance for Cruise Ships on Management of Acute Respiratory Illness (ARI) due to Viral Infection (June 2023)

[9] Celestyal "Discovery" General Arrangement Plan, Decks 0-3

[10] Celestyal "Discovery" General Arrangement Plan, Decks 4-7

[11] Celestyal "Discovery" General Arrangement Plan, Decks 8-11

[12] Celestyal "Discovery" General Arrangement Plan, Deck 12

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Appendices

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7. Appendix 1 – Residual Risk Assessment Worksheet

Node	Deviations	Causes	Consequences	CAT	S	Safeguards	Current Risk		Recommendations		Remarks	Residual Risk		
							L	RR	Recommendations	Responsibility		S	L	RR
1. **Passenger and Crew Accommodation**	1. Airborne virus transmission	1. Release or respiration droplets by infected passenger by coughing/sneezing inside the compact area of mechanically ventilated cabin. Virus transmission to connected areas by air circulation via common HVAC system	1. Virus air transmission in many ship areas cabins and public. Usually, the origin of contamination is very difficult to be detected at early stages depending on the time/symptoms of the cabin occupant.	PER	4	1. Cruise ship as part of the F&G system are able to isolate certain areas by HVAC shutdown in order to prevent the ingress of smoke and impact on escape routes, mustering areas, control room and other critical areas.	4	A	1. Install VDS real-time air sampling devices in HVAC units to detect pathogen aerosols.	LEDRA/ BetterAir UK & Universite Gustavȅ Eiffel	1. VDS installed and operated successfully inside Robot Cabin and covered 4 HVAC ducts simultaneously. Real-time detection, enabling timely isolation and response measures.	2	4	C
						2. Ship's decks are subdivided in five (5) Fire Zones with a number of HVAC systems serving every zone. Usually, one HVAC may serve part of cabins on two passenger decks port or starboard (aft or fwd.), serve two consecutive restaurant areas etc. Galleys are always isolated served by one dedicated HVAC system			2. Deploy an ECOS BA device to actively disperse probiotics via the HVAC system, inhibiting pathogen growth and reducing airborne risks.	LEDRA/ BetterAir UK & Universite Gustavȅ Eiffel	2. Probiotic dispersion using E-BIOTIC PRO incorporated and successfully tested in cabin			
									3. Ship operations to verify that HVAC system serving the particular cabins area (total cabins may be on 2 decks) can be maintained operational without cross circulation of air flow to other HVAC systems.	CELESTYAL	3. HVAC can be operated without cross circulation of air flow to other HVAC systems.			
									4. Ship to employ UV air sterilization inside all return air ducts to ensure that the system sterilizes air constantly with the AC is on.	CELESTYAL	4. UV air sterilization is operational			
	2. HVAC system contamination	1. Inadequate maintenance or cleaning of HVAC components	1. Circulation of bioaerosols from contaminated zones.	PER	3	1. Routine HVAC maintenance	2	C	5. Install VDS real-time air sampling devices in HVAC units	LEDRA/ BetterAir UK & Universite Gustavȅ Eiffel	1. VDS installed and operated successfully inside Robot Cabin and in Lavrion covered 4 HVAC ducts simultaneously.	2	2	C
									6. Operations to inspect and replace HVAC filters to maintain efficiency and minimize microbial retention.	CELESTYAL	2. Undertaken under standard maintenance compliance with EUMS Manual of Hygiene [1]			
		2. Circulation of bioaerosols from contaminated zones	1. Increased airborne and surface contamination in cabins, dining spaces, and lounges. Increased microbial growth due to lack of air exchange	PER	3	1. Optimize airflow distribution patterns. HVAC air flow increases automatically based on temperature increase in the serving area.	3	C	7. Deploy ECOS BA probiotic devices for continuous probiotic dispersion, creating an antimicrobial barrier in air circulation pathways.	LEDRA/ BetterAir UK & Universite Gustavȅ Eiffel	1. Probiotic dispersion using E-BIOTIC PRO incorporated and successfully tested in cabin and other areas in Lavrion facility.	3	3	C

