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Research proposal on architectural copper-based antimicrobic solutions in high traffic spaces

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Abstract. This contribution investigates research opportunities in the field of architecture and design management focusing on user health in high traffic spaces. The field of application is Airport Passenger Terminals. Looking at the COVID-19 pandemic and anticipating the possibility of events of the same magnitude, it is necessary to approach the problem of the safety in public spaces. Based on the State of the Art about antimicrobial material studies, Science of Architecture could propose innovative solutions that are compliant with health safety and prevention for high-use surfaces. These solutions will combine antimicrobial materials with a digital solution that could manage data about surfaces, allowing the maintenance team to valuate and optimize operations. After few hours the hygiene level of copper-based surfaces is higher than any other material. Copper-based furniture could be paired with sensors that send data to management software. Combining the use of scientifically demonstrated antibacterial surfaces with high-performance management tools could be the best option to achieve health safety and contribute to social sustainability. Airport terminals are the ideal high-traffic buildings to use as test model because they have all the characteristics that could be analysed concerning the safety and the perception of safety of architectural spaces by users.

1. Introduction

The COVID-19 pandemic has changed the way we approach a substantial number of daily activities. For example, it forced the academic institutions to move online a vast number of didactic activities, such as lessons, laboratories, and training. Meanwhile, in the travel sectors, new safety and hygienic protocols were introduced. Despite the lower flows, airports operate at a slower pace, to verify health conditions of inbound and outbound passengers. Challenges emerged in each sector of human activity to find new and innovative solutions to face the pandemic crisis. Education found in collective physical distancing a tool to maintain its functions and objectives, while the transport sector was compelled to introduce new health protocols, such as the verification of health certificates, personal protection devices, such as FPP2 masks, in-situ tests of travel environment health conditions - e.g., tests assessing the hygiene level of air and surfaces [1] - or passengers body temperature tracking to assert the presence of the virus. While physical distancing is an efficient mean to confront the pandemic, it is also a condition that must be addressed and overcame in time. While the vaccination phase is at full regime, reaching now the third and fourth cycles of inoculation – as it is happening in Italy and Israel at the time of writing - it is believed that people is wishing to come back to their usual behaviour, as it was before the pandemic [2]. International travel is a sensitive sector for health safety, considering that the diffusion of a virus is notably more dangerous and uncontrollable if spread in numerous countries at once. Limiting contagion rate is crucial and airports are a preferred starting point for better practices: airport protocols in checking passenger health constitutes a solid barrier to future spreading of bacteria, fungi, and viruses. Airports, being high-density pedestrian traffic structure, must be reviewed in their architectural project design and operation management [3]. Nowadays, security and safety checks take great amounts of time from passengers before boarding. Airport spaces were designed with the idea that passengers must flow easily and steadily, but they were not flexible enough to adapt to the new standards and the new safety and security protocols. The future research addresses these problems: how the passengers negatively perceive the airport experience and how it is possible to modify or manage better these processing space units to give the perception of increased comfort, security, and safety to passengers [4]. Beyond the management issues – that are central in addressing the amount of time wasted in waiting for verification measures – there is also the design aspect, which was only marginally been addressed by airport management [5]. The design aspect is crucial to enhance the compliance of the structure to better align with the new requirements and to procedures constantly changing [6]. Proper architectural solutions could be a great aid tool in making spaces closer to the new objectives which could guarantee security, safety, comfort, and sustainability.

