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PESARO 2022

Forward

The Twelfth International Conference on Performance, Safety and Robustness in Complex Systems and Applications (PESARO 2022) continued a series of events dedicated to fundamentals, techniques and experiments to specify, design, and deploy systems and applications under given constraints on performance, safety and robustness.

There is a relation between organizational, design and operational complexity of organization and systems and the degree of robustness and safety under given performance metrics. More complex systems and applications might not be necessarily more profitable, but are less robust. There are trade-offs involved in designing and deploying distributed systems. Some designing technologies have a positive influence on safety and robustness, even operational performance is not optimized. Under constantly changing system infrastructure and user behaviors and needs, there is a challenge in designing complex systems and applications with a required level of performance, safety and robustness.

We take here the opportunity to warmly thank all the members of the PESARO 2022 technical program committee, as well as all the reviewers. The creation of such a high-quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and effort to contribute to PESARO 2022. We truly believe that, thanks to all these efforts, the final conference program consisted of top-quality contributions. We also thank the members of the PESARO 2022 organizing committee for their help in handling the logistics of this event.

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UAVs as Means to Provide First Aid Kits to Lost at Sea Victims

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***Abstract*— In the last decade, airships acquired a new role in the civil industry. With their low impact on the environment, high safety standards and high payload capabilities, this technology is developing to become a massive business. The many advantages in terms of transport and ecological impact (respecting the constraints given by the United Nations Framework Convention on Climate Change) result in defining a new type of resource that can be useful in many civil scenarios. The variety of operations that Unmanned Aerial Vehicles (UAVs) can pursue are explained. The conditions where UAVs can play a role as first aid providers in disaster scenarios are suggested. Autonomous airships are employed as UAVs for patrolling and disaster response scenarios. In distress situations, victims may require fundamental needs which would be delivered by the airship. The study on how the payload mass influences the decision of the parameter of the airship, that should be used for the rescue operations without interfering with the patrolling mission, is carried out. The presented simulation describes the sprint-and-drift strategy employed for optimal search. This article has the objective of presenting a practical disaster supply kit for people lost at sea on the supposed Ligurian coast, where the technology of autonomous airships can be greatly employed by the coast guard.**

Keywords - airship; patrolling; simulation; human rescue; disaster supply kit.

I. Introduction

UAVs come in different sizes and are used for different purposes. The larger drones are most often used for transporting large amounts of gases or heavy cargo, and the smaller ones are for patrolling or delivering a cargo of small weight and volume. In addition, UAVs can be used for inspection and repair tasks requiring autonomous manipulation [1] or simply for logistical operations, such as parcel delivery. Moreover, there is considerable literature on the use of UAVs for monitoring purposes, which can be as diverse as monitoring infrastructure, particularly pipelines [2].

Speaking of patrolling, we imagine a smart city, where security is provided by many smart devices interconnected following the Internet of Things paradigm. At present, we no longer see this as a distant future but rather as a need to accelerate this process. In our view, however, patrolling drones should be seen not only as airborne smart surveillance cameras but also as devices capable of patrolling and saving lives at the same time.

In this paper, we propose the concept of a drone carrying a safety payload (kit). This will be carried by an autonomous vehicle (an airship) which would be patrolling the coastal area of the Ligurian sea. During the patrolling operation, when an airship notices that a situation requiring first aid is happening, then the airship will deliver the disaster supply kit, send a distress signal to the coast guard and then go back to its patrolling operations.

Our article consists of the following parts. Section 2 describes the state of the art and shows the most relevant articles in a literature review on the topic. Section 3 describes the different types of safety kits depending on the scenario in which a person is in danger and presents the most versatile option. In Section 4, we calculate the necessary payload capacity of the drone, which will allow it to "float" with the necessary equipment and safety kit on board. Also, in this Section, we give the corresponding dimensions of the drone, which allow it to stay "afloat" for 3-5 days and work in accelerated mode with high-frequency video and information transfer for 30 minutes. We also describe a system that allows us to find the drone in the future when it is no longer helpful to a person in danger by using the navigation system [3]. In Section 5, we introduce the possible application of airships for different types of missions. In Section 6 we present the results of our calculations and describe a human rescue scenario by an operator using a drone. Section 7 is dedicated to the presentation of the simulation based on the assumptions of a real-life scenario. Finally, in Section 8, the conclusions for this work are given and inputs for future research are presented.

II. LITERATURE REVIEW AND THE STATE OF ART

By the term patrolling, we understand the movement over the territory at regular intervals to protect or monitor it. To patrol the Ligurian coast, we consider an airship as one of the safest means of transportation capable of "floating" over any territory, carrying a payload in the form of a safety kit, communication systems, and propulsion system. The airship can be equipped with state-of-the-art devices with extremely high resolution. These are ideal for accessing hard-to-reach areas or operating in adverse conditions that can be lethal to human operators. The implementation of airships with modern technology can be helpful in different critical scenarios, for example, support for emergency responders in hazardous situations. Their employment would provide unique viewing angles unavailable when employing manned aircraft, with also the advantage of being cost-effective.

In the scientific literature, airships are referred to under various acronyms, such as UAV, Unmanned Aerial System (UAS), Remotely Piloted Aircraft (RPA), or Remotely Operated Aircraft (ROA). They have been considered especially as mobile measurement/utilization platforms (i.e., platforms for delivering an increasingly wide range of sensors and actuators). This work aims to develop a design of a disaster supply kit that would have to be delivered to an incident location. This kit would be delivered by an autonomous airship that will understand the emergency through a learning algorithm. After understanding that the situation requires the delivery of the disaster supply kit, the airship will deliver the kit, send an initial distress signal to the coast guard, and then will go back to the previous mission (in our scenario, a patrolling of the coast operation).

Capitta et al. [4] considered structural (stress and deformation) and technical (propulsion and structural) characteristics during their analysis. This work is of interest to us for the general calculation of a prototype of a smaller scale (7.5 m long) unmanned airship capable of transporting natural gas contained in sealed bags between two predetermined departure and arrival stations following ENAC (Ente Nazionale Per L'Aviazione Civile) rules.