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Node	Deviations	Causes	Consequences	CAT	S	Safeguards	Current Risk		Recommendations		Remarks	Residual Risk		
							L	RR	Recommendations	Responsibility		S	L	RR
									8. Integrate airflow sensors and real-time monitoring to ensure even air distribution throughout the vessel.	CELESTYAL	2. This is not the case for "Discovery" as AC flow is automatically adjusted on temperature level inside the area.			
	3. Contact transmission	1. Undetected infected passenger in cabin through prolonged contact with surfaces.	1. Infection spreads via touch of surfaces, towels, and items inside the room and via touch in high-traffic areas and public places.	PER	4	1. Safe separation of critical hygiene areas like galleys, restaurants, gyms, theaters by provision of dedicated HVAC loop systems servicing each area and the provision of isolation means of all Fire Zones via fire doors, air ventilation dampers, ad suitably placed exhausts away from HVAC intakes.	4	A	9. Ship to introduce method of passenger self-testing in cabins in order to minimize prolonged undetected occupancy and transmission spread. Adoption of Passenger Dashboard will provide the early self-checking of every passenger feeling unwell, measure body temperature and video call the medical facility onboard.	LEDRA/ UNPARALLEL	1. GCM Passenger dashboard was installed and successfully tested inside the cabin. System connected on CDF.	2	4	C
		2. Inadequate or infrequent disinfection of rooms.	1. Transmission risks increase due to longer undetected occupancy and infrequent thorough disinfection.	PER	3	1. Hygienic cleaning (anti-virus agents) usually includes food preparation, restaurant areas, lavatories and general areas.	3	C	10. Deploy an ECOS BA device to actively disperse probiotics via the HVAC, inhibiting pathogen grow and minimize contact contamination from surfaces.	LEDRA/ BetterAir UK & Universite Gustavě Eiffel / CTNLAB	1. Probiotic dispersion using E-BIOTIC PRO incorporated and successfully tested wall mounted in cabin and other areas in Lavrion facility.	2	3	C
											2. CNT LAB's transparent coating "LongLife Shield" and the textile treatment "AgTEX and successfully tested in cabin and other areas in Lavrion facility.			
2. **Passenger Embarkation and Movements onboard**	1. Airborne and/or contact virus transmission at embarkation/ reception areas	1. Undetected infected passenger or crew (coughing, sneezing) during peak passenger movements of embarkation/disembarkation in a heavily congested area of ship's gangway/reception.	1. Virus air transmission in a number of passengers or crew. The origin of contamination is very difficult to be detected at such early stages on the ship's cruise journey and without any association on cabin occupants.	PER	3	1. Passenger reception and security/documentation clearance takes place at cruise terminal not on the gangway. This in effect provides a first visual screening of the passenger and also minimizes congestion on passage onboard.	4	B	11. Ship Operations to introduce early passenger screening at terminal reception by thermal Imaging and fever detection.	CELESTYAL	1. Adopted during virus epidemic. .	2	4	C
						2. Due to congestion and high air temperature HVAC increases automatically air circulation to compensate.			12. Introduce electronic entry by passenger cabin room pass or use of RFID sensors to improve early identification of infected user.	CELESTYAL	2. Not currently tested or adopted as VDS is the preferred solution.			

