The inside story of COVID-19 pandemic on the Diamond Princess as the *prime mover* of present and future ship design studies

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"..But this coronavirus has forced us into a new framework, within which we move without any ease: everything has new ways, everything appears as never seen, it's like finding yourself in an uncharted territory.."
(G. Arma, 2020)

*"...Our cruise started on **January 20th 2020 from Yokohama** (Japan). It was a **2-week cruise around the South East China Sea**, departing from Japan for Hong Kong, Vietnam, Taiwan and back to Japan.*

*In early February, **towards the end of our cruise**, I received information that a **man disembarked from the ship in Hong Kong had been hospitalized** and **tested positive for Coronavirus**..."*

*"...At that moment the **timing of his contagion was not clear**, and we were eventually **asked to arrive in Yokohama a little earlier** to allow the **Japanese authorities** to come aboard for an **inspection**.*

*We docked in **Tokyo Bay** on the **evening of February 3rd**, and the **ship** has been **subjected to Japanese law** ever since.*

*On the morning of **February 5th** we were informed that among the samples detected, **ten people had tested positive for Coronavirus**..."*

*"...At that point the **ship** was officially **quarantined**. From that moment everything started to accelerate.*

*Given that quarantine procedures required the **isolation of each guest** in their cabin, everything we had been up to that moment no longer existed.*

***All the passengers** were **confined in their cabins.** As a consequence, restaurants and **public spaces** would have remained **unused**..."*

*"...There was a motto that I used in those days and that I shared with the people **LEARN_ADAPT_REACT**. And that's what we've all done. Being a new subject we learned, adapted and reacted!*

*All **1045 crew members** were simply fabulous. We had to take on different tasks based on the most pressing needs of our guests, the activation of the **room service** for all our cabins, **delivering meals three times a day**..."*

*"...During the emergency we practically wrote and put into practice **new procedures** and processes that undoubtedly marked a turning point also for the post-emergency.*

*I am thinking of the crew canteens and the spacing to be applied to the tables, tracing **safety routes** for movement inside the ship, the use of the laundry and the air conditioning system. We understood how **tracking was important**..."*

*"...Thanks to the smart **technological skills**, we have created a system that allows you to record the movements of people on board. Constant **activity tracking** throughout the day allows the **monitoring of the position of each subject on board** and relative contacts.*

***Embarkation and disembarkation procedures** have been rewritten to ensure safety, avoid crowds and even **contact with surfaces**. The check-ins will be done online, the **doors** of the cabins **will open automatically**..."*

*"...The cruise industry has always shown **great resilience** and is a sector that has greatly invested a great deal in the fight against COVID-19. The **strict and effective protocols** that have been **implemented**, combined with **vaccination** and **staff training** have made **cruise ships** again the most beautiful and **safe place** to spend the holidays."*

December 31, 2019

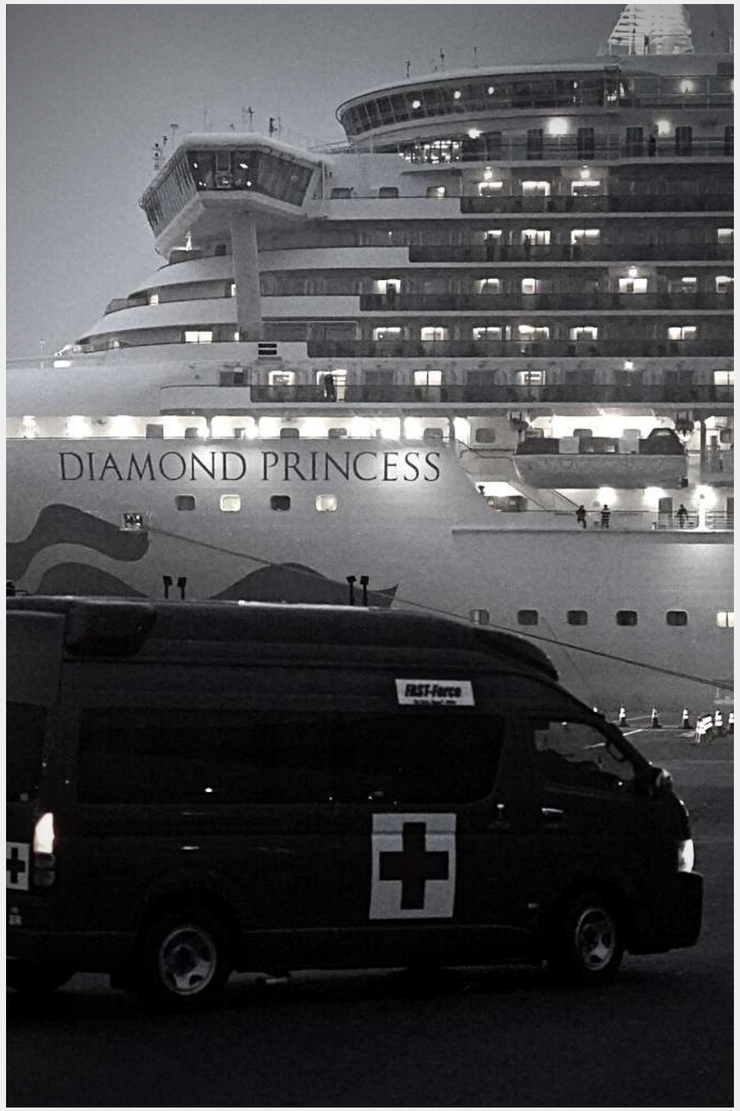
The **Municipal Health Commission of Wuhan** (China) **reported a cluster of pneumonia cases** of **unknown etiology** to the World Health Organization.