Numerous tests and assessments, both in situ and in laboratory, are being made to prove the efficacy of many antimicrobial materials. Copper-based products are proven to be extremely efficient in fighting pathogens responsible for serious infections in long hospitalization patients. Antimicrobial properties of copper seem to be known since ancient times: Egyptians used chirurgical blades made of copper to perform surgery on their patients and used copper as a container for fluids; Babylonians used copper filings in open wounds to sterilize them [7]. In 1852, a French physician named Victor Burq found that cholera, spreading through Paris, was not affecting workers of the copper smelting plans, even if the hygienic conditions were not different from the rest of the city [8]. Copper-based chemicals are also used from the XIX century in agriculture to fight vegetables diseases and parasites. Moreover, evidence emerged from recent research confirms the antimicrobial property of copper: its antimicrobial, antibacterial, antiviral, and fungicidal action is universally recognized and is used in hospital to contrast the diffusion of epidemic events and infections [9]. Pure copper surfaces can kill pathogens in the span of two-three hours, if compared to other kind of surfaces [10]. In this sense copper is a complying material to use not only in hospitals but in all other public spaces with high chances of pandemic casualties, such as airports and other transportation hubs [11]. Moreover, copper does not lose its antimicrobial property after the daily clean maintenance nor seems to be less effective with human palm sweat if used in handles and handrails [12]. It seems convenient to gain advantage of these properties and realize custom architectural solutions, also effective for better user experience from aesthetic and design points of view.

The principal aim of the research is to propose new industrial copper-based solutions as a whole architectural project concept, that will be valid from a hygienic perspective, as well as from a formal, aesthetic and design perspective [13]. The final goals are diminishing the risks for health of passengers and, moreover, increasing the value and perception of comfort in spaces where these solutions are used. To achieve the objectives of hygiene and comfort in high-density traffic buildings, the research found in the airport set the ideal environment to test the architectural solutions and innovative components, with the idea of translating the solutions found in other sensitive locations with great fluxes of people involved, such as other transport nodes – ferries, train stations, bus stations, underground stations, etcetera – and other public spaces – commercial centres, event hubs, exhibitions, etcetera. Architectural solutions will be valuated and tested with some digital application and with hygiene test. The digital tools that can be used are principally connected with sensors that register the movements of users and if and when they touched the surfaces: in this way it is possible, in the first phase, to valuate which are the more frequently touched surfaces and to assign antimicrobial materials to these parts; in the second phase, to have control on the hygienic state of every surface and therefore monitoring the level of pandemic risk of each spot in the room. In this way it is possible to alert the users if a surface is clean or not, with an application in augmented reality or with visible signals integrated in the design of the architectural solution. In this way the user will receive constant feedback on the hygienic state of the surface: this could enhance the passenger confidence and consequently his or her experience of comfort and safety of the environment. Two tools for monitoring and connecting data from the physical component to the digital twin are already under development [14] or already functioning. For example, for the supervision of high-risk spaces, some convolutional neural network [15] software does not need anything but a camera. The AI has an algorithm for recognizing users and valuating if they are too close to hazards, giving a real-time alert. Another digital tool that could be used will allow evaluating the architectural solution implemented trough satisfaction questionnaires, ideally designed with entertainment elements and achievements to encourage users in giving useful information about the experience. Such kind of digital tools are conceptually already existing and being developed in a separate research unit. Similar digital tools of evaluation of the architectural spaces are already being developed and used with great results, such as in the experience of the SAM4Care, a program for investigating the way the users perceive hospitals' rooms from an architectural point of view.

The research aims to connect the physical and digital environment in a unique ecosystem allowing remote control of the information provided by both the architectural components and the users, achieving a new level of comfort, psychological, social, and physical.

2. Research activities

The research will be divided in the following phases:

- Literature review of the state of the art, based on the selection of keywords of interest.
- Problems analysis from the management and the user point of view: which are the main issues for the management staff of the airport, and which are the main issues for the passengers? How are these problems connected with the ongoing pandemic of COVID-19?
- Design of experiments that could be implemented as solutions of the actual problems.
- Design of the architectural solutions to be tested in situ.
- Design digital prototype of the architectural component.
- Production of a physical prototype, in collaboration with industry (KME Spa, with an agreement signed in March 2022): the physical prototype will have a digital twin – an evolution of the digital prototype – that will connect the object in the environment with all the information contained in the common data environment. The digital information associated with the architectural components guarantee a correct maintenance and could also include data about the level of hygiene of the surface.
- In situ testing of architectural components, assessing the response to the real environment, comprehending users, passengers' flow frequency of surface touching, and many other critical factors.
- Validation and report of the tests results, both quantitative and qualitative: the first will be about, for example, frequency of use and level of cleanliness, the second about the comfort perception of the users.