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Node	Deviations	Causes	Consequences	CAT	S	Safeguards	Current Risk		Recommendations		Remarks	Residual Risk		
							L	RR	Recommendations	Responsibility		S	L	RR
									13. Deploy ECOS BA probiotic devices for continuous probiotic dispersion, creating an antimicrobial barrier in air circulation pathways.	LEDRA/ BetterAir UK & Universite Gustavè Eiffel	3. Probiotic dispersion using E-BIOTIC PRO incorporated and successfully tested in areas in Lavrion facility.			
									14. Incorporate VDS technology which provide real-time detection and alarm enabling timely isolation and response measures.	LEDRA/ BetterAir UK & Universite Gustavè Eiffel	4. VDS installed and operated successfully inside Robot Cabin and in Lavrion covered 4 HVAC ducts simultaneously.			
		2. Passenger waiting for security/boarding cards reading and guidance to the way to the cabins.	1. Infection spreads via touching of surfaces and via touching on stair bannisters and lifts in high-traffic areas. Close contact increases transmission risk.	PER	3	1. Due to the extensive use of boarding and passage facilities anti-bacterial cleaning is frequent.	4	B	15. Operations to adopt touch surface sanitation using antimicrobial coatings especially in stairs banisters, door handles and lift surfaces.	LEDRA/ CNTLAB	1. CNT LAB's transparent coating "LongLife Shield" and the textile treatment "AgTEX and successfully tested in cabin and other areas in Lavrion facility.	2	4	C
	2. Airborne and/or contact virus transmission at the passageways, stairs, and corridors.	1. Undetected infected passenger or crew (coughing, sneezing) during peak passenger movements in a heavily congested area of ship's passage areas.	1. Virus air or contact transmission to a number of passengers or crew. Increase of risk of infection for a large number of passengers/crew.	PER	4	1. As above	4	A	16. Use devices to verify the effectiveness of staggered schedules and timed entry systems to reduce overcrowding	CELESTYAL	1. Boarding and disembarking time controls by entry number and passenger deck/room numbers	2	4	C
									17. Deploy VDS devices to monitor bioaerosol levels in HVAC components and detect contamination early.	LEDRA/ BetterAir UK & Universite Gustavè Eiffel	2. VDS installed and operated successfully, covered 4 HVAC ducts simultaneously. Real-time detection, enabling timely isolation and response measures.			
									18. Air purification using probiotics and surface sanitization using antimicrobial coatings	LEDRA/ BetterAir UK & Universite Gustavè Eiffel	3. Probiotic dispersion using E-BIOTIC PRO incorporated and successfully tested in areas in Lavrion facility.			
3. **Passenger Facilities (gym, sauna, swimming pool, public toilets etc.)**	1. Contact transmission in in gym, swimming pools, sauna.	1. Inadequate or infrequent cleaning using anti-bacterial products. Prolonged contact with contaminated surfaces at the gym, changing rooms, sauna.	1. Infection spreads via touch of surfaces and use of gym equipment. Close contact increases transmission risk. Infection transfer through the connected zones of changing rooms, gym, sauna, swimming pool.	PER	4	1. As above	4	A	19. Operations to consider surface sanitation by introducing antimicrobial coatings in changing rooms surface counters, benches, railings and handles which provide long term pathogen elimination.	LEDRA/ CNTLAB	1. CNT LAB's transparent coating "LongLife Shield" and the textile treatment "AgTEX and successfully tested in similar areas at Lavrion facility.	2	4	C

