CHECKD.

From the (co)design to the prototyping of an automatic booth for disease testing.

Master's Thesis

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ABSTRACT

This thesis concerns the development an automated booth for disease testing that can be used in total autonomy by the general population without the need for specialized personnel. The study adopted a service design approach, incorporating its human-centered and collaborative principles with a more engineering-focused environment.

The research outlines the substantial preparatory part that investigated the work context of diagnostics and the different facets of service design. The design process was then analyzed in detail, starting from a draft concept and refining it through context analysis and user research.

To create CHECKD. an ad hoc Service Design process, which incorporated some traditional steps, activities, methods, and tools were applied, but deviations and adaptations were taken to adapt to the specific situation. Context analysis and user research were used to refine the initial concept of the booth. This involved carrying out user surveys and interviews to understand the user's needs, Co-design workshops with users were then leveraged to build on the concept and draft a final ideal solution. Two rounds of service prototyping were then accomplished, along with the building of a 1:1 scale prototype. The first round tested a sample collection procedure with users, adopting the experience prototyping technique and low-fidelity props. The second round reproduced the complete service experience, adopting a service walkthrough technique and mixed-fidelity artefacts, where participants could understand the full journey in a situated way.

The resulting product-service system is CHECKD., an automatic booth for diseases testing, which is fully automated and incorporates all the steps needed to run a PCR-based test and generate an official certification in total autonomy. The thesis remarks how critical a Service Design approach can be in the field of medical diagnositcs.

Adopting a service design approach was integral to comprehending the ambiguous context initially. Subsequently, it facilitated a concentrated effort on the users, enabling a more comprehensive understanding of their needs and requirements which had previously been disregarded. Co-creation and collaborative methodologies such as codesign and prototyping were utilized, resulting in informed design decisions that not only complied with technological specifications, but also enhanced certain processes and the overall experience. This approach led to a more profound understanding of the users' needs and improved the final product-service system.

1. INTRODUCTION

1.1 Goals, challenges and opportunities

This experimental Master's Thesis is the outcome of eight months of work done in collaboration with multiple actors, including the Department of Chemistry and Applied Biosciences at the Eidgenössische Technische Hochschule (ETH) Zürich (as the main host institution), Diaxxo AG, a biotech startup and spin-off of ETH's Functional Materials Laboratory, and PD|Z, a group within ETH that focuses on system-oriented product development and innovation.

The objective of this project was to leverage the innovative technologies developed by Diaxxo AG (devices capable of running Polymerase Chain Reaction analysis in a very short amount of time) to develop an automatic booth for Covid-19 testing, with the end goal of designing all the different elements of the Product-Service System through a human-centered approach.

The development of *CHECKD.* presented itself both as a challenge and an opportunity.

First of all, with this thesis a Service Design mindset was introduced for the first time in a context that primarily focuses on product engineering. Introducing service design in engineering-focused companies can be challenging for several reasons, but most relate to a profound different in the mindset itself.

Engineering-focused companies are traditionally oriented towards developing efficient, functional, and performant products, with the goal of maximizing technical specifications and minimizing costs. Service design, on the other hand, focuses on the user experience and the customer journey, emphasizing empathy and understanding of the user's needs and wants. Culture and frameworks are also in contrast: engineering-focused companies have established processes that tend to be linear in nature and keep a "hierarchical culture", while Service Design requires a more iterative, collaborative, and cross-functional approach. Finally, also metrics are different. Success, when dealing with engineering, is calculated in terms of technical specifications, efficiency, and cost reduction, while service design emphasizes customer satisfaction, loyalty, and revenue growth.

Second, the contexts in which this potential Product-Service Systema are placed are very complex and varied (pandemics/epidemics, particular economic-political system, lack of resources, disabilities, ethics), they involve situations that are often linked to strongly negative impressions and suggestions (panic, stress, prejudices), call for very specific requirements and are demandeed to follow strict guidelines.

Despite the challenges, the development of CHECKD. provided an opportunity to explore and apply the many possibilities of the Service Design approach in two areas that had not been extensively explored before: Research and Development, and medical diagnostics.

It allowed, in fact, to critically integrate the engineering approach with fundamental principles of empathy, humanity, and holistic vision, which are essential for the project and its various applications. Service design focuses on analysis and understanding of different profiles of end-users, their behaviours and needs, on mapping of the ecosystem in which they live and act, as well as their direct involvement in interactive co-design sessions. This brought to a real and in-depth understanding of how the product-service system could be structured to best integrate with their daily lives and respond to their real needs.

1.2 Thesis structure

The thesis will begin by providing a concise overview of the project's broader context, medical devices, and diagnostics, in Chapter 2 titled "Contextual Background" Chapter 3, "Disciplinary background" will follow by introducing the Service Design discipline, its origins, and a literature review of key theoretical topics, particularly on methodologies and tools, which will serve as a reference for the project's activities and analysis. In Chapter 4, "CHECKD. design phases" the methodology used will be defined, and the entire project process of CHECKD. development will be detailed across all its phases. Chapter 5 will summarize the project contents and present the CHECKD. Product-Service System. Finally, Chapter 6, "Conclusions," will summarize the research's main insights, conclusions, and future possibilities.

2. CONTEXTUAL BACKGROUND

2.1 Field of action: diagnostics

2.1.1 Introduction

Diagnostics are one of the most important parts of the healthcare system (Roche Diagnostics International Ltd, 2021), along with vaccines and therapeutics (application of remedies to diseases) (Catalysis Foundation, 2022).

Collin's English dictionary defines "diagnostics" as "Equipment, methods, or systems used for discovering what is wrong with people who are ill or with things that do not work properly"[1].

Diagnostics play a fundamental role in the wider process of defining a medical diagnosis, which means identifying a disease, condition, or injury from its signs and symptoms[2]. According to the Center for Diseases Control and Prevention[3], 70% of medical decisions depend on diagnostics: these (latter) procedures, in fact, provide extremely valuable data and information that will be used as a basis to provide patients with the right treatment. Diagnostics are also considered fundamental for biomedical research and medicine advancements (Dusheck, 2016).

Within healthcare diagnostics are therefore crucial and have multiple and key roles: guiding medical intervention, informing about disease status and bringing about important changes in people's lives (Catalysis Foundation, 2022), influencing also the broader quality of patient care, diminishing health outcomes and therefore also lowering the associated costs and resource utilization (The Lewin Group, Inc., 2005).

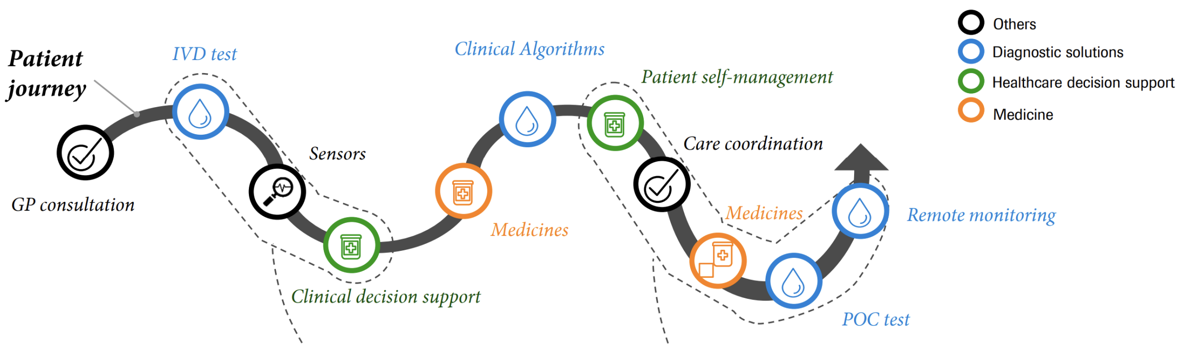


Figure 1 - Diagnostics along the patient journey. Source: Roche.

[1] Diagnostics definition and meaning | Collins English Dictionary (collinsdictionary.com)
[2] https://www.cancer.gov/publications/dictionaries/cancer-terms/def/diagnosis
[3] Strengthening Clinical Laboratories | CDC

2.1.2 In-vitro diagnostics

There are two main categories in which diagnostic products are classified, based on their nature: in vivo and in vitro.

In vivo, meaning "within a living organism", refers to diagnostic tools and equipment that allow to carry out procedures on (or in) a living organism[4] products mainly include imaging technologies, such as MRIs, X-rays and ultrasound.

In vitro, instead, is Latin for "in glass" and derives from the fact that these tests are carried out in a test tube or on a laboratory dish. In vitro diagnostics (IVDs) have been defined by different institutions. The most comprehensive definition has been given from the United States Food & Drug Administration[5]:

"*In vitro diagnostic products are those reagents, instruments, and systems intended for use in diagnosis of disease or other conditions, including a determination of the state of health, in order to cure, mitigate, treat, or prevent disease or its sequelae. Such products are intended for use in the collection, preparation, and examination of specimens taken from the human body."*

IVDs, include, therefore, all non-invasive tests which are used on biological samples (eg. blood, tissues or urine) and not directly on a person. IVDs' role is not to provide treatment to the patients, but to supply information about the status of specific body functions (Erbach, 2014).

Its usage, then, cannot bring about direct harm to the patient. Rather, it is possible to cause detriment indirectly, if incorrect diagnoses are defined from invalid or inaccurate results which are not recognized as such (Erbach, 2014).

For the remainder of this thesis, the term diagnostics will be used to refer only to in vitro diagnostics (IVDs), unless additional clarification is provided.