Today, we can use helicopters and airplanes over territories for patrolling. However, they have disadvantages, such as high costs, dependence on pilots, and relying on operators for image transmission, while their efficiency is limited.

The decision to patrol using drones is also supported by the safety of operators and the lack of the need for more rescuers.

Ferrara et al. [5] examine the use of hybrid UAVs to detect illegal dumping using two or more geophysical methods. The advantages of aerial platforms include:

- increased visual field, which allows quick patrolling of large areas;
- the ability to reach otherwise inaccessible areas;
- the steepness of the investigated matrix, quickly displaying the extent of the phenomena under study;
- the safety of the operator, who does not need to put himself at immediate risk.

Bigazzi et al. [6] developed and implemented solutions for the precise maneuvering of small autonomous (e.g. 350 class) drones based on intelligent modifications of low-cost mass-market technologies. On the positive side, the patrol autonomy is provided by a cyber-pilot, which allows moving along a fixed trajectory. As a solution, it is possible to single out the disadvantage that the considered class of vehicles has low payload capacity, and only a limited number of sensors and computing devices can be installed onboard.

Di Paola et al. [7] presented the implementation and integration of several autonomous navigation and surveillance functions on a multi-sensor mobile robot for terrain monitoring tasks. The research is of interest to us in the use of computer vision. Laser, Radio Frequency Identification (RFID), and computer vision data are used for mapping tasks. However, one of the limitations of the presented system, as noted by the authors themselves, is that the detection of objects and people is done in predefined target positions, where the robot stops and remains stationary for data processing.

Di Fava et al. [8] propose a vision-based approach for mobile robot autonomous navigation as suitable for patrolling indoor and outdoor areas. The proposed architecture consists of a high-level (deliberative) and a low-level part (reactive). The use of visual tools supports the deliberative part: one to determine the road (path) that the robot must follow to navigate the patrolled areas, and the other to detect moving objects/people. Outdoor localization is accomplished by updating odometry via Global Positioning System (GPS) and compass, processed with an advanced Kalman filter. The deliberative part uses vision tools to provide the information needed for the two behaviors of the reactive part. The robot's vision is used to find road edges during external navigation, both on well-defined paths and on roads without clear markings (such as city parks). The algorithm used is a modified version of Supervised Classification Applied to Road Following (SCARF). SCARF is a color vision system that recognizes complex roads and intersections. It recognizes roads with uneven surfaces and edges in complex shadow conditions without lane markings. The work uses computer vision tools based on RGB image information, so this approach works in daylight conditions, which is a significant disadvantage to patrolling the area in an emergency or when it is necessary to rescue people.

Lee et al. [9] proposed an autonomous indoor patrol and surveillance system using drones. The system consists of six components: (1) a low-cost vision-based UAV position estimation system, (2) a vision-based condition estimation system, (3) a UAV patrol route planning system, (4) a UAV control system at desired path points, (5) a hand-held joystick control system, and (6) a priority hierarchy assignment system for multiple robot control inputs. Real-time images from the UAV camera are transmitted to the office for observation by security personnel. If suspicious people or potential crimes are detected, management can override the autonomous control of the UAV to track the criminal using the remote control joystick. The results obtained by the authors have good accuracy, but the drawback for us is the need for the operator to be present at all times during patrols.

Hildmann and Kovacs [10] examined the use of UAVs as autonomous or semi-autonomous data collection platforms, often referred to as Mobile Sensing Platforms (MSPs) in smart cities and public safety, and the use of UAVs for civil security and disaster response. Indeed, UAVs are predicted to play an important role in smart cities and citywide IoT (Internet of Things) infrastructure [11]. Concerning safety issues in disaster response, the authors distinguish three categories (stages) of disaster response operations:

1. Disaster preparedness: preempting actions that may cause or worsen the consequences of the disaster and implementing measures to mitigate (or completely prevent) the consequences of the event.

2. Disaster assessment: evaluating the areas affected by a disaster, determining the extent to which they are affected, and summarizing this information in the form of reports.

3. Disaster response and recovery: effectively respond and take action based on the above.

For disaster management, Jo [12] proposes using UAVs controlled by humans but capable of performing autonomous functions. In addition, the authors propose the use of Wireless Sensor Networks (WSNs) and multiple UAVs as a combined system with minimal human involvement.

Capitta et al. [13] describe the airships and the lifting process well, including formulas for calculation.

Many studies are presenting the advantages and disadvantages of employing autonomous vehicles and robots. In the presented specific scenario, many things should be considered for future improvements of the system such as the ability to work at very low altitudes, autonomy, the ability to fly to hard-to-reach areas, and the ability to carry heavy payloads.

III. Rescue process

The main scenario considered in our work is the event where an airship, as part of a fleet, will provide first aid to a victim spotted during the patrolling operations of the Ligurian coast. As said, the primary mission of the airship would be the patrolling of the coast following the hypothetical path of the coast guard, but in the air. The idea is that the airship will deploy a disaster supply kit once, during the patrolling operations, it would spot a distress situation. Being an autonomous entity, the airship will send a signal of the location of the victim, deliver the supply kit by identifying the region around the victim, and then will go back to its reconnaissance duties. The airship should gently deliver the supply kit by deploying it with nylon cables (not dangerous for the victim in case of wind) until the touchdown on the sea surface. The basic supply kit provides the victims with what we studied to be the fundamental needs for a distress situation.

The scenario proposed for the employment of such a kit is one of the people lost at sea. This does not mean that it is the only scenario in which such technology can be employed. A similar analysis would be possible to be carried out in the situation of people lost in the mountains or the desert, but, given the location of our study (the Ligurian coast), we did not take into consideration the application in other scenarios. Within the scenario in which the airship would be used as a means for reconnaissance and patrolling port areas, we can give a brief description of what a grab bag would contain: a hypothetical liferaft with a liferaft manual and survival instructions; water supply and, eventually, a device to turn salt water into drinkable water; food supplies; eventually a battery-powered radio with an eventual dynamo (a hand-crank design can be helpful); a waterproof torch; a first-aid kit; a whistle; a floating knife; a pair of oars; a dust mask (this in the scenario in which the area contains hazardous materials in the air); items for personal sanitation; wrench or pliers for emergencies in case of failure of the boat; nautical charts of the local area; a locator beacon; red hand flares; eventually, parachute rockets; an emergency cellphone with a backup battery; a rescue quoit.