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Node	Deviations	Causes	Consequences	CAT	S	Safeguards	Current Risk		Recommendations		Remarks	Residual Risk		
							L	RR	Recommendations	Responsibility		S	L	RR
	2. Airborne virus transmission in gym, swimming pools, sauna.	1. High traffic passenger/crew areas usually in congested environments which facilitate the transfer of pathogens. Passengers typically featuring sharing gym equipment, congested sauna areas, swimming pool facilities.	1. Virus air transmission in a large number of passengers. Usually, the origin of contamination is very difficult to be detected.	PER	4	1. Regular cleaning, available disinfectant sprays for use on gym equipment.	4	A	20. Ship Operations to introduce screening outside the gym, pool areas.	CELESTYAL	1. Only adopted during virus epidemic periods.	2	4	C
									21. Depending on the size of facility electronic entry by passenger cabin room pass or use of RFID sensors will improve early identification of infected user.	CELESTYAL	2. Not currently tested or adopted as VDS is preferred option.			
		2. Enclosed spaces leading to poor ventilation, respiratory droplets in air.	1. Circulation of bioaerosols from contaminated zones.	PER	4	1. Depending on the swimming pool facility size and the gym, these areas can be served by separate HVAC systems. 2. UV air sterilization inside all return ducts which sterilizes air flow when AC system is on.	4	A	22. Install VDS real-time air sampling devices in HVAC units to detect pathogen aerosols.	LEDRA/ BetterAir UK & Universite Gustavè Eiffel	1. VDS installed and operated successfully inside Robot Cabin and Lavrion testing facility covering 4 HVAC ducts simultaneously.	2	4	C
		3. Due to the continuous use of facilities efficient anti-bacterial cleaning is usually infrequent or inadequate.	1. As above	PER	3	1. Pool chlorination system together with regular testing ensures the safety of swim water.	3	C	23. Operations to follow timely reporting procedures on antibacterial cleaning in order to improve frequency during peak usage times.	CELESTYAL	1. Undertaken under ongoing hygiene maintenance in compliance with EUMS Manual of Hygiene [1].	2	3	C
		4. Restrooms and changing rooms sharing common HVAC system are further impacting on to the facility with circulation of bioaerosols.	1. High Infection risk to large groups due to stagnant air or overcrowding.	PER	4	1. As above	3	B	24. Improve sanitation by introducing air purification with probiotics.	LEDRA/ BetterAir UK & Universite Gustavè Eiffel	1. Probiotic dispersion using E-BIOTIC PRO incorporated and successfully tested in areas in Lavrion facility.	2	3	C
	3. Airborne and contact virus transmission in public toilets.	1. Infected passenger/crew using the toilet facilities which facilitate the transfer of pathogens. Inadequate or infrequent cleaning using anti-bacterial products.	1. Infection spreads via touch of surfaces or due to infected person's impact symptoms (coughing, sneezing) in a relatively small area.	PER	4	1. Regular cleaning activities following monitoring/reporting procedure. Hand disinfection products for passengers.	4	A	25. Improve surface sanitation by antimicrobial coatings especially on lavatory doors/handles.	LEDRA/ CNTLAB	1. CNT LAB's transparent coating "LongLife Shield" and the textile treatment "AgTEX and successfully tested in similar areas at Lavrion facility.	2	4	C
									26. Operations to adopt wastewater management using black water samplers with the ability to inform whether a pathogen is present or not and with which intensity at the point	LEDRA/ BetterAir UK & Universite Gustavè Eiffel	2. The RWO sampling device has been successfully tested in wastewater onboard "Discovery".			

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Node	Deviations	Causes	Consequences	CAT	S	Safeguards	Current Risk		Recommendations		Remarks	Residual Risk		
							L	RR	Recommendations	Responsibility		S	L	RR
									of sampling. Samples should be collected from many different sources including cabins and public spaces.					
		2. The location of toilet facilities onboard is based on passenger convenience (corridors, restaurants, entertainment areas) which facilitate usage by large numbers of passengers.	1. Increased airborne and surface contamination in toilets, due to the large number of passenger/crew use throughout the day.	PER	4	1. All toilet units are served by dedicated HVAC loops independent of other service areas.	4	A	27. Deploy VDS devices to monitor bioaerosol levels in HVAC components and detect contamination early.	LEDRA/ BetterAir UK & Universite Gustavȅ Eiffel	1. VDS installed and operated successfully inside Robot Cabin and Lavrion testing facility covering 4 HVAC ducts simultaneously.	2	4	C
									28. Operations to consider introducing thermal Imaging and fever detection in access corridors serving entertainment functions, restaurants, public toilets, and in general in areas where due narrow spaces detection can be efficient.	CELESTYAL	2. Not currently tested or adopted.			