January 9, 2020

The **Center for Disease Control and Prevention of China** identified a **new coronavirus** (first named 2019-nCoV) as the etiological cause of these diseases. Authorities have also confirmed **inter-human transmission** of the virus.

February 5, 2020.

Japanese authorities announced positive test results for SARS-CoV-2 for 10 people on board the **Diamond Princess cruise ship**. the consequent cancellation of the cruise, and that the unit was entering **quarantine** for 14 days based on World Health Organization guidelines. This episode has been recorded as the **first pandemic episode outside China**.



2666 Passengers (average age: **66** years)

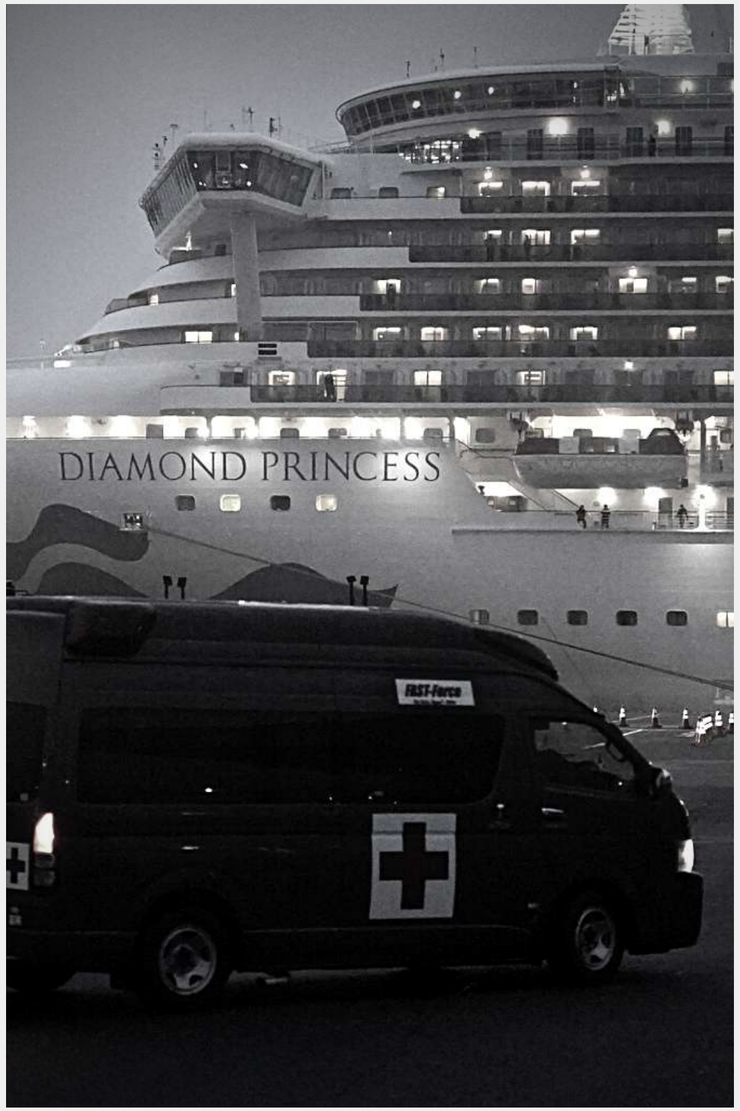
567 Infected

1045 Crew (average age: **33.6** years)

145 Infected

14 Deaths

The high number of **senior people** among the guests (many of them with **limited mobility** and affected by different comorbidities), interpolated by a **sharing of leisure and social activities** in public areas, favored a **quick escalation of cross-infected cases**.



Cruise ships are **isolated communities** with **high population density**, shared sanitary facilities and common water and food supplies. Infectious diseases can be easily transmitted on board, from infected people and through contaminated surfaces, food and water.

Quarantine time to be observed on board, **lasting 14 days**, is **longer** than the **average duration of a cruise** and this led to logistical difficulties in providing food and medicines on-board.

The **Diamond Princess cruise ship** was placed **at anchor** in a precautionary state **during the first period**.