IV. Calculating the payload of the UAV

As we have already covered in our previous study [14], we have the final goal of designing an airship that would carry out several operations, including reconnaissance and patrolling. Since airships are lighter-than-air vehicles, we have to determine the payload value that we intend to load. Therefore, we decided to start from this analysis to obtain the most efficient model in terms of cost and design.

Following the constraints given by ISO 9650-2 [15], we can think about a scenario where the airship will deploy a disaster supply kit for a maximum of 4 people. The liferafts described by the ISO 9650-3 are standardized for four people, each weighing 75 kg. Each passenger will have 0.250 m^2 of space, and the liferaft must be manually deployed if the survivors are on a drifting boat. From what we could study, there are already projects that can provide liferafts. Two are the configuration of storage that can be thought of as a suitcase or in a container. Every configuration must be waterproof and be buoyant. From a practical point of view, the configuration we can be interested in is the suitcase one, to minimize the weight. To have a not too heavy payload that may become a hazard for the victims, we think it is best to think about installing a liferaft of a second specialized airship to not have too heavyweight (only the liferaft would be about 30 kg) for the reconnaissance airship.

Essential to people lost at sea is water. We cannot know how long the victim has been lost at sea, but one of the first concerns is to ensure the hydration of the person. We can supply the disaster supply kit with a container of 2 liters of drinkable water, in a scenario where two people are lost at sea. Supposing that a person should drink 2 liters of water a day, we can suppose that for near-coast operations, 2 liters would be enough for such a disaster supply kit. Another option is to supply the kit with less water and add a convertible for turning salt water into drinkable water (for example, the device described in [16]). A physical device would be the best option given the emergency conditions. By looking at different devices on the web, we considered a technology that: can provide at least 4 liters of water per hour through Reverse Osmosis Membranes and human power as an energy source and weighs around 2.5 kg [17].

As for food supplies, we can equate the disaster supply kit with a vegetarian food supply for one day, always with the idea of near-coast operations. The vegetarian choice is to provide help to the majority of the cases (thinking that nonvegetarians can comply with the situation until rescued). Therefore, we consider that emergency food supplies should be around 0.5 kg for a maximum of two victims for a time span of 12 to 24 hours.

For the waterproof torch, we can think about rechargeable scuba diving torches (and so we will equip the kit with a double pair of batteries), ensuring a wide light beam and a long burning time. These torches usually have about 2000 lumen output, a depth rated about 150 meters but can be pretty heavy, up to 600 grams.

Marine First Aid Kits are essential if it is necessary to carry on first aid operations. As we can find on the Internet, a standard kit contains:

- A variety of adhesive bandages
- Antiseptic wipes to clean wounds
- Gauze pads
- Adhesive tape
- First aid cream
- Aspirin
- Sting relief wipes
- Cold packs
- Scissors

We suppose that the kit would weigh about 1 kg.

An emergency marine whistle of bright color can be highly effective for location. However, we suppose it will not be more than 50 grams.

A floating knife made of floating materials (like the handle in cork) can be strongly effective in an emergency. These types of knives can weigh about 100 grams.

Dust masks can be reliable items for victims in hazardous areas. Thinking of equipping the kit with 2 FFP3 2505 masks, it would come to about 50 grams.

When lost at sea, the victim may need to clean himself/herself and have bags where to store items and trash garbage. We think that considering 300 grams for personal sanitation supplies should be enough.

In case of a boat emergency, it may be necessary to have additional tools. We think that special tools made from light materials may come to be helpful. We think that, in general, the tools should weigh a maximum of 400 grams.

It may be necessary to have nautical charts of the local area to give the victim an idea of where he/she is. We think that 100 grams maximum should be a sufficient weight.

The hand flares must be of a design that would occupy the minimum volume in terms of space but have the maximum efficiency. They must be used both during the night and during the day. Considering what would be available on the market, we can say that the RED hand flare from IKAROS can be an optimal solution. They have a luminosity intensity of 15000 cd with a possible burning duration of more than a minute. All this is enclosed in a small volume of 243x30 mm and weighs 225g. Although it is suggested not to look directly at the flame for safety reasons, it is necessary to hold it downwind and possibly out of the liferaft to avoid flares dropping on the deck [18].

We suppose that parachute rockets, for how much they are an essential item for search and rescue operations, may not be needed even in case of rescue operations during the night. In this case, we would consider the airships equipped with night vision sensors to facilitate rescue operations.

It can be necessary to recover other victims at sea, or it may be needed to have rope. This is why a rescue quoit is a necessary item in a disaster supply kit. This item has a length of 30 meters, a width of 5 mm floating polyline, and a weight of 900 grams.

TABLE I. CONTENT OF THE SUPPLY KIT

Equipment	Weight
Liferaft + manual (on specialized vehicles)	30.0 kg
Water supply + drinkable water device	4.50 kg
Food supplies	0.50 kg
Waterproof torch + batteries	0.60 kg
Marine First Aid Kit	1.00 kg
Emergency Marine Whistle	0.05 kg
Floating knife	0.10 kg
FFP3 2505 masks x2	0.05 kg
Personal sanitation kit	0.30 kg
Additional repairing tools	0.40 kg
Nautical charts	0.10 kg
RED hand flares x3	0.68 kg
Rescue quoit	0.90 kg
TOTAL	9.18 kg (+ 30.0 kg on specialized vehicles)

V. DELIVERING THE SPARE PARTS

Airships can carry out a multitude of operations including support to marine platforms and ships. Airships can, for example, deliver different types of tools or equipment to infrastructures that are not easily reachable by humans. Airships, as we mentioned above, have great advantages from an ecological point of view and can be integrated with modern technology to develop UAVs able to autonomously carry on the necessary operations.

Another studied scenario is a bust pipe of an oil production infrastructure or the failure of components of a cargo ship. In these types of scenarios, a signal would communicate to the central hub the necessity for spare parts. These will be then delivered to the location point. We suppose that in the future, with the help of similar calculations as we will propose after, the computer will be able to decide which airship to use depending on the requested payload.