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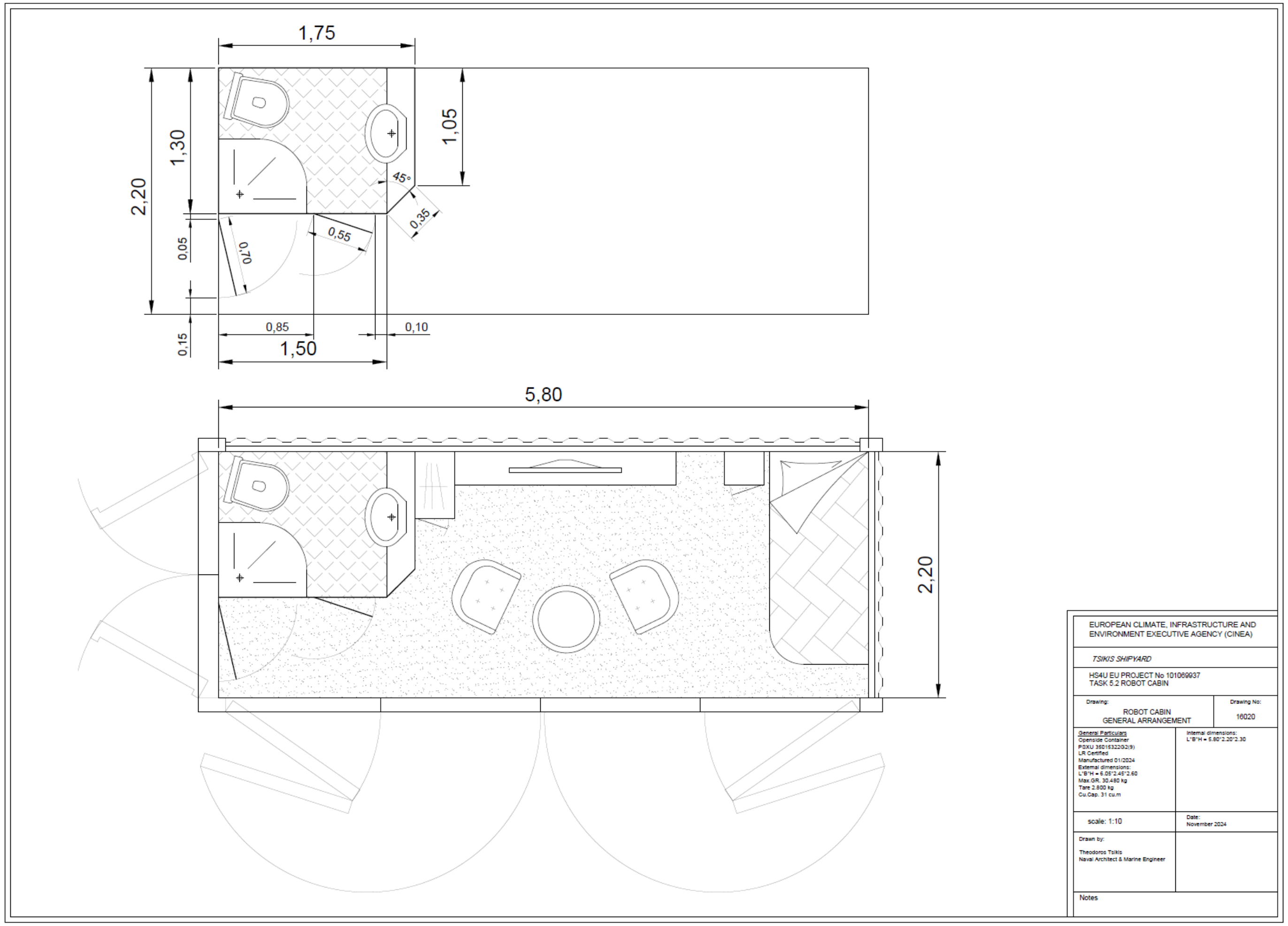