The first phase will identify the general issues, focusing on general keywords of interest. This will give the research the base to going in the specific cases addressed by the main problem presented: how making a high-traffic building, like an airport terminal, comfortable and safe for management staff and users, especially after the introduction of new security and safety protocols?

The second phase will focus on more specific issues, for example problems that were not initially considered and that could be pointed out by people directly or indirectly involved in the airport processes, like airport managers or passengers. This phase consists in interview and direct investigation phase, where the dialogue with both the passengers and the management staff will be beneficial to redirecting the subsequent design phase. In this phase it will be essential identify which surfaces are most frequently touched: this will give fundamental information about what materials must be used and where, therefore crucial data on processes, flows, and location.

The design phase, in fact, is composed by organizing the experiments to be conducted, which will verify a set of parameters suggested by the direct survey, by designing the architectural and digital solutions associated and the digital prototype that will undergo the phase of physical production.

The realization of the physical prototype will be made in association with the research industrial partner KME S.p.A., that will offer technical, logistical and expertise support to produce high-quality architectural solutions. The developing in parallel of a digital solution that could associate the digital twin prototype with the physical prototype will be a crucial support tool to keep the data under control. Once the prototype is installed in an experimental setting, it undergoes a phase of testing: it is a turning point phase, where the data must be collected and then analysed. Will the results give feedback on the validity of the solution proposed: is the prototype functioning correctly? Does it simplify operations, management, and overall comfort for both airport staff and users? If the answer is compliant, then the prototype could go under a validation phase that will lead to file for a patent. The prototype becomes a real architectural component that could go to market, referring to target clients, enhancing sustainability of the management process, user experience and security, health safety and travel comfort.

3. Research Methodologies

The research will analyse some case studies that address the main objective: design an integrated architectural solution that combines materials and digital information.

The analysis will be made extracting data from existing facilities, particularly airports, and will focus on spaces dimensions, materials used, digital tools used for management and will collect information on number of users, localization, and airport connection with other facilities. The analysis will take note of the IATA formulas for dimensioning spaces for users, and the EASA (European Union Aviation Safety Agency) ECDC COVID-19 Aviation Health Safety Protocol, with the recent additions based on health safety travel and health protocols [16].

Once the analysis phase is completed, data could suggest in a more specific way the design choices that must be made. For example, how copper could be associated with other materials, if there are other scientifically proved antimicrobial materials [17–19] that could be used in association with copper or if there is a module that could be used to guarantee health safety.

Information and data about frequently touched surfaces will be collected mainly from literature. There is a great compendium of research about microbiological activity on copper surfaces in hospital facilities that could be used for the design phase, allowing to find which are the most frequently touched surfaces in public spaces [20,21].

After the literature review and data collection, a prototype space for the airport terminal could be designed and proposed, in its physical, but also digital features. The prototype will be not only an architectural solution that will be analysed, but it will be also a tool to acquire data from the environment, allowing getting conclusions in a more homogenous way. With the aid of sensors and cameras, the prototype will take information on number of users visiting the space and at what hour, will register which surfaces are the most touched and when. This test investigation will try to understand if frequently touched surfaces identified in literature correspond to the environment selected for the prototype tests. The prototype will help the researcher to connect spatial, chronological, and quantitative data in one common environment, giving significative and controlled information.