VI. DEFINITION OF THE CHARACTERISTICS OF THE UAV

As we well know, the principle behind the physics of an airship is Archimedes' principle. The airship envelope is filled with a lifting gas (hydrogen, helium), providing the body with the necessary lifting force. The carrying capacity of the airship will be proportional to the internal volume of the envelope, taking into account the mass of the structure.

Calculating the payload, we think we can round the result to 11 kg thinking of wrapping the disaster supply kit in a lightweight, impact-resistant casing and considering the eventual weight of the equipment for the surveillance and patrolling operations.

A blimp can be assumed to be submerged in a fluid, air. This will be the fluid providing the lift for the airship. This means that the volume of the airship has to be equal to the volume of the displaced fluid.

For buoyancy:

$$B = \rho_f \cdot V_f \cdot g \quad (1)$$

Where *f* indicates our fluid, the air. Another note is that V_f is the same volume as the airship

$$V_f = V_{airship} \quad (2)$$

The buoyancy is pushing up in the airship but pulling down as if we want to hang something from the airship. We want to find this mass, the one that we want to lift. Moreover, we have to consider the mass of the gas that is filling the airship and pulling the mass and the mass of the airship itself. The final equation for the buoyancy will be:

$$\rho_f \cdot V_f \cdot g - m_{gas} \cdot g - m_{payload} \cdot g - m_{airship} \cdot g = 0 \quad (3)$$

We have to know the air density in the scenario that we want to present and decide which gas we will use as lifting gas. Then, knowing the volume of the envelope, we can obtain the mass of the lifting gas by knowing its density.

What is unknown are the V_f and the $m_{airship}$. However, this last one can be calculated if put in relationship with the volume of the envelope [19]. In particular, considering the available resources on the market and making assumptions to simplify the problem slightly, we can consider the material of the envelope of mylar, a polyester, whose studied optimal thickness can be 1.5 mm (h_{env}). Considering then the density of the material of 1390 kg/m^3, we can write:

$$m_{airship} = V_{env} \cdot \rho_{envelope} \quad (4)$$

And the final equation will be:

$$\rho_f \cdot V_f - \rho_g \cdot V_f - m_{payload} - V_{env} \cdot \rho_{envelope} = 0 \quad (5)$$

With

$$V_{env} = A_{env} \cdot h_{env} \quad (6)$$

Leaving us with:

$$V_f = \frac{m_{payload} + A_{env} \cdot h_{env} \cdot \rho_{envelope}}{\rho_f - \rho_g} \quad (7)$$

For safety reasons, we will choose helium as lifting gas ($\rho_g = 0.1785\ kg/m^3$). Because we are designing an object that would have to fly above the sea surface, we are not expecting that it will fly at high altitudes; this is to avoid the negative effects of the wind. Given this statement and following the altitude-density graphs, we can consider the reference density of air between $1.2\ kg/m^3$ and $1\ kg/m^3$. For our scenario, let's consider a density of $1.1\ kg/m^3$.

Given the area of the prolate spheroid (the shape we are assuming resembles the best of an airship):

$$A_{env} = 2\pi a^2 + 2\pi \frac{ac}{e} \arcsin(e) \quad (8)$$

Where a is the minor semi-axis, c the major semi-axis, and e the eccentricity (given by $e = \sqrt{1 - \frac{a^2}{c^2}}$ in the case a<c), the value of V_f can be described by the function:

$$V_f(a, c) = 11.93 + 0.19 \cdot \left(2\pi a^2 + 2\pi \frac{ac}{e} \arcsin(e)\right) \quad (9)$$

From the function, we can see how the results are strictly dependent on h_{env}.

It has been researched that several technologies allow us to employ thicknesses up to 125 microns (when employing polyurethane, for example). This would allow us to have better results and arrive to compare with already existing technologies that can be employed. A configuration in which $a = 1{,}1\ m$ and $c = 6\ m$ would give us the following results:

$$A_{env} = 59{,}379\ m^2$$
$$V_f = 23.178\ m^3$$

These results seem to be acceptable and would make us think about the necessity of developing a new configuration or employing designs already available on the market. But this decision would be strictly connected to the economic resources available in the future.

VII. Simulation Model

To understand the movement of patrolling airships, we set the parameters describing the Ligurian coast. We simulated that during the patrolling operations, the airships would receive a distress signal alerting that a victim is lost at sea. This, in real life, would happen while the airship is at a random point in the patrolling area. The airship, as part of a fleet, will start the search for the victim by following a sprint-and-drift strategy to save energy [14, 20]. The idea behind this concept states that the vehicle will sprint in a direction for a designated time and then drift with the wind employing only minimal energy for correction actions. Figure 1 shows the results of this simulation.

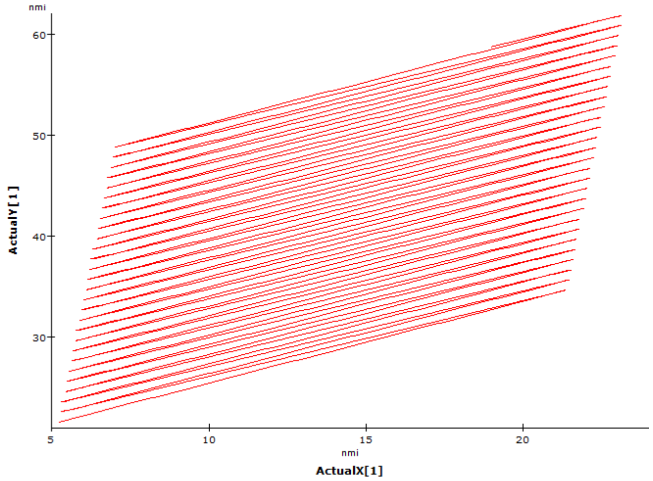

Figure 1. Sprint-and-drift patrolling strategy. ActualX describes the sprint phase and ActualY describes the drift phase.