The **need to leave the pier** for **sewage disposal** became a **barrier to patient transport** and, furthermore, **issues** were related to **refueling** and **waste unloading**.

There were several **difficulties** on board the cruise ship, such as **securing the traffic lines** between **infectious** (**red zone**) and **noninfectious things** (**green zone**) including humans,

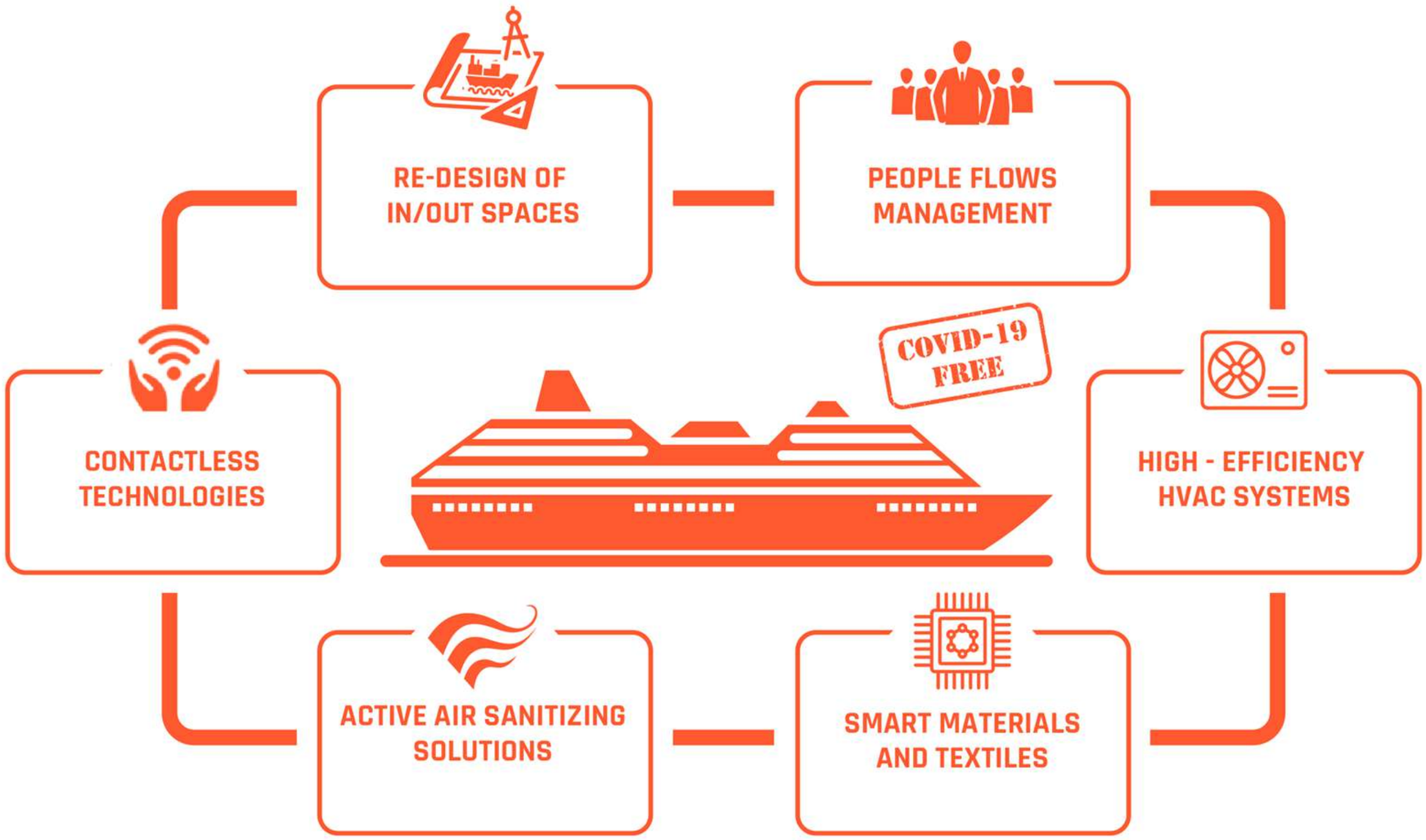
There has been a **drastic reconfiguration** of all **functions on board**. A part of the **crew staff** addressed for receptivity and entertainment activities was **called to provide room service**, serving **3 meals a day** for all the cabins. They had **frequent contact with quarantined passengers** and interacted closely with other **potentially contagious colleagues**.

Medical assistance was provided **directly in the cabins**, with consequent **limited diagnostic possibilities** by the medical staff.

More than 28% of the cabins doesn’t have a direct supply of natural light and fresh air from outside, which has to be provided by **HVAC system**.

In order to overcome this situation, it was the captain himself who devised the so-called ***fresh air program***, a careful scheduling which allowed the guests to reach the decks in an organized way for an hour per day, together with the compliance of strict procedures for leaving the cabins and wearing PPE.