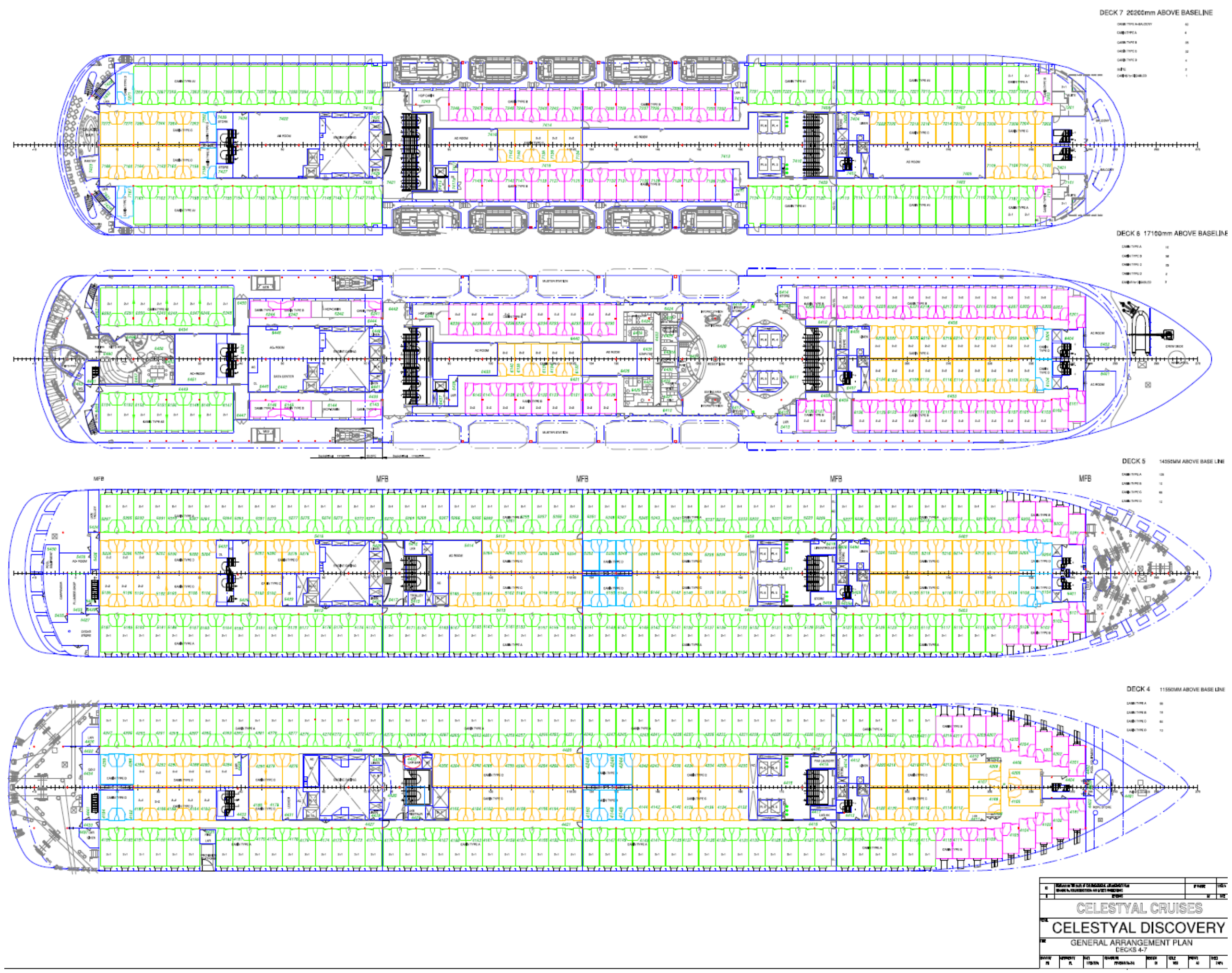
Appendix 2 – Robot Cabin General Arrangement