We start by setting the limits of the patrolling area for each airship of the fleet. Being the fleet of airships interconnected, we would be able to assign each of them to a specific area. The random starting point of our simulation is {9,178; 5,475} in nautical miles (nmi), within the patrolling area of one of the airships. The concept is that once the airships receive the distress signal, they will start the search for the victim in an area wider than the patrolling one. As we can see from the graph, the sprint-and-drift patrolling strategy allows covering a wide area, but it requires more than one airship for the search because we are not covering all. Because different airships are initially assigned to different initial patrolling areas, we can suppose that the assumption of using a fleet of autonomous airships would bring the desired result of locating the victim.

VIII. Conclusion

In the past years, airships resulted to be an emerging business. The many advantages in terms of transport and ecological impact (respecting the constraints given by the United Nations Framework Convention on Climate Change) result in defining a new type of resource that can be useful in many civil scenarios.

The presented work described the scenario of delivering a disaster supply kit to people lost at sea. The UAV intended is thought of as part of a fleet carrying out surveillance and reconnaissance operations on the Ligurian coast. During the patrolling operations, the airship would detect the victims, send the signal to the port authorities with the coordinates of the event and deliver them the disaster supply kit. The airship will then go back to its mission. In the case of far-from-coast reconnaissance, we are supposing that the airship will send a signal to both the port authorities and the airship carrying the emergency liferaft. This scenario will be studied further in future research.

The description of the content of the disaster supply kit is quite exhaustive and we considered it the first step for the determination of the characteristics of the airship. Given the weight of the payload, consisting of the disaster supply kit and the instrumentation, we were able to develop a preliminary calculation on how to determine the dimensions of the semi-axes of the needed airship.

The presented simulation showed the hypothetical pattern of search for victims lost at sea. Future studies will be aimed at calculating different searching patterns to optimize the time, the costs, and the path to reach the victims' location. Given the results, we are confident that this article represents the first step of many future projects and applications of this technology in the emergency and safety fields.

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Integral Safety Layers for Residential System Development

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***Abstract*—Integrally safe, or integral safety, is a challenge because safety is in different hierarchical layers across the entire life cycle for products and systems. Safety is beyond a specific layer, and challenges for safe integration are present through the complete chain of hierarchy. The system hierarchy helps to understand the system as a part of an integral whole, composed of components which interact with its environment. This paper provides an overview of integral safety, aiming to present an organisational view of the system's structure under consideration both internally and externally through the concept of safety layers. The paper builds upon the currently established hierarchical concepts and explains how the concept is applied in the tiny house project, where technology was successfully integrated with residential areas.**

Keywords - Safety layer; product safety; system integration; hierarchy.

I. Introduction

A hierarchy is an arrangement of items (objects, names, values, categories, etc.) in which the items are categorised as being 'above', 'below', or 'at the same level' as one another. According to the Oxford English dictionary, levels in a hierarchy may also represent authority, control or ownership of lower levels (command structure). It is important to note that the depth of the hierarchy is adjusted to fit the complexity of the system. Moreover, for the sake of efficiency, a system may focus on specific levels. Logical hierarchy, also known as a conceptual order, has uses in various disciplines, such as risk assessment or system governance as presented by [1]. Leveson had proposed the hierarchy model called the Systems-Theoretic Accident Model and Processes (STAMP) as an alternative safety incident investigation and to improve the performance analysis of a system [2].

The logic of hierarchy is closely related to the sequence of integration. In engineering practices, creation comes before integration. That is a logical approach where the functionalities are first identified, the systems and subsystems are designed, and then the components or subsystems are built and integrated. Systems engineering discipline pays extra attention to the importance of integration. It defines the purpose of the integration process as 'to synthesise a set of system elements into a realised system (product or service) that satisfies system requirements, architecture, and design', see [3]. This discipline mainly focuses on subsystems and integration. The concept of integration has been extended from just a technical integration in various literature, for example, [1] [4]. This study aims to propose a framework for integrating the technical and non-technical elements.

The rest of the paper is structured as follows. In section 2, we introduce the seven layers for safe integration introduced in [4], [5]. Then, in Section 3, we present its application to the LIFE project. And finally, in Section 4, we offer our conclusions.

II. Layers of safe integration

Through the concept of hierarchy, safe integration starts with the integration of components, where a combination of two or more parts or elements makes a subsystem. Then, integrating all the subsystems together with the human interactions results in the technical system. Integration of humans with the technical system is known as system integration. The integration of various systems is also known as systems integration or System of systems (SoS). SoS need to offer social services to function, and that leads to sociotechnical integration. National governments' control and monitoring of sociotechnical systems reflect the conformity with societal values regarding national norms, standards, and policies. And they also need to comply with regional, continental, or international regulations. Each integration layer applicable for safe products or systems is elaborated on below.

1) Safe integration of subsystems refers to a combination of two or more components or elements that make a subsystem. Subsystems or components are parts of a system and often do not function independently. Therefore, component integration or subsystem integration is often the earliest action in physical integration. The integration of components often occurs in the production or assembly stage.
2) Safe integration of technical system refers to the integration of components, elements or subsystems, or human interactions to realise a system that accomplishes the system objectives. In the system engineering community, a system is defined as 'an integrated set of elements, subsystems, or assemblies that cooperate to accomplish

a defined objective'. These elements include technological products (hardware, software, firmware), processes, people, information, techniques, facilities, services, and other support elements, according to [6]. The Systems Engineering (SE) handbook defines integration as a technical process making integration of the elements of a system possible. In this context, successful system integration is a system that works and delivers the required functionalities without failures. The failures that happen in this process are seen as defects of a component or interface. At this level, the main focus is on components, subsystems, or interfaces. The SE Handbook does recognise that the integration of humans and systems is not a technical process and therefore recommends focusing on human systems integration (HSI) across the design or engineering of systems instead.

3) Safe integration of humans with technical system (HTSI) refers to the integration of the humans and technical systems. HTSI focuses on the human, an integral element of every system, over the system life cycle. It is an essential part of engineering systems, as it promotes a 'total system' approach that includes humans, technology (e.g., hardware and software), the operational context, and the necessary interfaces between and among the elements to make them all work in harmony, see [7].