The numerous publications indexed at this regard highlights how the case study of the **Diamond Princess has constituted de facto epidemiological laboratory**, which provided a wide amount of data useful for understanding which are the main vectors of virus propagation.


RE-DESIGN OF IN/OUT SPACES
PEOPLE FLOWS MANAGEMENT
COVID-19 FREE
CONTACTLESS TECHNOLOGIES
HIGH - EFFICIENCY HVAC SYSTEMS
ACTIVE AIR SANITIZING SOLUTIONS
SMART MATERIALS AND TEXTILES

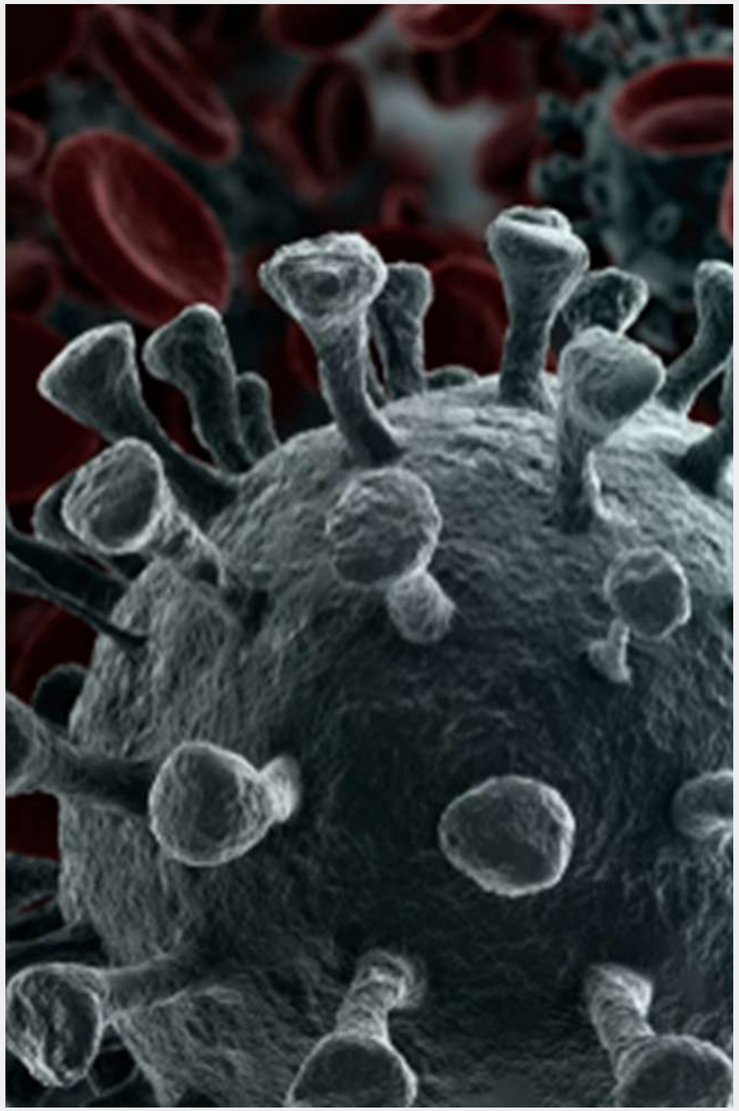
POTENTIAL ROLE OF HVAC SYSTEM AGAINST COVID-19 AIRBORNE TRANSMISSION

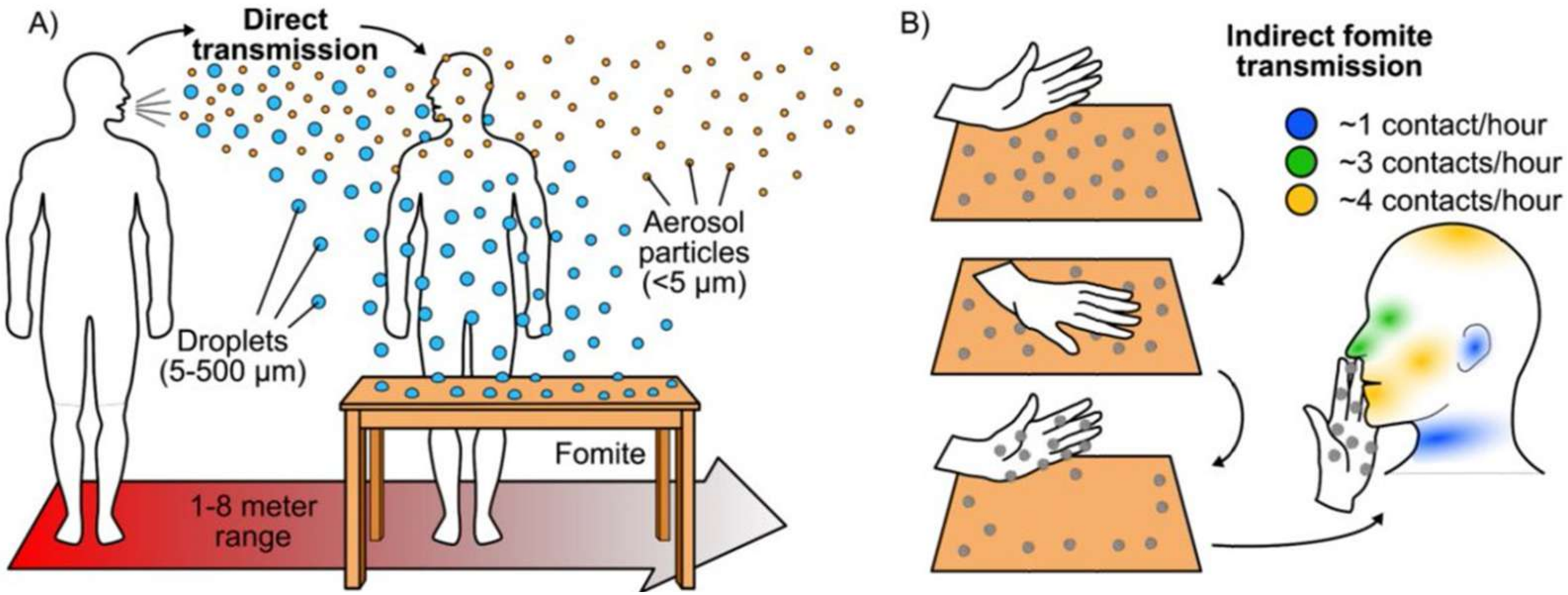
The primary routes of respiratory virus transmission are:

- **Close contact** between individuals (within 1.5 metres);
- **Indirect contact** via contaminated objects, also referred to as **fomites**;
- **Airborne transmission** via **droplets** (diametre > 5 μm) and **aerosols** (diametre < 5 μm).

Infectious diseases widespread through airborne transmission are often associated with **building ventilation** and its corresponding **airflow pattern**.

HVAC system design, **maintenance** and **operation** is important to keep a proper degree of **thermal comfort** and **indoor air quality**, decreasing the risk of transmission of infectious diseases through the **dilution of of potential contaminated aerosols**.




A)
Direct transmission
Aerosol particles (<5 µm)
Droplets (5-500 µm)