2.1.3 IVDs classifications

Diagnostics products can be divided either by technology/test type or by application:

Figure 2 – Overview of diagnostics products, ddapted and revised from https://www.fortunebusinessinsights.com/industry-reports/in-vitro-diagnostics-ivd-market-101443

Technology/ test type	**Definitions**	**Examples**

[4] In vivo – Drug Development and Diagnostics
[5] CFR - Code of Federal Regulations Title 21 (fda.gov)

Hematology/ coagulation	*Study of the blood, blood–producing organs and cells of the body.* *Designed to count and characterize blood components (e.g., hemoglobin, white blood cells, platelets).*	White blood cell count (WBC), Red blood cell count (RBC), Platelet count.
Clinical Chemistry	*Measurements of base compounds in the body. Detection and measurement of certain chemicals indicative of changes in organ function or status of various biological systems (e.g., circulatory system, metabolic systems, digestive system).*	BUN, electrolytes, Ca, P, liver function tests, cardiac markers.
Immuno-diagnostics	*Match antibody-antigen response to indicate the presence or level of a protein. Tests in this category measure the body's antigen/antibody reaction (i.e., the body's natural immune response) to foreign agents (e.g., external environmental agents, internal autoimmune response).* Technologies: Radioimmunoassay (RIA), Fluorescence immunoassay (FIA), Colorimetric immunoassay (CI), ELISA, CLIA	Alere HIV Combo - Rapid Test, ELISA tests, Mantoux test.
Molecular diagnostics/ genetics	*Study of DNA and RNA to detect genetic sequences that may indicate presence or susceptibility to disease.* *Tests in the molecular diagnostics category investigate the molecular relationships within organisms (e.g., link between genes and function of metabolic pathways, drug metabolism and disease development), with a primary focus on the study of DNA, RNA and proteins.* Technologies: PCR/RT-PCR, Sequencing, FISH, ISH, Chips and microarrays, Transcription Mediated Amplification, Isothermal Nucleic Acid Amplification Technology (NAAT), Mass spectometry	PCR tests, Antibiotic susceptibility testing

Application	Definition
Cardiology	Branch of medicine that deals with the study and treatment of disorders of the cardiovascular system, specifically the heart, veins and arteries. Considered as a sub-specialty in internal medicine, it focuses on the diagnosis and treatment of cardiovascular conditions that range from congenital defects to heart diseases including congestive heart failure and coronary artery disease[6].
Oncology	A branch of medicine that specializes in the diagnosis and treatment of cancer. It includes medical oncology (the use of chemotherapy, hormone therapy, and other drugs to treat cancer), radiation oncology (the use of radiation therapy to treat cancer), and surgical oncology (the use of surgery and other procedures to treat cancer)[7].
Infectious diseases	Infectious diseases are illnesses caused by harmful agents (pathogens) that get into your body. The most common causes are viruses, bacteria, fungi and parasites.[8]
Diabetes	Diabetes is a chronic disease that occurs either when the pancreas does not produce enough insulin or when the body cannot effectively use the insulin it produces. Insulin is a hormone that regulates blood sugar[9].
Nephrology	Renal medicine, also known as nephrology, is a field of medicine that focuses on the diagnosis and care of patients suffering from kidney disease[10].
Autoimmune disease	

[6] https://www.docdoc.com/medical-information/specialties/cardiologists
[7] https://www.cancer.gov/publications/dictionaries/cancer-terms/def/oncology
[8] https://my.clevelandclinic.org/health/diseases/17724-infectious-diseases
[9] https://www.who.int/news-room/fact-sheets/detail/diabetes
[10] https://www.docdoc.com/medical-information/specialties/nephrologists)

	A condition in which the body's immune system mistakes its own healthy tissues as foreign and attacks them. Most autoimmune diseases cause inflammation that can affect many parts of the body[11].
Drug testing	Technical analysis of a biological specimen, for example urine, hair, blood, breath, sweat, or oral fluid/saliva—to determine the presence or absence of specified parent drugs or their metabolites[12].

2.1.4 Main components of diagnostics

As presented in the paragraph above, diagnostics, by covering a wide range of contexts and situations, can be very different in terms of process and technology, dimensions and use setting. Regardless, they have basic and common functional elements that are always present and used in different combinations to diagnose, screen or evaluate a specific condition (The Lewin Group, Inc., 2005):

- Samples. Samples are specimens that are taken from patients to run tests outside of the body; (e.g., blood samples, throat swabs or urine samples from patients) (The Lewin Group, Inc., 2005).

- Controls. Used to ensure that reagents and lab instruments are working within predefined specifications, thereby safeguarding the reliability of patient test results [13].

- Reagents. Substances used in diagnostic tests to detect disease agents or antibodies by causing an identifiable reaction[14].

- Diagnostic instruments. They utilize samples and reagents to produce data on measurable markers or endpoints, which can range from home testing devices to automated devices used in large clinical labs (The Lewin Group, Inc., 2005).

- Accessory products. They are used in conjunction with diagnostic instruments to aid in the diagnostic process. This can include software programs used to run instrumentation, as well as diagnostic components used to obtain and store biological samples (The Lewin Group, Inc., 2005).

[11] https://www.cancer.gov/publications/dictionaries/cancer-terms/def/autoimmune-disease
[12] https://en.wikipedia.org/wiki/Drug_test
[13] tinyurl.com/jebedjep
[14] tinyurl.com/mt2dx355

- Testing systems. Testing systems combine diagnostic instruments and accessory products into one package, allowing for the seamless upload of test results into electronic medical records, hospital databases, or decision support systems for management of patient care. This enables abnormal results to be flagged for clinician attention (The Lewin Group, Inc., 2005).

Figure 3 - Main components of diagnostics.

2.1.5 The evolution of diagnostics

Diagnostic procedures on patient specimens were carried out as early as 400BC in Egypt and Mesopotamia. To confirm the presence of certain infections, ancient physicians would test bodily fluids by pouring them on the ground and observing if (and which) insects were attracted by it (The Lewin Group, Inc., 2005).

During the Middle Ages diagnosis and disease understanding was brought to a halt. Because of radical religious beliefs, that considered all types of illnesses as a divine punishment for the commitment of sins, only practices like urology were applied on people's specimens (Berger, 1999).

The 17th century was fundamental to pose some groundwork for future important diagnostic developments. The microscope, for example, invented in the early 1600s, was actually applied to analyze samples by Dutch Antony Van Leeuwenhoek (Ball, 1966).

Blood circulation, instead, was discovered in 1628, which allowed to understand other bodily functions and processes (such as digestion, metabolism, respiration) (Encyclopedia Britannica, 2022).

Along with these events, Thomas Willis proposed the first principle to diagnose different types of diabetes by applying a qualitative analysis of urine based on its sweetness level (Berger, 1999).

Real developments in the field of diagnostics started during the 19th century. Worldwide industrial revolution and theoretical foundations of modern sciences supported the birth and establishment of the hospitals and clinical laboratories. Despite the initial lack of hygienic measures and safety standards, medical practitioners and patients started to increasingly rely on diagnostics and consider them as a basic element of health care (Büttner, 2000).

By the turn of the century new tools for the analysis of urine and blood tests were developed and for diseases such as tuberculosis, cholera, typhoid, diphtheria, and syphilis lab tests were introduced, supported by improved and new knowledge about public and personal hygiene (Berger, 1999).

From the 1900, constant improvements were made in diagnostic techniques, which aided and supported a more formal establishment of different kinds of clinical laboratories, which became permanent institutions of US hospitals. By 1920 they were organized and self-regulated structures, with adequate and trained staffed, proper equipment, 4 or 5 divisions and direction from a chief physician (Berger, 1999).

The emergence of HIV and the West Nile virus, coupled with the Introduction of blood transfusion (1940) and the subsequent need to identify blood-borne pathogens spurred the development of diagnostic tools that could screen the blood supply and ensure its quality (The Lewin Group, Inc., 2005).

In 1953 the structure of the DNA was discovered by Watson & Crick, originating a new wave of research and studies which brought to a deeper understanding of genetic and molecular structures (The Lewin Group, Inc., 2005).

In the dramatic evolution of healthcare and medical services of the late 20th century, diagnostics, and its constant progress, assumed increasingly important roles and value for society, particularly when automation was introduced. Many manual tests were replaced by totally autonomous equipment, thus increasing efficiency in laboratories (The Lewin Group, Inc., 2005).

In 1977, a method of DNA sequencing was developed by Sanger, while in 1985 Mullis proposes the polymerase chain reaction (PCR) for copying DNA, substantially changing the understanding of the relationship between genes and diseases (The Lewin Group, Inc., 2005).

Scientific advances and technical achievements also called for the formulation of multiple bodies of regulations, both Europe and the US. In 1976 the Medical Device Amendments to the Food, Drug, and Cosmetic Act, brought the FDA to have control of IVDs and other diagnostics. In Europe, instead, only in 1998 the first EU In Vitro Diagnostics Directive was proposed (The Lewin Group, Inc., 2005).

In the last two decades the international laws on IVDs were expanded significantly, also increasing in complexity and severity, causing multiple challenges for the players in the diagnostics industry (Rohr et al., 2016). Despite this, technological innovations in this field (such as array-based and biosensor technologies) are a constant and coupled with advanced informatics and micro processing allow the highly sophisticated equipment to be manufactured and put on the market (The Lewin Group, Inc., 2005).

As of today, diagnostics are fully integrated into clinical practice and considered a basic tool for obtaining high-quality medical outcomes: more the 40.000 different products in the market are available for patients and professional practitioners to apply in regards to multiple conditions (Rohr et al., 2016).

The World Health Organization underlines even more the importance of these kind of tests by introducing in 2018 a list of tests that should always be available in every country, as they are critical in "advancing universal health coverage, addressing health emergencies and promoting healthier populations" (World Health Organization (WHO), 2020b).