   HTSI ensures consideration of the human in the system capability definition and system development. Here, the human is considered an element of the system; its integration with the system must be fully accomplished. It includes domains, such as human factors engineering (human performance, human interface, user-centred design), workload (regular and emergency), training (skill, education, attitude), personnel (knowledge, attitudes, career progression), working conditions and health (ergonomics, occupational standards, and hazard and accident avoidance), e.g. [6].
4) Safe integration of System of Systems refers to the integration of two or more systems. According to [8], a system of systems is a set of systems and system elements that interact to provide a unique capability that none of the individual systems ever could accomplish on their own. A system of systems is, in itself, wholly integrated. Also, it has elements that are managerially or operationally independent. Mo Jamshidi considers integration as the critical viability of any system made of systems [9]. To achieve optimal results, having shared objectives among organisations, co-creation of desired capabilities and co-integration of interoperable services are crucial to success, according to [10].
5) Safe integration with sociotechnical systems focuses on the integration of the system of systems or related services with society. In other words, a system of systems needs to be up-to-date with social demands in order to function optimally. A system of systems requires to conform to regulations, norms, values, and culture [11]. For example, the language of communication has an impact on the sustainable performance of the system of systems [12].
6) Safe integration with political system refers to the control or monitoring of sociotechnical systems by national governments and makes societal policies. Governments have the task of controlling sociotechnical systems while maintaining societal values and policies. Organisational chains of responsibility, authority, and communication ought to measure and control mechanisms to effectively drive the organisation and enable people to perform their roles and responsibilities, see [13].
7) Safe integration with global system refers to shared concerns of human societies which may, for example, be represented by international regulations. Globally essential considerations, such as the use of green energy, reducing the usage of fossil fuels, and minimising CO_2 emissions.

An illustration of the layers is provided via the application of the concept, which is described in Section 3.

III. Example application

A. Introduction to LIFE

The University of Twente, in 2019, initiated the 'Living project for Future Innovative Environments' project or more conveniently referred to with its acronym 'LIFE'. The project aimed to research the interplay between the technology, humans and the infrastructure system in supporting society's transition towards a future of low carbon footprint, climate-friendly living, and a circular economy [14]. Ten small-and-medium enterprises around the Twente region, known as the LIFE Project Partners, contribute to the project over the entire lifecycle, starting from conceptual design to equipment installation, support, maintenance and eventual disposal.

The aspiration is that the residential buildings become autarkic, meaning that they are self-sufficient in water and energy. Solar panels will be used to generate electricity and capture heat. A hydrogen system and batteries will act as electrical energy storage, charged and discharged cyclically. Heat is stored in an underground buffer and distributed via a heat pump throughout the house. Rainwater is harvested and treated before use. Used water is also treated and re-used wherever possible. The conceptual idea of LIFE can be seen in Figure 1.

The project will span over ten years, with six 'tiny house' units built initially as a pilot and function as 'living labs'. Energy generation and consumption data will be collected to enable researchers to evaluate the residents' interaction with installed technology.

B. Integration levels in the project

The hierarchy of integration for the LIFE project can be depicted in Figure 2. Various elements of the project residing at each hierarchy level are represented by dots. Lines connecting the dots suggest a direct influence, or interaction, between the elements. The elements within each hierarchy were identified simply from a brainstorming exercise.

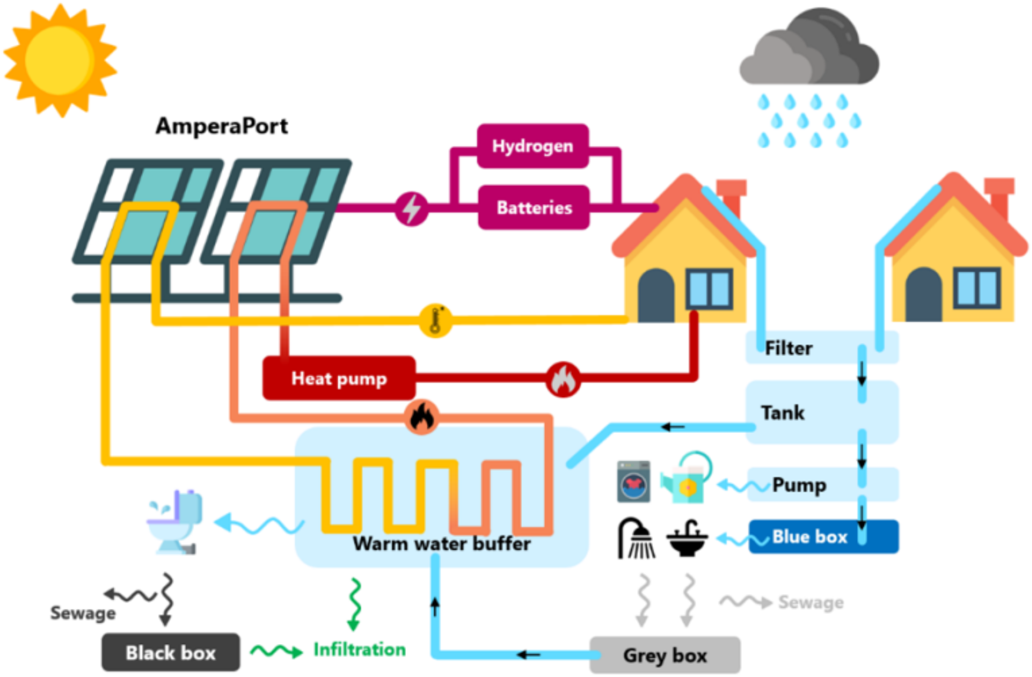

Figure 1. Conceptual depiction of the LIFE Project. Graphics from the LIFE project documents [14]

The inner-most box contains the various subsystems. Collectively, these subsystems are integrated to form the technical system, i.e., the 'tiny house'. The figure does not make a rigid distinction between components, subsystems, and systems. For example, the thermal energy subsystem consists of several components, of which a few are depicted in the figure. The electrical energy storage subsystems comprise several battery types and a hydrogen system. The hydrogen system can be broken down further into equipment and components used in hydrogen production and storage and the fuel cells.

The 'tiny house' technical system naturally has interfaces with human elements at the various asset lifecycle phases. For example, during the 'design' and 'construction' phases, the 'tiny house' has the most interaction with the building designer, builders and subsystem providers. In contrast, the homeowner, inhabitants and the facility manager come to the fore during the 'use' and 'disposal' phases.