The prototype space with the architectural solutions implemented will be installed in an airport terminal and then undergo a microbiological laboratory test phase. Microbiological samples will be collected from control space and the prototype copper antimicrobial space. Samples will be collected in defined hours of the day, every day, in priorly defined spot in the room. Data from the two spaces will be compared, to see if there is evidence of a less microbiological activity in the antimicrobial prototype room. The prototype room that would be realized in an existing airport terminal will be selected having in mind that is better collect and process microbiological samples inside a 24-hour span, to achieve better results. The data referring to number of users, frequency of touches, antibacterial capacity (including the copper halo effect), are quantitative aspects of the research, which will be addressed with a scientific approach.

As for the microbiological part of the research, a team of microbiologists, who will be PhD Rosa Donato and PhD Cristiana Sacco of the Environmental hygiene and microbiology Department of the University of Florence (see page 8, Acknowledgement), and they will collect the samples from the public spaces selected. One space will have equipped copper-based materials and the control space will have equipped stainless steel or other commonly used metal for public facilities.

Methods of collecting these samples are extensively described in literature [10,17–20,22] and vary based on data of interest for the specific research. However, one recurring method is using a sterile swab and a sterile silicon template of 10 cm2 of surface (2x5 cm). The swab is moistened in sterile peptone water and immediately transferred in a 15 ml tube containing 1 ml of sterile peptone water. Samples, stored at 4°C, are immediately transferred to the laboratory, where they undergo the analysis process [18].

The research will also undergo a qualitative phase assessment: the potential final users of the architectural solutions will give feedback about the use of space. This qualitative test will assess if users were satisfied or not with the use of space and if there is room for improvement. It seemed necessary in planning this research to use a go-to-market strategy: the final aim is to have an architectural solution that potentially could be used in the future and that could change the approach and the way the airport spaces are experienced.

Obtaining this requires an accurate investigation of the problems that airport management staff and passengers experience frequently using the airport terminals. It is critical, therefore, design an interview using rules, processes and standards of social science interviews and collecting useful data from airport terminal users, distinguishing them initially in the two main categories of management staff/airport staff and in users. In the users' group the research aims to understand how copper material is perceived, and if there are significative differences in the comfort perceived by aesthetic or design choices from the most used materials in public spaces. The interview will explore the problems experienced by users in the airport terminals, to understand which design solutions could be best applied in enhancing the airport experience. Moreover, it could be greatly significant to ask the users which solution they find more attractive or comfortable. It is possible, in this phase of analysis, ask questions that could be referred also to the perception of colours, compared to others more traditionally used in airport design, to understand how users perceive copper and how they respond to oxidation states if showed by the material. "Unstructured" interviews – for their inherent qualitative aspects – could be the best way to achieve valuable data from the aesthetic and design perception perspective [23,24].

4. Expected Results

Results may vary considerably. Therefore, the experimentation phase is highly important. Following this research, three groups of findings will be expected following the data collection from the architectural solution prototype, the hygiene tests samples, and the customer interviews.

The data collection from the camera and sensors of the architectural solution prototype will give insights about which are the most frequently touched surfaces. It is expected that data will confirm that the most frequently touched surfaces are those already selected in existing literature, i.e., plan surfaces as tables, countertops, benches, as well as doorknobs and rails. Sensors and camera controls will, however, give more information, maybe adding other surfaces in the list or giving a frequency rate on each single health hazard element.

As for the data collection from the hygiene in situ test samples, and given the premises, which confirm that copper shows antimicrobial properties, the results will confirm evidence already found in laboratories and in field tests in hospitals.