2.1.7 Future trends

The field of diagnostics has great potential for expansion in the near future and bring about relevant changes and improvements along all the healthcare value chain by revolutionizing the lives of patients, providers, and scientists (Vadas et al., 2022). The avenues of prospective development are different, and they are driven by different factors.

Two common main drivers of the future trends of diagnostics are linked to wider societal and healthcare challenges: the aging population and an increase in chronic and infectious diseases (Jakab, 2007; PwC, 2021).

Regarding the first, the WHO forecasts that the world population over 60 years old will nearly double before 2050 (from 1 billion in 2020 to 1.4 billion, until 2.1 billion in 2050), with 2/3 of it living in low- and middle-income countries[15]. This steady increase in life expectancy, which we are already experiencing to some extent, will induce major repercussions, starting from the shift in disease burden and subsequent rise in the demand for age-related procedures and treatments. These are immediately followed by the exponential increase in the need for long-term care and constantly growing costs of health services (Cristea et al., 2020).

Chronic diseases, instead, which are also known as non-communicable diseases (NCDs), include complex conditions such as cardiovascular disease, diabetes, chronic obstructive pulmonary disease, and cancer[16]. Despite being traditionally linked to older segments of the population, NCDs can affect also younger people. Virtually, in fact, everyone is vulnerable to the risk factors (such as unhealthy diets, physical inactivity, use of tobacco, smoke, or alcohol), but in the last decades, a remarkable rise in NCDs was detected in the ages that span between 30 and 69 years old[17]. Routes to approach NCDs are long-term and very complex and involve steep costs for treatment. Moreover,

[15] https://www.who.int/news-room/fact-sheets/detail/ageing-and-health
[16] https://www.cdc.gov/chronicdisease/about/index.htm#:~:text=Chronic%20diseases%20are%20defined%20broadly,disability%20in%20the%20United%20States
[17] https://www.cdc.gov/chronicdisease/about/index.htm#:~:text=Chronic%20diseases%20are%20defined%20broadly,disability%20in%20the%20United%20States

chronic illnesses are also one of the biggest contributors to mortality and disability in the world (Busse et al., 2010).

Trend #1: Results rapidity.

One of the most important characteristics that will need to define future diagnostic products is "fastness" (PwC, 2021). The challenges connected to the increase in life expectancy and the necessity of early detection and prevention of chronic illnesses see the need for less lengthy and less expensive procedures[18]. This applies especially in cases where there is the necessity for more timely results as so to provide treatment to serious and immediately-life-threatening health problems (The Lewin Group, Inc., 2005). Other keywords will therefore be "increased accuracy" (both specificity and sensitivity), "more informative", "more affordable" and less invasive diagnostic tests (PwC, 2021).

Trend #2: Technological advancements and digital innovations.

This trend encompasses different facets. Advanced automation of both diagnostic equipment and support platforms is an important point, which has already started to produce positive impacts but will be at the core of future industry developments. Large laboratories, which are the most common in current diagnostic ecosystems, are suffering from reduced manpower, while still having a high number of tests to run (PwC, 2021). Streamlining laboratory operations (such as automated sample verification, quality control and calibration, real-time inventory management, and remote system support to catch maintenance issues before they become problems) can dramatically enhance the efficiency and effectiveness of the workflow (PwC, 2021; Roche Diagnostics International Ltd, 2021), halve errors (The Lewin Group, Inc., 2005), reduce unnecessary testing and reduce costs (Roche Diagnostics International Ltd, 2021).

Another point under this trend is the improvement of the accuracy of tests themselves and their becoming more specialized, due to technological advances, such as multiplexing (PwC, 2021). As there are advancements in the understanding of new biomarkers, a wider spectrum of disease information and data are captured: this supports more consistent responses to changing health needs and more precision in diagnosis.

The two points are connected by the opportunities that are offered by new analytics systems and big data. The vast amount of data generated does not have to be processed manually, but it is automatically analyzed (Roche Diagnostics International Ltd, 2021), supporting the development of more "accessible" diagnostic products in cases of low-level (or even none) medical training (The Lewin Group, Inc., 2005).

[18] https://www.who.int/news-room/fact-sheets/detail/noncommunicable-diseases

Trend #3: Real-time and personalized treatments.

The use of a “snapshot”-type testing and "personalized" approach to manage specific diseases allows patients to adapt treatments to their own specific condition and changes in the course of the diseases (The Lewin Group, Inc., 2005). A common example is blood glucose and glycated hemoglobin tests for monitoring diabetes. The development of these kind of equipment is focused on increasing the range of diseases and conditions, while, at the same time, convey the information properly and efficiently to both the medical practitioner and to the patient (The Lewin Group, Inc., 2005). The last avenues of development are seeing the support of wearable devices, which are increasingly diffused, both in a "at home" situation, but also in the hospital and focus on comfort and mobility opportunities (Roche Diagnostics International Ltd, 2021).

Trend #4: Point-of-care (POCT) and home testing.

The necessity to rapidly detect and identify chronic and infectious diseases has been a driver for POCT kind of equipment for the last 30 years (The Lewin Group, Inc., 2005) and it is bound to exponentially grow further (PwC, 2021). Point-of-care consists of near-patient testing: the diagnostic test is performed at the time and place where the patient is, instead of relying on hospitals or other laboratories for sample analysis.

Home testing, as a type of POCT, has grown particularly in the last decades: from the simple over-the-counter pregnancy test to genetic tests, patients can complete in the comfort of their own home a lot of different test procedures (Roche Diagnostics International Ltd, 2021). Today there are 500 approved OTC home-based medical devices/tests by the FDA[19]. Despite these tests becoming more and more common, they are an important area of development that still holds great opportunities for improvement, especially when regarding the enhancement of chronic disease management and the development of more accurate technologies (The Lewin Group, Inc., 2005). This path for IVDs goes along a wider healthcare trend, that sees a general improvement in patient access to medical services while reducing their cost, especially for low-income or rural families[20], but also the acceleration of the consumerization of diagnostics and the birth of new business models based on direct-to-consumer (Vadas et al., 2022).

2.2 Point-of-Care Testing

2.2.1 Introduction

One of the most interesting and promising trends in the diagnostic world is Point-of-Care Testing (POCT). The “POCT revolution” has started in the late 20th century with a first, slower, innovation

[19] https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfIVD/results.cfm
[20] At-Home Medical Tests Are Putting the Power of the Clinic in Your Hands (futurism.com)

wave, that accelerated at turn of the millennium, and since then it has been majorly shaping laboratory medicine (Bissell, 2001).

As of today, the POC segment constitutes almost 30% of the IVD market and has become a multi-billion-industry where competition is high in all its multiple sectors (Dima, 2021). In 2010 the global Point-Of-Care market size was US$13.4 billion (Abel, 2015); in 2021 it grew to 36 Billion US mostly due to the COVID-19 outbreak[21]. The mounting pressure towards safeguarding public health all over the world and the interest in rising the quality of wellbeing gave a new positive push to the development of new POC technologies, which positively affected all the POCT sectors and not only the ones connected to infectious diseases[22].

The market outlook for POC is, therefore, a very positive one: it is projected to reach a value of 66 billion dollars by 2028, with North America and the Asian region being the leading regions in the field[23].

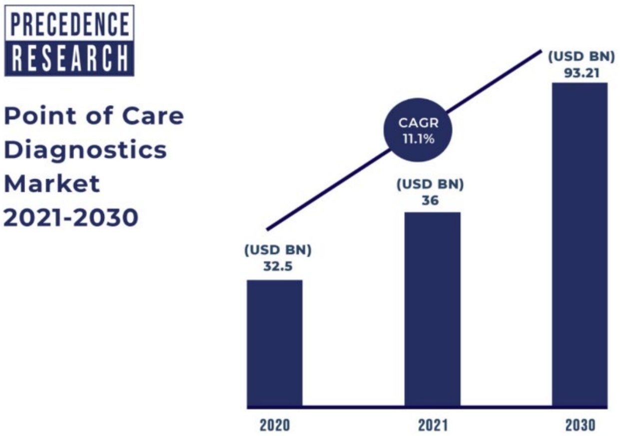


Figure 4 - PoC Diagnostic Market 2021-2024. Source: PrecedenceReasearch.

2.2.2 What is Point-of-Care testing?

Point-of-Care testing does not have a formally shared definition. The National Academy of Clinical Biochemistry (NACB) defines POCT as "clinical laboratory testing conducted close to the site of patient care, typically by clinical personnel whose primary training is not in the clinical laboratory sciences or by patients themselves (self-testing)" (Dima, 2021).

[21] https://www.globenewswire.com/en/news-release/2022/01/07/2363168/0/en/Point-of-Care-Diagnostics-Market-Size-to-Hit-USD-93-21-Bn-by-2030.html
[22] https://www.gminsights.com/industry-analysis/point-of-care-testing-market
[23] https://www.factmr.com/report/point-of-care-diagnostics-market

With this typology of testing physicians, or other individuals, can perform rapid diagnostic testing wherever that medical care is needed (Kost, 1995), while the patient waits, without the need to send samples to centralized laboratories or hospitals (The Lewin Group, Inc., 2005).

POCT, in fact, also refers to "any testing performed outside of the traditional, core, or central laboratory"(Dima, 2021). Moreover, multiple other terminologies are used to refer to POCT: near-patient testing, bedside testing, ancillary testing, satellite testing, decentralized, near-patient, patient-focused, peripheral, portable (Nichols, 2020).

2.2.3 How it works and main characteristics.

As it was previously mentioned, in Chapter 2.1.5 "The evolution of diagnostics", the modern clinical laboratory has been a major pillar of the healthcare system for more than 50 years. In this time frame it has been a subject of constantly increasing research and innovation, particularly in terms of high throughput instrumentation development and sophisticated automation implementation (Abel, 2015).