Human systems integration is critical to ensure that the LIFE system's envisioned benefits can be realised. For example, human-related activities, such as misoperations and mistakes during maintenance, account for most hydrogen subsystems accidents [15]. Therefore, proper communication and systematic sharing of information among the relevant stakeholders are essential to reduce the human-factor failures during all phases of an asset lifecycle.

The 'tiny houses' exist within a more extensive system of systems, interacting with elements, such as the electrical, water and sewage network. Should a complete autarky design be impossible, the 'tiny houses' are connected to the local water, electricity, and sewage grid. Even if total autarky can be achieved, the 'tiny houses' must be connected to the University of Twente's emergency response system since it is considered a working laboratory. The laboratory administrators must comply with existing procedures for managing hazardous activities and the organisational structure of the emergency response.

The sociotechnical system integrates the social aspects with the system of systems. For instance, society's acceptance of 'tiny houses' is underpinned by the ability to satisfy environmental concerns and affordability while also providing a quality of living. Assurance is also needed that the novel technologies deployed, such as the electrical energy storage subsystems, do not endanger public safety. There is also the expectation that research organisations contribute to society's advancement by providing empirical data and being a catalyst for innovation. The LIFE project's 'living lab' concept enables researchers to collect information about society's energy consumption behaviour - from a small control group with above-average skills and capability in using novel technologies - when living in a building equipped with relatively state-of-the-art energy systems.

The political system balances the need to protect consumers, avoid the potential unintended consequences of technological disruption, and foster innovation. Government bodies create, maintain and enforce regulations in line with national policies and laws. Commercial bodies also are interested in trends that can impact their business model.

Following the example of energy storage subsystems,

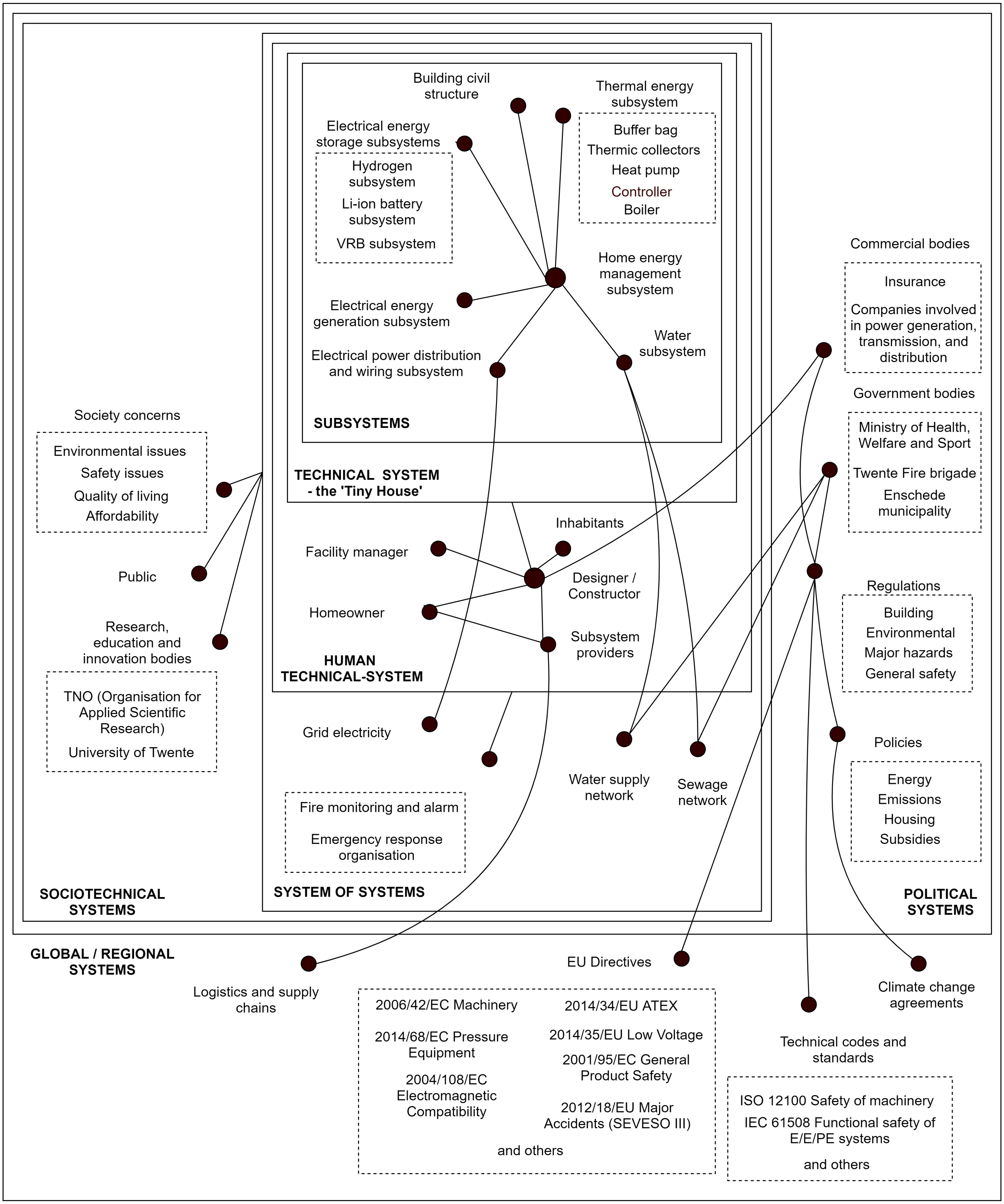
Building civil structure
Thermal energy subsystem
Buffer bag
Thermic collectors
Heat pump
Controller
Boiler
Electrical energy storage subsystems
Hydrogen subsystem
Li-ion battery subsystem
VRB subsystem
Home energy management subsystem
Electrical energy generation subsystem
Water subsystem
Electrical power distribution and wiring subsystem
SUBSYSTEMS
TECHNICAL SYSTEM - the 'Tiny House'
Commercial bodies
Insurance
Companies involved in power generation, transmission, and distribution
Government bodies
Ministry of Health, Welfare and Sport
Twente Fire brigade
Enschede municipality
Society concerns
Environmental issues
Safety issues
Quality of living
Affordability
Public
Inhabitants
Facility manager
Designer / Constructor
Homeowner
Subsystem providers
Research, education and innovation bodies
TNO (Organisation for Applied Scientific Research)
University of Twente
HUMAN TECHNICAL-SYSTEM
Regulations
Building
Environmental
Major hazards
General safety
Grid electricity
Water supply network
Sewage network
Policies
Energy
Emissions
Housing
Subsidies
Fire monitoring and alarm
Emergency response organisation
SYSTEM OF SYSTEMS
SOCIOTECHNICAL SYSTEMS
POLITICAL SYSTEMS
GLOBAL / REGIONAL SYSTEMS
Logistics and supply chains
EU Directives
2006/42/EC Machinery
2014/34/EU ATEX
2014/68/EC Pressure Equipment
2014/35/EU Low Voltage
2001/95/EC General Product Safety
2004/108/EC Electromagnetic Compatibility
2012/18/EU Major Accidents (SEVESO III)
and others
Climate change agreements
Technical codes and standards
ISO 12100 Safety of machinery
IEC 61508 Functional safety of E/E/PE systems
and others