Fomite
1-8 meter range
B)
Indirect fomite transmission
~1 contact/hour
~3 contacts/hour
~4 contacts/hour

On the Diamond Princess, **random distribution of cases** of infection and the lack of any spatial cluster (within cabins) suggests that **no cross-room transmission** between passengers who were in different cabins during the isolation occurred.

This might be partially explained by the fact that **no recirculation was allowed** during the passenger confinement period. The observed higher rates of infections prior to the quarantine implies that **most transmission occurred during leisure and social activities**.

Cruise lines companies are focusing on **HVAC** as a **line of defense against COVID-19**, using the system to

- circulate more **fresh air** inside;
- **filter air** more effectively;
- application of such technologies as in-duct **UV-C lights** and **bipolar ionization** to fight and eradicate viruses.

A further design parametre to be controlled is the **in duct air speed** through the system; it cannot move too fast in order to trap and kill viruses. ASHRAE's COVID-19 guidance suggests using **high MERV rating filters**.

These latter may not be a viable option for some HVAC systems as they

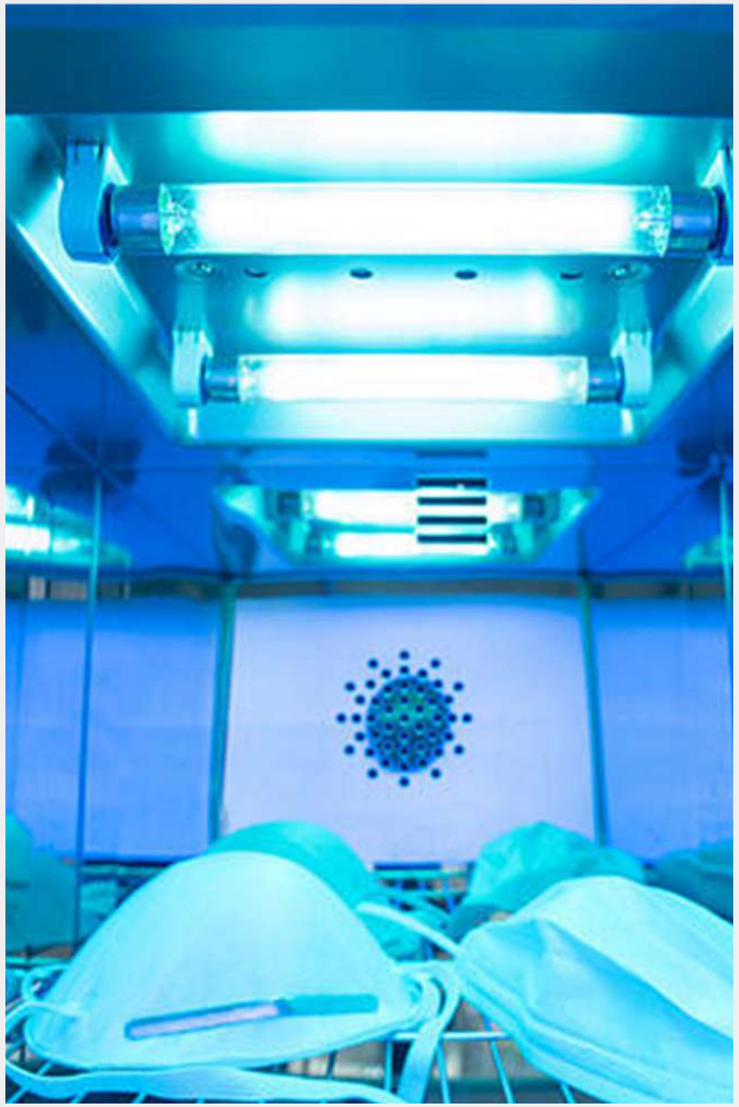
- can hamper the **fresh air exchange**;
- can cause **greater resistance to air flow** than allowable by design prescriptions.