At the same time central hospital and specialized laboratories also had to face the increased demand for tests, brought about by the wider access to healthcare and new public interest in management and monitoring of chronic and infectious diseases[24].

In the traditional lab-based setting the flow it is started by a doctor who orders a test. The patient then travels to a specific location (such as an hospital, or a clinic) where a physician performs the test in a controlled environment (David, 2016). The specimen, generally a biological sample such as blood, sweat, urine or tissue, outside a living organism, that is collected is afterwards sent to proper diagnostic laboratory (David, 2016). Here, the sample is analyzed by medical technologists and medical laboratory scientists, that possess specific training and skills in laboratory analysis with the

[24] https://www.siemens-healthineers.com/fi/news/atellica-current-challenges.html

use of highly complex equipment (Nichols, 2020). The collect relevant data and main results are then communicated to the doctor, or directly to the patient itself (David, 2016).

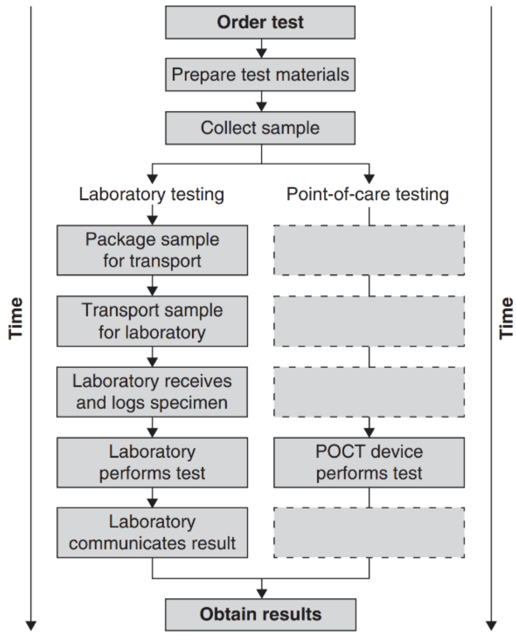


Figure 5 - Differences in processing between POCT and laboratory testing. Source: Larsson et al., 2015.

Despite the advanced automation of operations and efficient workflows, central laboratories are still run and managed by a limited number of staff and small quantity of complicated machinery, which causes the amount of time taken to complete a the process of testing a results communication to be prolonged up to many days (David, 2016; Nichols, 2020).

POCT, instead, allows to critically reduce the testing turnaround time (TAT) to 5 to 15 minutes, "without compromising the quality of information on which clinical decisions are based" (Dima, 2021).

In the POCT flow, in fact, the intermediate steps of sample delivery to a different lab for inspection are skipped: the analysis itself it is done right where the sample was obtained, such as in an exam room, a doctor's office, or someone's home (The Lewin Group, Inc., 2005). This is possible because of the kind of devices that are used: they are portable, small in size, easy to operate, they only need a small volume of sample and they run highly simple processes to deliver results (Nichols, 2020; The Lewin Group, Inc., 2005).

Another main characteristic that allows POCT to deliver rapid results, is the fact that it can be administered in different sites, with multiple devices and operators (Nichols, 2020). Moreover, these operators do not mandatorily have to be skilled professionals: on the contrary users can have limited technical background, such as in the case of nurses, doctors, pharmacists or even none (eg. patients themselves) (Larsson et al., 2015).

Table 1 Sites of POCT

- Hospital
  - Bedside (alternate/alternative, ancillary, decentralized, and waived testing)
  - Critical care workstations in the operating room, emergency department, and intensive care unit
  - Hybrid laboratory instrument sites
  - Modular plug-ins for intensive care systems
  - Near-patient testing locations (permanent, temporary, and mobile)
  - Patient-focused care centers
  - Patient monitoring stations interfaced with *ex vivo* and *in vivo* systems
  - Procedure suites (e.g. cardiac catheterization laboratories)
  - Satellite laboratories
- Outpatient
  - Clinics and specialty care centers
  - Home (e.g. self-monitoring of blood glucose)
  - Patient-focused care facilities (e.g. ambulatory surgery, heart center, and chronic care)
  - Physician offices
  - Urgent care centers
  - Wellness testing areas (e.g. screening)
- Rescue and unique locations
  - Emergency ground vehicles (e.g. ambulances)
  - Helicopter and fixed-wing aircraft for patient transport
  - Military field operations and battlefields
  - Patient travel including remote and inaccessible locations
  - Points of disasters and emergency rescues
  - Ships, submarines, and other nauticals
  - Space shuttles and space station

Figure 6 - Sites of POCT. Source: Kost et al., 2008.

The procedures and technologies that POCT includes are very wide. Some examples of the most common uses are pregnancy testing, blood glucose concentrations for monitoring diabetes, cardiac marker testing of heart injury/heart attack, hemoglobin concentration (Abel, 2015; Larsson et al., 2015; The Lewin Group, Inc., 2005), but also for drugs of abuse, therapeutic drug monitoring (Clarke & Marzinke, 2020) and testing for numerous infectious diseases like streptococcus, mononucleosis, influenza, and HIV (Clarke & Marzinke, 2020; Larsson et al., 2015).

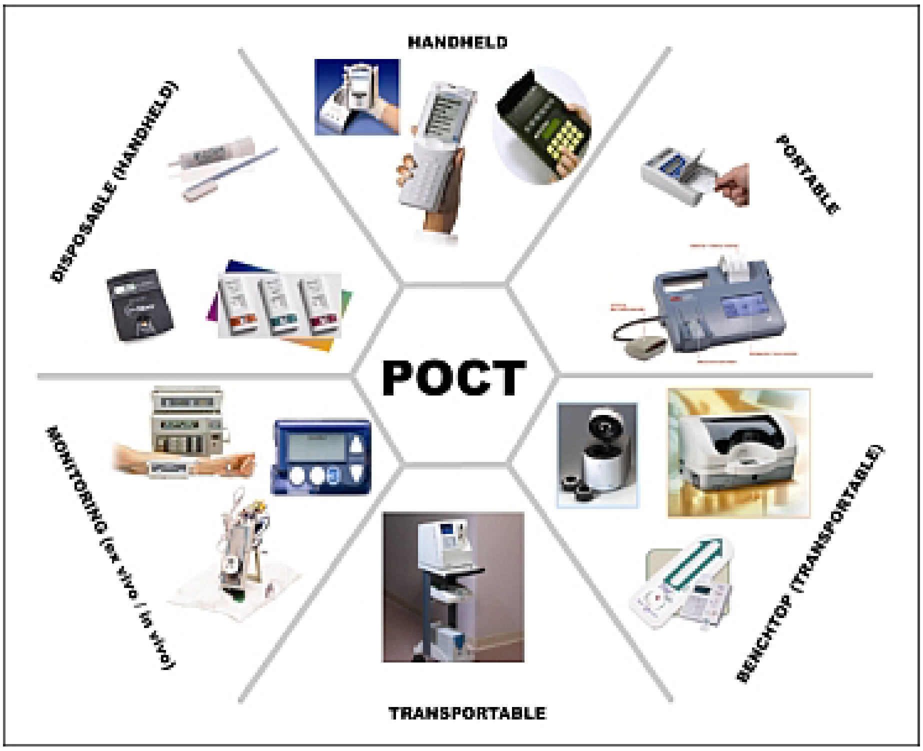


Figure 7 - PoC medical devices. Source: BioSpectrum Bureau.

2.2.4 POCT outcomes and benefits

The POCT approach can provide multiple benefits. First, the reduced TAT has relevant positive effects on health decision-making. Since results are given rapidly (or in some cases, immediately) and still hold accurate data, allow physicians to give immediate and precise diagnosis and subsequent clinical treatment to the patients (Clarke & Marzinke, 2020; Dima, 2021; The Lewin Group, Inc., 2005). The latter are therefore moved through the hospital system very quickly (rosa), reducing hospitalization and/or length of stay (LOS) (Dima, 2021), for example by increasing the number of patients eligible for self-monitoring (Larsson et al., 2015). POCT also reduces overcrowding and patient waiting time, surgery rescheduling, and plays a key role in preventing the waste of expensive surgeon and operating room time (Nichols, 2020). Finally, with its simple equipment it can reduce patient discomfort and expand adoption due to its simplicity of use and low cost (Li, 2019). Hence POTC brings clear improvements in the efficiency of delivering care (Clarke & Marzinke, 2020) and it is linked to outcomes such as lower total medical cost, increased clinician and patient's satisfaction (Dima, 2021), reduced patient acuity, criticality, morbidity, and mortality, especially during life-threatening and emergency situations (Kost et al., 2008).

POCT is not benefiting only the patient and the medical staff, but the health care institution and the society at large: in fact, when seen in advanced healthcare systems it can provide substantial reduction of downstream healthcare costs and general quality of life (Larsson et al., 2015; Nichols, 2020; The Lewin Group, Inc., 2005).

2.3.5 SWOT analysis

To give a wider overview of the POCT system a brief SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis is provided.

Strengths

- POCT devices only need a sample with small volume and still allow for a high flexibility in sample nature (eg. blood, saliva, other bodily fluids). (Clarke & Marzinke, 2020)
- The equipment used for sample collection applies significantly less invasive methodologies, which can increase the utilization frequency (Larsson et al., 2015)
- As of now there is a wide range of applications available for POCT. (Clarke & Marzinke, 2020)
- POCT practices do not involve convoluted handling and processing of samples and reagents (The Lewin Group, Inc., 2005). This easiness of use allows the devices to be used by a variety of individuals with minimal training (Nichols, 2020).
- POCT equipment has an enhanced portability and avoids the more traditional heavy, large, and complex structures that can be found in central laboratories (The Lewin Group, Inc., 2005).