Figure 2. Hierarchy of integration of the LIFE project.

energy-related national policies and regulations should be aligned to remove implementation barriers. For example, hydrogen is considered an industrial gas subject to strict legal and safety requirements in the Dutch context. Therefore, the installation of hydrogen systems in residential zones would still require compliance with national legislation similar to that of industrial sectors, such as the 'Major accidents decree (BRZO), the 'Public Safety Decree' (BEVI), the 'Spatial Planning Act' (WRO) and the 'General Provisions Environmental Legislation Act' (WABO) [16]. On the other hand, regulations around using batteries in residential buildings are less restrictive, leading to situations where more guidance would help manage the associated safety hazards.

Commercial interests would also need to be considered. Insurance companies providing cover for buildings equipped with novel energy generation and storage technologies would naturally strive to balance profitability with risks by seeking more assurance of such equipment's safety levels. In addition, stakeholders involved in power generation, transmission and distribution would be interested in emerging trends that impact revenue and expenditures.

At the all-encompassing hierarchical level, global or regional systems represent the various concerns of the worldwide society. Internationally-adopted agreements, such as the Paris Agreement 2016, provide the impetus for changes in national policies around funding and technology deployment to reduce greenhouse gas emissions. Such a mandate makes a clear case for the need for energy storage technology. EU directives necessitate some changes in its member states national laws, while harmonised standards become references for national standards and regulations. According to van der Meer et al., the five EU directive that affects the deployment of hydrogen technology are the Major Accident Hazards Directive 2012/18/EU ("Seveso III"), ATEX Directive 2014/34/EU (the recast of "ATEX 95"), Industrial Emissions Directive (IED) 2010/75/EU, Strategic Environmental Assessment (SEA) Directive 2001/42/EC and the Environmental Impact Assessment (EIA) Directive 2011/92/EU [16]. In addition, Laumann et al. mentioned that hydrogen systems would need to obtain the 'CE' mark by complying with these directives: Machinery Directive 2006/42/EC, Low Voltage Directive 2014/35/EU, Electromagnetic Compatibility Directive 2004/108/EC, Pressure Equipment Directive (PED) 2014/68/EC and ATEX directives [17].

The technical standards can address safety, quality and cost concerns for designers, producers, installers, and end-users and reduce market barriers for products. For instance, the recently published NEN 4288 by the Royal Netherlands Standardization Institute is expected to provide clarity and guidelines around the safe use and operation of batteries storage technologies in homes by business providers. This standard, in turn, should help assure end-users of the safety of battery systems [18].

C. Discussion

The safety layers can describe how technologies are interrelated with individuals, organisations, other supporting systems, the society, and (inter)national authorities in a broad ecosystem. In general, all the layers for safe integration are mutually supportive of one another. For example, the acceptance of buildings conceptually similar to the LIFE project could be high if there is public trust in its safety and the perception that such a design can effectively reduce the carbon footprint of society's lifestyle.

It should be noted that the elements within each layer could be competing with one another (e.g., commercial versus society concerns) or setting constraints for others (e.g., regulations vs innovation). These interactions need to be evaluated during a product's conception.

By applying the safety layers to the LIFE project, we learned that a system integrator could use the hierarchy of integration to identify a stakeholder map to aid the communication and information flow between the various stakeholders and system elements. Safety hazards can be systematically identified through these interactions, and the risks assessed accordingly. The priorities and concerns of each stakeholder might differ and need to be considered. For example, the subsystem provider's most significant concern would be whether the supplied subsystems are inherently safe, while the first responders' foremost concern is personnel safety.

With this, we summarise our observations through the following propositions:

- From the methodological point of view, we find it necessary to distinguish between the 'technical system' and the 'humans' who interact with the system aiming for safe integration. Therefore, although it may sound trivial, we find it helpful to use 'human and technical system integration' instead of 'human system integration'. That makes the integration goals more transparent. In other words, as smart appliances and novel technology become more pervasive in our daily lives, we propose that the 'human and technical system integration (HTSI)' provides more transparency for achieving safe integration as practised in system safety discipline.
- We observed that integration at the technical system level is different from integrating humans with a technical system. Therefore, we propose that humans are not best described as a subsystem or an element of the system (as conventionally practised by systems engineering discipline) but are considered a separate category.
  We suggest that the conventional view may imply that technical tools are meant to provide a higher level of control when in principle, it should be humans that should dictate the manner of their interaction with technology. The latter perspective requires a different starting point of a technology's design philosophy, utilising a more diverse set of knowledge, tools, and methods.

IV. Conclusions

The seven layers for safe integration, described in this paper, create the ‘big-picture’ of the residential system development. The starting integration levels (e.g., technical system or system integration) align with the systems engineering standard practice. Yet, the proposed approach encourages the designer to look beyond the direct system stakeholders or system environment. The integration considerations beyond the technical system are rather critical for introducing new technologies.

We also observed that a clear distinction between the technical system and the humans in the system provides further transparency into what the LIFE project is meant to deliver.

The LIFE project was still in development at the time of this study, and the operational aspects of the project need further elaborations.

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