As for the data collection from qualitative interviews, the variables that may vary considerably and are linked with the feeling of comfort by materials used and the perceived simplicity of use of the digital twin associated with the physical object. In the first case, if the design phase has been conducted with proficiency, the copper-based architectural solutions will be well accepted by users. However, copper oxidates quite rapidly, causing a change of colour, if it is not pre-processed to avoid it. Users may find the oxidation as a sign of dirt or bad maintenance. In the case of architectural solutions that users may touch, this could lead to a decrease in the perception of comfort. The users may stop using the architectural component or avoiding the space in which the architectural component is located completely. These results will emerge by collecting data about the passengers' flows, their dwell time and asking directly how they perceive the space, if they find it comfortable, relaxing, and close to their needs. The design phase must address the copper oxidation in a way that the users could find it enjoyable even if does not conform with the perceived cleanliness standard of the modern surfaces. The use of copper in addition with other materials could lead to a solution that is well received by users and does not need explanation for its appearance.

As for the digital part composing the architectural solution, its intuitive features will be assessed within the same qualitative interview, letting costumers use it and then giving feedback.

To better understand the core aspects of the architectural solution proposed, the SWOT analysis below proposes a landscape view on the matter. SWOT analysis are a simple tool to review the solution in a holistic approach. The SWOT quite subjective point of view could be a great advantage to assess core points of a new development: SWOT analysis are easy and quick to be made and, moreover, are easily understood and communicated also at a non-professional audience. It must be done, however, in the mind-set to gain sustainable competitive advantage, therefore finding peculiar aspect that could address users' needs [25].

Table 1. SWOT analysis of the experimental research proposed.

Strengths	Weaknesses
1. Copper is a workable material and has antimicrobial properties 2. Copper is an upcycled material because it is fully recyclable 3. Copper does not lose its economic value 4. KME S.p.A. offers its expertise in the production of architectural copper-based solutions 5. The physical prototype is associated with a digital twin prototype that gives real-time data about hygiene and health control 6. Copper oxidates rapidly, increasing the durability of the material and without losing its antimicrobial properties	1. Copper oxidates rapidly, increasing the design difficulty of the architectural solution 2. Test in situ in terminal airports are not being made at the current date. Hygiene results may differ from those obtained from hospitals 3. Copper has a high market cost
Opportunities	**Threats**
7. The current pandemic of COVID-19 has pushed management – especially transport management – to find solutions to health hazards 8. The research unit associated with this research has long-going contacts with airport terminals and hygiene departments of University of Florence	1. Perception of users about copper from the aesthetic, safety, and functional point of view may vary considerably 2. Airport management perception of the architectural solution proposed (physical and digital) about the efficiency and efficacy from the maintenance point of view may vary considerably

In the SWOT analysis presented above, copper oxidation is the greatest variable in the design of the architectural solution: it is its most valuable quality and, at the same time, from the users' perception, the most uncertain aspect. Are users going to appreciate the non-homogenous texture of the material? Final interviews are going to assess this core point and give some feedback.

Another core point is the health safety management: as the pandemic of COVID-19 is still ongoing, and creates “new normal” situations, the importance of being able to control the health safety of an environment has increased. This dramatic event became, in our research proposal, an opportunity to investigate new health control systems, with the aid of an expert team in the microbiological field and the support of a leader firm that could provide the base material to conduct the research. However, the perception of usefulness of the architectural solution proposed depends on the airport management, who could decide in a positive or negative way. Copper has a high value on market; therefore, airport management could decide not to invest in such architectural solution.

5. Conclusions and Further Research

The research aims to develop new industrial copper-based architectural solutions that are valid and sustainable from different perspectives: hygienic, aesthetical, safety, security, social, management issues are all addressed by this solution that aims to reduce health risks for the high-traffic pedestrian buildings and complex infrastructures. Airports will be a perfect set, for its design complexities and its social implications, as well as for its high contamination risk environment. The virtual and digital prototyping, moreover, could enhance the opportunity to assess the validity of the physical solution, from a health and functional point of view. The simplicity of use of these solutions, both in the physical and digital world, will be a crucial factor for their widespread diffusion.
In these years of pandemic turmoil, having a reliable design solution for public spaces, starting from the most sensitive locations, as the transports’ nodes and the travel facilities, could be a good starting point to make architecture most safe and comfortable.

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