Weaknesses

- POCT can suffer from greater imprecisions and biases (Dima, 2021), first of all due to the number of operators and tests being conducted (Clarke & Marzinke, 2020). POC tests are highly dependent to the skills, abilities, time and role of the operator who administers the test (Clarke & Marzinke, 2020; Nichols, 2020).
- POCT do not reach the same accuracy and precision as central laboratory tests, also because they are single-use, therefore there is no certainty that different "kits" will function in the same way (Clarke & Marzinke, 2020; Nichols, 2020).
- Due to the portability of POCT devices, the reagents contained inside are exposed to varying environmental conditions (eg. exposed to cold in the winter and heat in the summer), so their risk of damage is higher than central laboratories (Nichols, 2020) and can lead to incorrect results (Clarke & Marzinke, 2020).
- Regulatory compliance for development, manufacturing and actual usage is complex and multifaceted and can be time- and labor-intensive (Clarke & Marzinke, 2020).
- In certain cases POCT can be more expensive than traditional tests, because of some single-use reagents who are not packaged in bulk for high volume analysis, such as the one done in a laboratory (Clarke & Marzinke, 2020; Larsson et al., 2015).

Opportunities

- Seamlessly incorporating POCT in the wider system of patient care can bring a big shift in healthcare delivery and quality of life.
- POCT devices and its characteristics can be an important resource to apply in third-world countries and remote areas where medical and healthcare access is made more complicated by political, economic, and social situation. POCT can deliver advanced testing for epidemiologically important diseases, such as tuberculosis of HIV infection (Li, 2019)
- Comprehensive and highly structured risk management plans can reduce errors to a minimum, as well as more research an innovation in the development of devices (Clarke & Marzinke, 2020).
- Technological innovations (such as nucleic acid amplification techniques, microarrays and multiplexed technologies), combined with experimentations in increased portability and automation are creating the foundations for the next generation of POCT diagnostics (Abel, 2015).

Threats

- With POCT it can be difficult to achieve continuity of care, since the tests made in different sites can give results which are not equivalent (Nichols, 2020).
- Quality management is complicated: if not properly controlled by the staff or if the manufacturer's instructions on are not followed properly, POCT devices can be reservoirs for nosocomial and antibiotic resistant organisms and subsequently transmit infections (Clarke & Marzinke, 2020).

2.4 Infectious diseases

2.4.1 Introduction

Individuals have been at risk of viral infections that cause diseases since ancient times, and through all the history of human existence they have been the origin of death and misery (Morens et al., 2004). During the last century, though, developed countries reduced this threat exponentially and in multiple cases it brought to an effective and efficient control of some dangerous viruses (Strauss & Strauss, 2008b). Key elements that provided this shift were: first, general improved technologies in sanitation and water supply management (Strauss & Strauss, 2008b); second, the identification of viruses and other microbes as agents of infectious diseases (Morens et al., 2004); third, the development of antibiotics, antimicrobials, vaccines and the implementation of better medical care (Strauss & Strauss, 2008b).

Despite this, viral diseases are still an extreme burden for humans (Strauss & Strauss, 2008b) and are forecasted to remain a steady challenge for the foreseeable future (Morens et al., 2004).

Infectious diseases are one between some of the leading causes of death worldwide (Fauci, 2001; Morens et al., 2004).

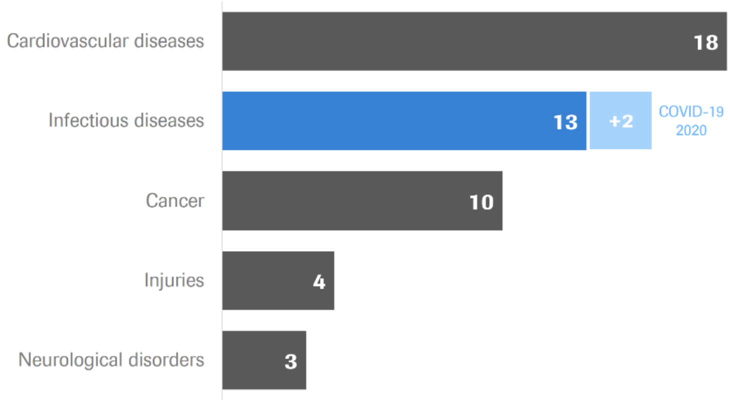


Figure 8 - Cause of death globally (millions per year). Source: United Nations.

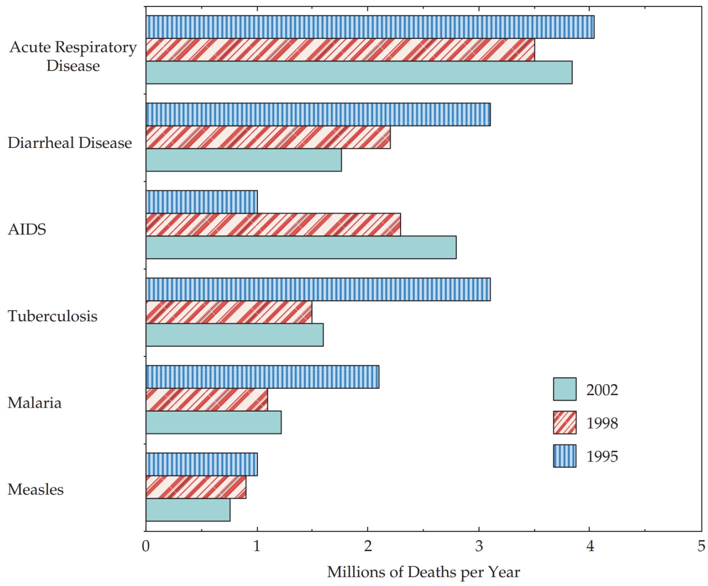


Figure 9 - Six leading infectious diseases as causes of death. Source: World Health Organization.

Each year, worldwide, around 56 million people die (Ritchie et al., 2018) and about 15 million (> 25%) of these deaths are estimated to be brought about by infectious diseases (Morens et al., 2004). Viral infections and its continual evolutions make it impossible to completely eradicate the problem (Fauci, 2001) and both viruses that are well known and recognized and new emerging ones will keep causing widespread problems (Strauss & Strauss, 2008a).

Only between 1940 and 2004, 335 infectious diseases have emerged in the global human population and they obviously impact significantly global health and the functioning of the world economy (Jones et al., 2008). Emerging infections include newly emerging infections, which have not previously recognized in humans (Morens et al., 2004), and re-emerging infections, which have existed virulently in the past and died down, but for different reasons they are resurging again (Fauci, 2001).

Both the emergence of non-zoonotic and zoonotic infections are connected to a wide and complex web of factors, that span from genetic and biological ones, to social, political and economic factors (Fauci, 2001). Some examples are:

- Changing climate and ecosystems disruption (Morens et al., 2004), that interfere with temperature, rainfall and severe weather events and therefore vectors proliferation (Jones et al., 2008).
- Human demographics and behaviour (Morens et al., 2004), first of which the always increasing human population growth and human population density and development of settlements and cities closer to wildlife settings (Jones et al., 2008).
- Economic development and land use, such as farming, new types of domestic pets, hunting and camping, deforestation, which can be privileged situations for infectious agents to invade human hosts (Morens et al., 2004).

Figure 10 - Range and recognized site(s) of origin of variety of emerging and reemerging infections. Source: Fauci, 2001; National Institute of Allergy and Infectious Diseases (NAID).

In the light of the recent emergence of Covid-19 it is clear how the 21st century will present human society with many challenges related to infectious diseases. Therefore, the evolution and constant improvement of scientific and technological elements that can support in the control, detection and management of such diseases is going to be critical for the whole global health (Fauci, 2001).

2.4.2 Scientific background

To make the next sections clearer and more comprehensible, a scientific background is provided, where some of the very basics of biology are briefly proposed in rather simple terms.

THE DNA

History

DNA was first isolated in 1869 by the Swiss physician Friedrich Miescher, who named the previously unknown chemicals “nuclein” since they were isolated from the nuclei of the cells (Rye et al., 2013).

It was not until the mid-1950s that actual progression on the understanding of DNA occurred. Martha Chase and Alfred Hershey performed a series of experiments that were fundamental in confirming with actual evidence that chromosomes contained DNA, which was not proteins, but genetic material (DiGiuseppe et al., 2003, p. 1; Rye et al., 2013). Another important step was, for example, the definition of Chargaff’s rules by Austrian biochemist Erwin Chargaff, always in second half of the 20th century (Rye et al., 2013).

These events and other advances in biology research were the building blocks upon which Francis Crick and James Watson worked on together, at the University of Cambridge, to delineate the structure of the complex molecule which is DNA (Rye et al., 2013). In 1953, along with Rosalind Franklin, for the first time, they proposed their notorious DNA “double helix model” (DiGiuseppe et al., 2003).

Structure

The nucleus of every cell of the human body contains 23 pairs of chromosomes (Rye et al., 2013). Chromosomes are larger structures formed by an aggregate of thousands of genes, smaller elements, which determine the genotype and phenotype of an individual (Rye et al., 2013; Scheiner & Scheiner, 2014). The human haploid genome has between 20,000 and 25,000 functional genes (Rye et al., 2013).

The gene, which can be defined as “the fundamental unit of information”, is a sequence of DNA (Scheiner & Scheiner, 2014).