Furthermore, most of actual common HVAC systems, wouldn't ensure efficient cooling/heating, since they are designed for **recirculation of 40–60% from total airflow**. In the event that the heat exchanger has enough spare power to provide 100% fresh air intake, the **energy consumption** would **increase** significantly.

Finally, there should be the possibility of **isolating** those branches of the HVAC system acting on some **areas dedicated to the management of emergency situations**, thus preventing possible virus outbreaks

In particular, the vessel can be split into more **gastight zones**, by considering the existing main vertical fire zones subdivision.

A further implementation is to provide **in-duct UVGI lamps** or by **designing upper air zones devices** inside cabins with **high ceiling elevation**.



INDIRECT CONTACT (FOMITE) TRANSMISSION

Respiratory secretions or droplets expelled by infected individuals **can reach surfaces and objects**, often referred to as **fomites** or **passive carriers**.

Because the biological function of viruses strongly depends on their integrity, the use of **physical treatments** (such as UV irradiation, heating, and desiccation) and **chemical sanitization** (strong acids, alkalis, oxidants, alcohols, and surfactants) would **disrupt virus survival** on the surface by compromising its structure.

The possible development of **antimicrobial surfaces** and coverings for objects that are frequently used by the public can be a practical route to avoid the release of polluting substances in the environment, which can be dangerous also for personnel in charge of the sanitation procedures.

Before understanding how to convey present and future design choices, it is necessary to analyze the **ability of SARS-CoV-2 to resist on surfaces**, especially on **non-porous ones**.

In the initial stages of the study aimed at finding **traces** in **recovery units**, only the **genetic heritage** of the virus **was sought** and not the presence of intact viral particles, the only ones capable of infecting where they came into contact with the human organism.

Laboratory experiments tested their permanence on different types of materials, including **copper**, **cardboard**, **stainless steel** and **plastic**, at the following environmental contiditions, comparable to those present in a domestic space:

- **ambient temperature** of **21-23** °C;
- **relative humidity** level of **40%**.

From the results it emerged that the **most inhospitable** materials were **copper** and **cardboard,** with a halving of the infectious capacity of respectively < 2 hours and within 5 hours). A complete suppression of viral load was observed after 4 hours for copper and 24 hours for cardboard.

As for **stainless steel**, the infectious charge was halved after about 6 hours, compared to 7 hours for **plastic**. The time period required to zero infectivity was much longer than before: at least 48 hours for steel and 72 for plastic.