Appendix 3 – Celestyal “Discovery” General Arrangement Decks 4-7 and 8-11



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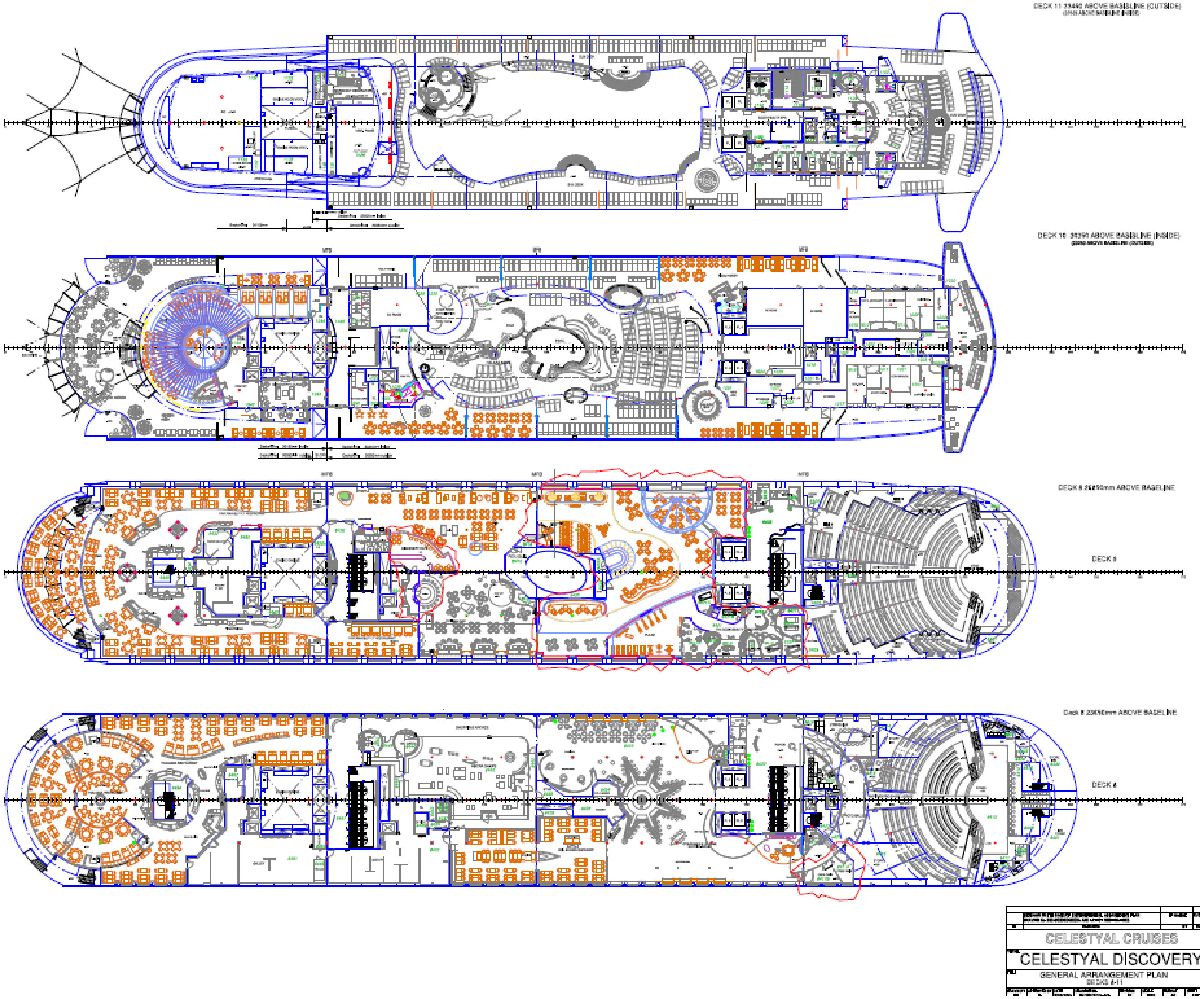

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