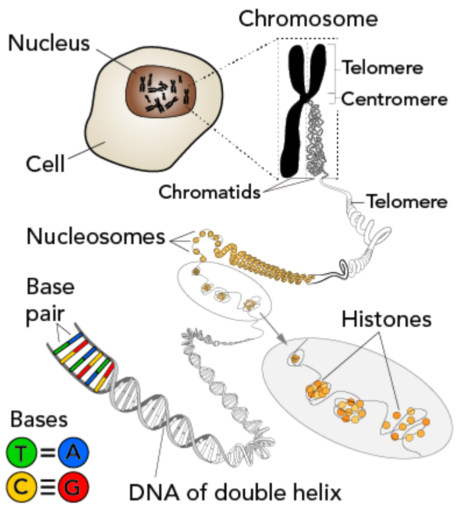


Figure 11 - Basics of biology. Source: Let's Talk Science.

DNA, as described in the model advanced by Watson and Crick, consists of two strands of repetitive basic units called nucleotides (DiGiuseppe et al., 2003).

Nucleotides can also be further broken down in three important components: a nitrogenous base, deoxyribose sugar (5-carbon sugar), and a phosphate group, all bonded to each other (Rye et al., 2013). The double helix model of DNA forms a structure that can be compared to the one of a ladder: the sugar and phosphate groups create the backbone, or the struts of the ladder, while the base pairs, which stick out from the backbone of each DNA strand, form the rungs (DiGiuseppe et al., 2003). Moreover, this ladder (or double helix) loops around a protein, further intensifying the complexity of the configuration that will end up being a much larger and very compact structure, the chromosome (Scheiner & Scheiner, 2014). When stretched out end to end the DNA carried by one human cell can reach 1.8 meters (Scheiner & Scheiner, 2014).

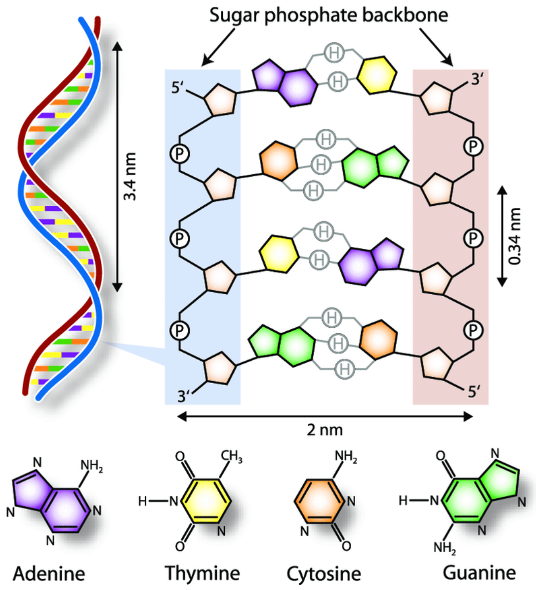


Figure 12 - Schematic representation of double-stranded DNA.. Source: Gauthier, 2007.

Each nucleotide is named depending on the nitrogenous base (Rye et al., 2013). Four types of nitrogenous bases exist, and form four types of DNA units: adenine (A), guanine (G), thymine (T), and cytosine (C) (Scheiner & Scheiner, 2014).

As proposed by Watson and Crick, two strands that twist in a clockwise direction make up the DNA molecule (Rye et al., 2013). Each of the bases of one DNA strand are paired with bases in the other strand through what is called “complementary base pairing” (Scheiner & Scheiner, 2014). In fact, not all the bases can be paired together: a purine is always paired with a pyrimidine, so Adenine (a purine) is always paired with thymine (a pyrimidine), and guanine (a purine) is always paired with cytosine (a pyrimidine) (Rye et al., 2013). The nucleotides are linked in a chain through phosphodiester bonds, whereas the complementary bases hold the DNA together and make it very stable through a collective of hydrogen bonds (Scheiner & Scheiner, 2014).

RNA

RNA is a second type of nucleic acid (ribonucleic acid) similar to the DNA: it is, in fact, a polymer of nucleotides, essential for all known forms of life group (DiGiuseppe et al., 2003; Jefferson Computational Medicine Center, 2020).

Analogously to the chemical structure of the DNA, RNA’s nucleotides consists of a nucleobase, a ribose sugar, and a phosphate group (Jefferson Computational Medicine Center, 2020).

RNA and DNA, though, present some differences. First, RNA is not a double-stranded helix (as DNA): rather, it exists as short single stranded chains (rna). Second, RNA contains a different sugar than DNA (deoxyribose sugar), which is called “ribose” because it has an extra hydroxyl group (DiGiuseppe et al., 2003; Jefferson Computational Medicine Center, 2020). A third and final difference, is that instead of the base thymine found in DNA, RNA contains the base uracil (DiGiuseppe et al., 2003).

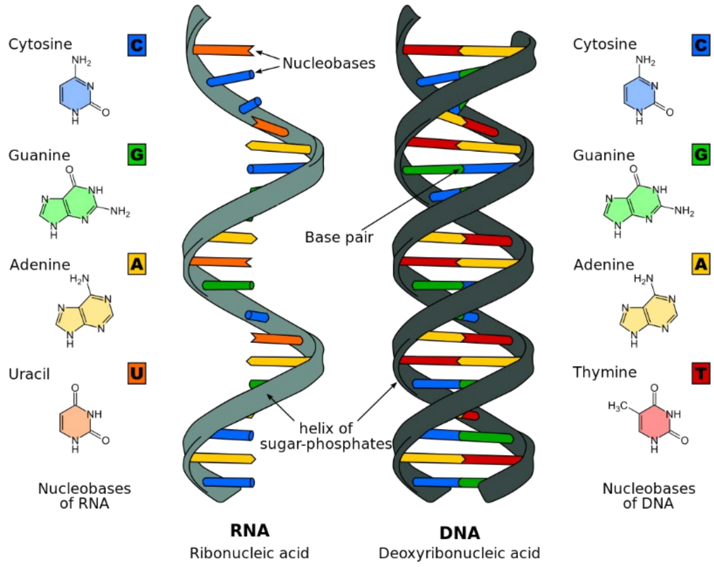


Figure 13 - A comparison between the structure of DNA and the structure of RNA. Source: Microbiology Laboratory Manual.

Regarding its function, RNA has many, since it is one of the cell's key regulatory players (Gray & Beyer, 2014; Jefferson Computational Medicine Center, 2020). For example it is fundamental in protein synthesis (translating the genetic information carried in deoxyribonucleic acid (DNA) into proteins) as a transfer and messenger, but it can cover other important roles, such as being a carrier of genetic material for certain viruses (Gray & Beyer, 2014).

PARASITES

Parasites can be defined mainly as "organisms that live at the expenses of other organisms", namely "hosts", and that bring them some kind of harm (Varki et al., 2022, p. 40). Different classes of parasites exists, but only three of them can establish a parasitic infection and therefore disease into humans: protozoa, helminths, and ectoparasites (Centers for Disease Control and Prevention (CDC), 2022c).

- Protozoa. Microscopic unicellular eukaryotes (less than 50 μm in size) which can infect humans with different levels of outcomes (from asymptomatic to life threatening) (Baron, 1996). Transmission of this parasite predominantly occurs through the fecal-oral or blood route (Centers for Disease Control and Prevention (CDC), 2022c).

- Helminths. "Worm-like parasites", they are multicellular organism that can clearly be seen with a naked eye in their adult stage (Centers for Disease Control and Prevention (CDC), 2022c). This kind of parasite grows into human hosts starting from an egg phase, to then become a larvae and finally an adult, when they adhere to the hosts internal tissue[25]. Transmission occurs through aquatic environments, where eggs, released by feces, urine or sputum, hatch and penetrate another host[26].

- Ectoparasites. Broader term that includes blood-sucking arthropods (eg. Mosquitoes, ticks, lice, mites) (Centers for Disease Control and Prevention (CDC), 2022c).

BACTERIA

Bacteria and their phages are “the oldest and most abundant life forms on the planet” (The National Institutes of Health (NIH) & TheAmerican Society for Microbiolog (ASM), 2007). On one side they are fundamental for a proper human development and nutrition, while from the other they can also become harmful: they, infact, are responsible for multiple infections and for 25% of human deaths (Thiel, 1999).

They are microbes, prokaryotic organisms that carry their genetic information in a double-stranded circular molecule of DNA[27].

Different typologies of bacteria exist, but they all reproduce through the same process: binary fission [28].

Binary fission happens through simple steps: after completing DNA replication, one cell reaches its twofold dimension to then split into two identical parts, called clones (with their own complete genome) (Thiel, 1999). This process will then be reproposed to create a mass of cells, called a colony (Thiel, 1999).

VIRUSES

History

Despite nowadays there is a significant amount of knowledge available on how viruses behave and evolve, their origins are still unclear, as they do not leave historical footprints, such as fossils (Rye et al., 2013).

The discovery of the first virus technically occurred at the end of the 19th century. In 1892, after several observations, the Russian botanist Dmitri Ivanovsky noticed “filterable” infectious agents in plant tissues afflicted with mosaic tobacco disease, that he initially considered to be only bacteria (López-García & Moreira, 2012). It was only in 1930 when scientists recognized that in fact it was an actual virus (Rye et al., 2013). In the subsequent years of research and evolution of molecular

[25] Helminths: Structure, Classification, Growth, and Development - Medical Microbiology - NCBI Bookshelf (nih.gov)
[26] Helminths: Structure, Classification, Growth, and Development - Medical Microbiology - NCBI Bookshelf (nih.gov)
[27] Bacterial Infections: Overview - PMC (nih.gov))
[28] Bacterial Infections: Overview - PMC (nih.gov))

biology and electron microscopy the understanding of viruses and their nature has increased exponentially (López-García & Moreira, 2012). Since 1898 more than 9000 virus species have been described in detail[29].