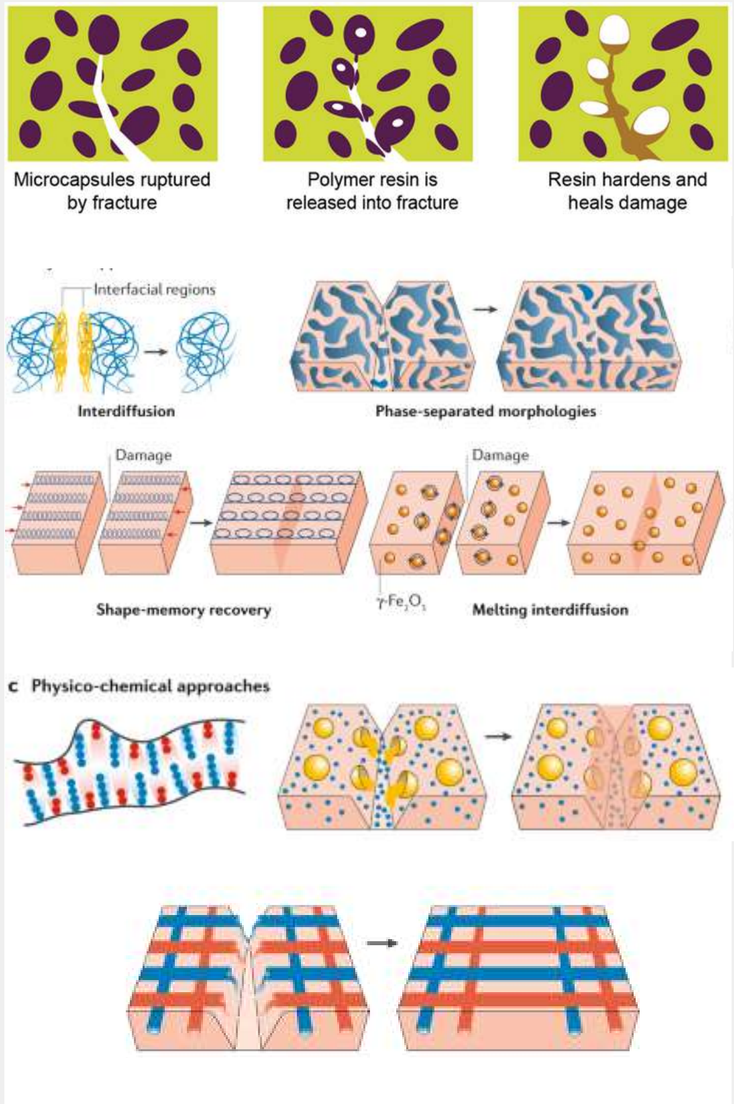
Hence the need, starting from the behavior of parent materials, to adopt such **solutions** that could **combine** specific **performance characteristics**.

SMART MATERIALS

In this way, the presence of **smart materials** comes out. They are capable of reacting to an **external stimulus** (which can be acoustic, electrical, magnetic, luminous, mechanical, thermal) **by modifying their structural, morphological, chromatic or thermal properties**.

Among them, especially in kitchen and maintenance areas, the presence of **self-healing materials** can be advised. They are polymers, metals, ceramics and their composites that have the intrinsic ability to **repair damage** due to normal usage. It ensure a significant bacterial reduction activity.

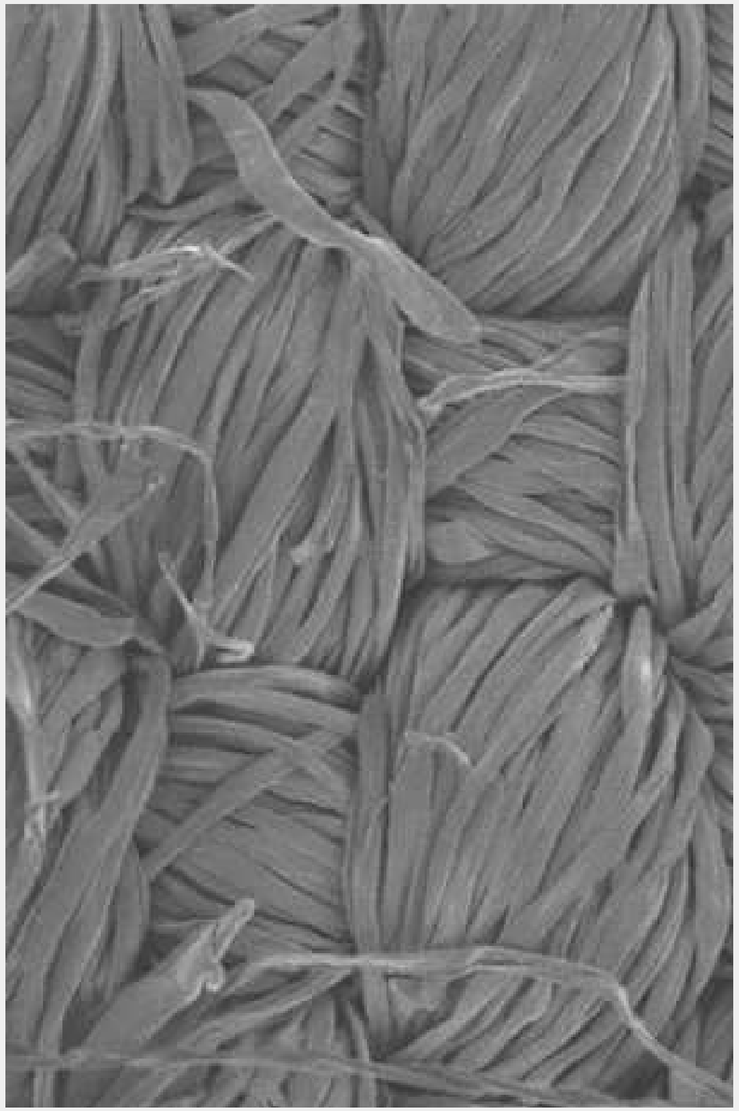
It is worth mentioning **ceramics coated with polymer composites containing nanoparticles** such as silver, gold, copper, zinc oxide and titanium dioxide, which allows the **degradation of pollutants** through a process called **photocatalytic oxidation**.