Structure

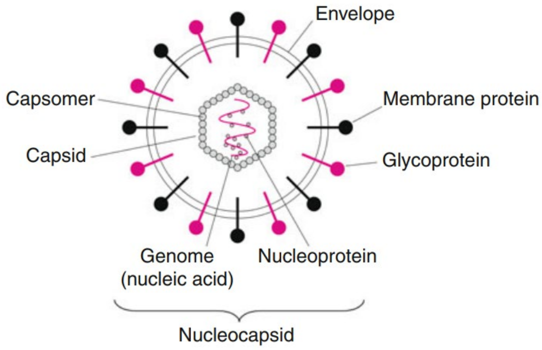


Figure 14 - Structure of a virus. Source: Modrow et al., 2013.

A virus can be considered as an extremely small infectious units, that can range from 16nm to 300nm (López-García & Moreira, 2012; Modrow et al., 2013). They do not have a cellular structure on their own, so they are labeled as "acellular" parasitic entities (Rye et al., 2013).

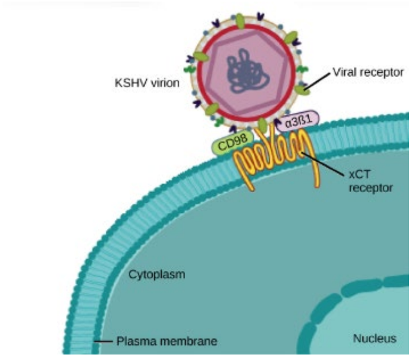
As a single independent particle, the virus is called virion, and it contains one kind of nucleic acid (DNA or RNA, the genetic material, that encodes the structures of the proteins by which it acts) surrounded by a capsid (a protein shell) and occasionally also a lipid envelope (López-García & Moreira, 2012; Modrow et al., 2013; Rye et al., 2013).

Since viruses are not cells, they cannot reproduce by division, therefore they propagate in the living cell that they infect (Modrow et al., 2013; Rye et al., 2013). Viruses totally depend on these host cells, eukaryotic or prokariotic, because they are more complex metabolic structures that can allow them to develop their reproductive cycle (Gelderblom, 1996, López-García & Moreira, 2012)

- The infective cycle begins with a virus attaching to a host through a viral receptor, a particular surface molecule that therefore needs to be present on the host cell surface (Rye et al., 2013). This entails that only certain cells within certain species of hosts can be infected by the different viruses (Rye et al., 2013).

- Entry. The virion then enters the cell, injecting or releasing its nucleic acid (DNA or RNA), leaving the capside and the envelope outside (López-García & Moreira, 2012).

[29] https://ictv.global/taxonomy



- Replication and assembly. Once in the host cell, the viral genome undergoes a replication mechanism that depends on its own nature (Rye et al., 2013). Viral genomes can be either transcribed (in case of DNA) or act directly as mRNAs (in case of RNA) and then translated by the host cells, by relying on its machinery and energetic resources (López-García & Moreira, 2012; Rye et al., 2013). It is the viral mRNA then, that directs the cell processes to synthesize viral enzymes and capsid proteins (Rye et al., 2013). At the same time, new virions get assembled via viral genome replication: capsid proteins, in fact, will self-assemble spontaneously encapsulating viral genomes (López-García & Moreira, 2012).

- Egress. The novel infective particles produced will be released from the cell and be liberated into the host organism, where they repeat their replication cycle by infecting adjacent cells (Rye et al., 2013).

Animal (human) viral infections can have different types of outcomes.

1. Productive or lytic infection
   - The host cells lyses (is broken down or destroyed): this happen when a high number of virions are rapidly synthezed (assembled) and released (López-García & Moreira, 2012; Modrow et al., 2013).
   - Sometimes is can also happen an inapparent infection, because some viruses replicate without actually creating damage (new1)
2. Chronic infection
   - The host cell does not lyses, but it keeps producing low levels of progeny virions and remains persistently infected (Modrow et al., 2013).
3. Intermittent/laten infection
   a. the host cell incorporates the viral genome, creating a situation where the infection is in a latent state: it does not produce infectious particles until an external situation starts a new temporary lytic cycle again (López-García & Moreira, 2012; Modrow et al., 2013).

4. Nonpermissive infection: the cell is able to totally resist the infection (Strauss & Strauss, 2008b).
5. Nonproductive infection: the viral infections process is started but certain conditions block it irreversibly (Strauss & Strauss, 2008b).

Virus transmission

As pathogens, viruses in order to survive and further create progeny they must repeat the infection cycle in new hosts. Virus transmission, therefore, happens when a virus leaves an existing reservoir and infects a new one. When referring to viruses linked to human diseases, viral genome generally spreads from person to person, but in other cases it can also start from wildlife and then it is brought to humans (eg. Through bites of foxes, coyotes, skunks, raccoons, and bats) (Strauss & Strauss, 2008b).

Multiple routes are possible for virus transmission:

1.Droplets:

- It occurs when an individual comes in contact with respiratory droplets (aerosol) or mucus which contain the virus (Strauss & Strauss, 2008b).
- These droplets might be transmitted directly from one human to the other (eg- through coughing) or "indirectly", by the person touching contaminated fomites (eg. doorknobs or on a companion's hands) and then mucosal surfaces (eg. Eyes, nose) (Strauss & Strauss, 2008b).

2.Airborne:

- It occurs when air can disperse the virus, over long distances, because the infected particles are very small and can be suspended (Strauss & Strauss, 2008b)
- It occurs also when an infected individual is just "in presence" of a non-infected one (Strauss & Strauss, 2008b)
- Examples: foot-and-mouth disease (livestock), measles

3.Insect vectors:

- It occurs when bloodsucking arthropods act as vectors that bring the virus to a human host, after becoming infected by taking a blood meal from a viremic vertebrate (Strauss & Strauss, 2008b). Common intermediaries are mosquitos, ticks, midges (blood-feeding insects) (Strauss & Strauss, 2008b).
- Examples: West Nile virus, the equine encephalitis viruses, dengue virus, chikungunya virus, and zika virus. (arboviruses).

4.Fecal-oral:

- It occurs with the ingestion of contaminated food or water and continues the cycles once that it is excreted in feces or urine (Strauss & Strauss, 2008b).
- Examples: rotaviruses and the Norwalk like viruses (noroviruses), human hepatitis A (via contaminated produce or uncooked shellfish).
- Examples: upper respiratory tract and cause respiratory disease > influenza viruses, rhinoviruses (one of the common cold viruses), severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS) coronaviruses.

5.Contact with contaminated fomites:

- It occurs by an inanimate reservoir (eg. Food, soil, water) (Strauss & Strauss, 2008b)

6.Exchange of infected bodily fluids, tissues, or organs:

- It occurs when there is an exchange of bodily fluids (eg. through blood transfusions, use of dirty needles, trauma (bleeding), organ or tissue transplantation…) (Strauss & Strauss, 2008b)
- This category contains also transmission by sexual contact (warts in the genital area, semen or vaginal secretions) or artificial insemination (Strauss & Strauss, 2008b).
- Examples: HIV, HBV, and HCV (blood, semen or saliva). HIV also breast milk. Rabies virus (saliva). STDs. Ebola.

A virus does not limit to one transmission route: in fact, some infections can happen through multiple of them (Strauss & Strauss, 2008b).

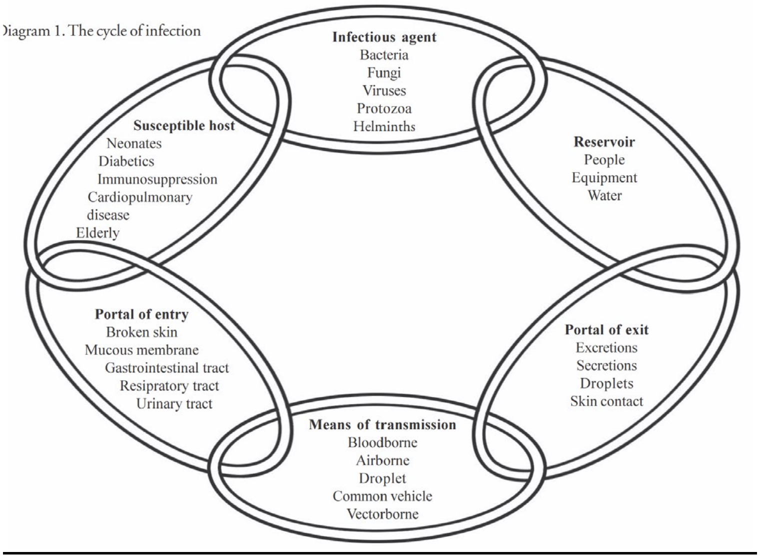


Figure 15 - The cycle of infection. Source: World Health Organization.

Infection outcomes

Virus infections in nature can happen to almost every living organism, from prokaryotic bacteria (the smallest and simplest of the cells), to plants and animals (López-García & Moreira, 2012).

The latter case directly refers to humans: animal viruses are, in fact, the cause of a wide variety of human diseases (Strauss & Strauss, 2008b). They can be grouped in three main categories:

– Acute disease. It begins rapidly (with the host showing increasingly worse symptoms), it can last from days to months. If the pathogen is controlled or cleared (eliminated by the immune system or with other methods), the host can recover from the infection. Otherwise the virus infections will bring to the death of the host (Rye et al., 2013; Strauss & Strauss, 2008b).

Examples are influenza, acute bronchitis, gastroenteritis, meningitis.

- Chronic disease. It is characterized by a timespan of years/lifetime, because it has a very prolonged progression, and could bring to the death of the host (Strauss & Strauss, 2008b).

Examples are tuberculosis, HIV/AIDS, Hepatitis B and C, Lyme Disease and Malaria.