It retraces a chemical reaction in nature that mimics the **chlorophyll photosynthesis** of trees in absorbing and **transforming pollutants into harmless elements**.

Among the so-called **smart textiles**, there are fabrics developed with an **extrusion of graphene** applied during the **yarn production phase**. Its conductive and antiviral properties allows to mitigate the possibility of transmission without losing their thermal and antiviral properties over time. They can be used in the manufacture of medical devices such as **masks**, **hospital gowns** and bed **sheets**.

Antibacterial materials are already widely used on board, but will become even more prevalent as cruise companies will tend to further reach an even higher degree of safety. Changes to cabin routines could also include **antimicrobial carpets**, **touch-free tools** and toilets with glass dividers instead of curtains.



CONTACTLESS TECHNOLOGIES

In the field of application of contactless technologies we include all those devices and software capable of increasing the operational efficiency on board, such as **electronic bracelets** and **smarthone applications** which can be easily downloaded and used by the guests.

Biometric check-in systems allow to effectively manage **embarkation and disembarkation procedures** by identifying passengers at the moment they arrive at the port, thereby **avoiding congestion** and **bottleneckings**.

They help staggering the entrances, thus **minimizing the cumulative contact time between hosts and staff**.

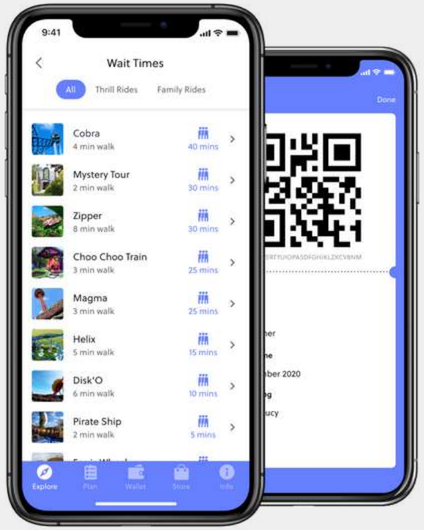
Virtual queuing apps avoid crowdings in public areas (restaurants, fitness centre, pools). It is also **possible to order the meal** to be delivered out of restoration areas.

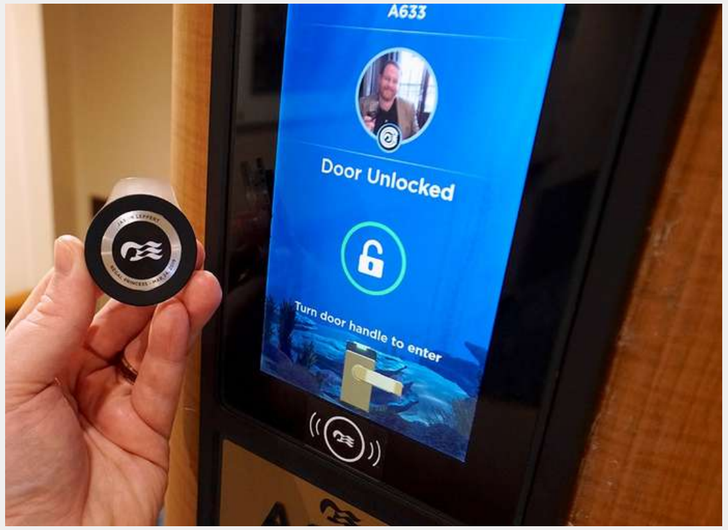
Booking activity to organized events allows to predict in advance the correct venue and the number of expected guests.

Telemedicine techniques are exploited in order to reduce contact and potential contagion between people.

Upon arrival in the cabin, the **opening of the doors is contactless**, as well as the **control of the temperature, lighting levels** and the **payment method**.

It is also important for cruise ship companies to constantly **monitor the flow of passengers** to refine the offer, compatibly with the needs of the customer. Finally, it is possible to **keep track of the guests activities** in order to trace movements and, in case of overt and **presumed infectivity**, proceed with the interpolation of the contacts that the person has had on board before ascertaining the positivity to the virus.





CONCLUSION

The **Diamond Princess** case study constituted a **confined control volume** that allowed the entire scientific community to **acquire** an **important set of data** and information a**bout the virus** and its **propagation modes**.

From the storytelling of **Captain Gennaro Arma** it suddenly emerged the set of **multiple challenges** raised by an **unknow virus widespread**, which overwhelmed the complex daily routine activities.

It is important to remember how **similar episodes**, in their drama, **have significantly boosted the formulation of guidelines** which succeeded in **managing emergency situations of pandemic nature** in an increasing efficient way, **both at sea and on the mainland**.

Thank you for your attention

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