- Latent disease. This kind of viral infection is also considered long-term and may last years. After showing clear symptoms on the host the viral genome remains “silent” in the body for a long time, appearing when the host’s immune system is impaired (Strauss & Strauss, 2008b).

Examples are Varicella-zoster virus, Human herpesvirus, TB, HIV/AIDS, syphilis.

2.4.3 Diseases Overview

To really understand the context revolving around infectious diseases and their specific implications, a thorough desk research was carried out on the most common infectious diseases, that are also the ones the startup’s devices are compatible with.

TRAVEL RELATED DISEASES

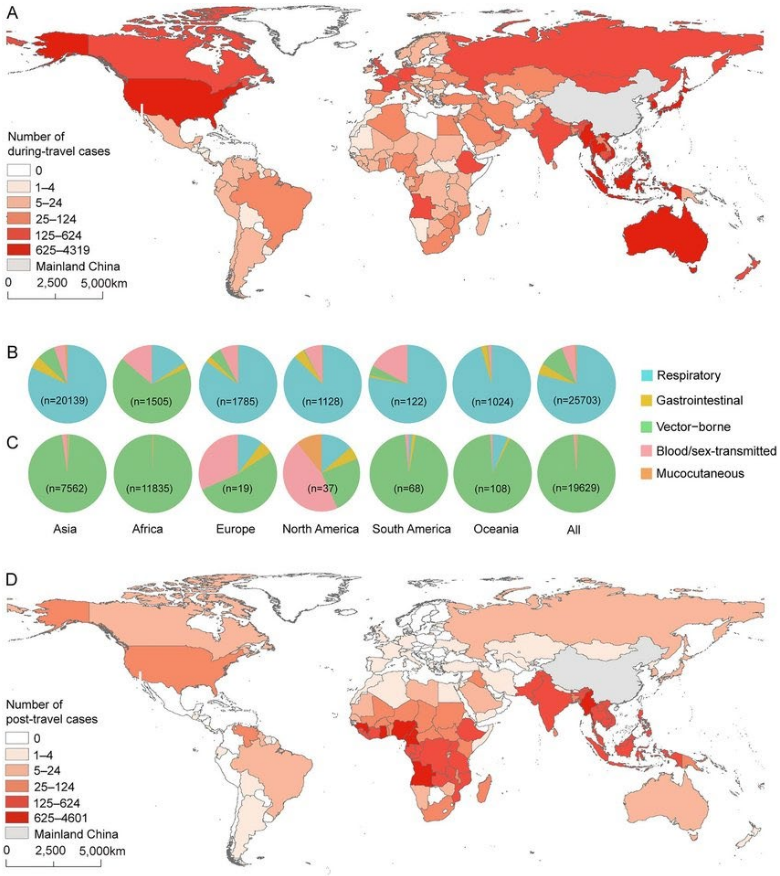


Figure 16 - Travel related diseases, numbers of infections. Source: Wu et al., 2020.

International travel has increased rapidly in recent decades, leading to an increase in the incidence and spread of infectious diseases across borders. According to a study published in the Journal of Travel Medicine, travelers account for approximately 40% of the global movement of infectious diseases (Leder et al., 2013). The transmission of infectious diseases, as presented in previous chapters, can occur during travel through various means such as direct contact with infected individuals, consumption of contaminated food and water, or exposure to insect vectors. The emergence and spread of new infectious diseases such as SARS, Ebola, and COVID-19 have further highlighted the potential for travel-related disease outbreaks (Heymann & Shindo, 2020), making it an important point of discussion. Understanding the link between travel and infectious diseases is in fact crucial for the prevention and control of outbreaks both domestically and internationally.

Travel-related diseases can have significant impacts on individuals, communities, and the global population, not only regarding health effects but significant economic consequences as well. Travel-associated infections can result in severe illness, hospitalization, and even death (Leder et al., 2013). Medical expenses associated with treating travel-related illnesses can be substantial, especially in cases where hospitalization is required. A study conducted by Park et al. (2023) found that the average cost of treating a single case of malaria in the US was almost $28,000. Similarly, the cost of treating other travel-related illnesses such as dengue fever and Zika virus can also be significant[30]. These medical expenses not only affect individuals but can also put a strain on healthcare systems in both developed and developing countries.

In addition to the direct health consequences, travel-related diseases can, in fact, also have wider economic impacts through lost productivity, and decreased tourism revenue (Wilson, 2003). In some cases, travelers may need to take time off work to recover from an illness, which can lead to lost income and decreased economic activity. For businesses, travel-related illnesses can result in decreased productivity and increased absenteeism among employees who travel frequently.

When outbreaks of infectious diseases occur in popular travel destinations, tourists may choose to cancel their travel plans, leading to decreased revenue for airlines, hotels, and other tourism-related businesses. For example, the 2003 outbreak of severe acute respiratory syndrome (SARS) in Asia resulted in an estimated $50 billion loss in global tourism revenue (R. Pine & McKercher, 2004). Also the COVID-19 pandemic, with its global consequences, has had a significant impact on the tourism industry, with many countries implementing travel restrictions and quarantine measures to prevent the spread of the virus (Heymann & Shindo, 2020).

According to the Centers for Disease Prevention and Control (CDC), the most common travel-related diseases are Malaria, Yellow fever, Typhoid fever and Dengue fever(Centers for Disease Control and Prevention (CDC), 2022). It is estimated that each year, there are 10 million cases of malaria in travelers[31] and over 10000 cases of dengue fever only in Europe (Gossner et al., 2022). Other common travel-related diseases include hepatitis A and B and measles.

The impact of travel-related diseases emphasizes the importance of frequent testing, other than taking preventive measures (vaccinations and proper hygiene practices) when traveling to reduce the risk of infection and transmission.

Malaria

Malaria, from the Italian “mala aria”, is an infectious disease which affects both humans and other animals, caused by the Plasmodium parasite group (White et al., 2014). This disease, despite being preventable and curable, is still life threatening in 2020, of the 241 million cases counted, the amounts of deaths reached 627 000 people[32].

[30] Cost of Zika Outbreak in the United States Could Be High | Johns Hopkins | Bloomberg School of Public Health (jhu.edu)
[31] Travellers' malaria (biomedcentral.com)
[32] Malaria (who.int)

Charles Laveran, in 1880, was the first one to officially identify the malaria microorganism, while Sir Ronald Ross in 1898, advanced the understanding of the diseases, by proving that is transmitted by some species of mosquitoes (White et al., 2014).

The areas in which Malaria is endemic are predominantly the ones nearer the equator and slightly higher latitudes (Bell et al., 2006), therefore making the tropical and subtropical regions of Africa (Sub-Saharan), Asia (South-East) and the Americas (South) the hot spots for the proliferation of the disease (White et al., 2014).

In the past Malaria was also endemic in Europe and North America (White et al., 2014), but these wealthier countries, such as the US, Italy, Greece and Spain, from the 1930s to the 1960s, carried out multiple eradication attempts and were able to reach a positive outcome, with the total elimination of malaria and a subsequent increase of socioeconomic development (Sachs & Malaney, 2002).

Nowadays, despite this disease being detected in more than 100 countries in the world (Bell et al., 2006), the higher morbidity and mortality of Malaria is still in the 32 countries located in sub-Saharan Africa, where about 93% of all malaria deaths globally happen(World Health Organization (WHO), 2022).

The extreme presence of the disease in these regions is linked to the own nature of it: since it is mosquito-borne, the environmental situation is the main driver of its development (Sachs & Malaney, 2002). Rainfall, consistent high temperatures and humidity found in some regions of the world create the ideal conditions (eg. Stagnant waters) for mosquito larves to grow and keep breeding (White et al., 2014), therefore making the exposure to mosquitoes perennial (Sachs & Malaney, 2002).

Malaria is transmitted from human to human mainly through the bite of a mosquito, the anophelene (Bell et al., 2006). The female exemplar can carry one of the four species of Plasmodium parasites (Bell et al., 2006) and, by taking a blood meal, disperses the pathogen through its saliva directly into the human circulatory system (White et al., 2014).

Transmission of plasmodium parasites can also occur from one person to another, since it lies in human red blood cells: organ transplant, shared use of needles and syringes and blood transfusions are the most common ways (White et al., 2014).

Multiple symptoms can transpire when a human is infected with the Malaria parasite, and some of them are in common with other well-spread infectious and non-infectious diseases, which makes it harder to efficiently diagnose (Rafael et al., n.d.). Symptoms, that will show 8–25 days following infection, can be fever and headache, but also decreased consciousness, significant weakness, convulsions and breathing problems (White et al., 2014). A high number of infection progress in very short time, bringing the person to a come and then death, while others will cause acute and severe illness, but not be fatal, or also become chronic (Bell et al., 2006).

This disease is considered a significant global health burden (Bell et al., 2006; Rafael et al., n.d.; Sachs & Malaney, 2002). Climate related situations (global warming and extreme weather events), large population movements, deforestation and careless agricultural practices are all factors increasing the spread and proliferation of Malaria (Sachs & Malaney, 2002). Rising cases worsen the already dire conditions of the health system infrastructures that are available in the most affected regions, which are some of the poorest in the world (Bell et al., 2006). Ulterior complications are brought by the fact that most of the drugs and insecticides used to counter this disease are losing efficacy (Sachs & Malaney, 2002), causing the ones that actually work to have outstanding prices and having entire communities rely only on rapid diagnostic methods (Rafael et al., n.d.).

Growing caseloads substantially impact the economic development of the regions, by impending it: health and healthcare expenditure creates severe problems for families and communities, especially the ones with lowest incomes, but also has effects on urban expansion and regeneration, trade, tourism, and foreign direct investment in production sectors (Sachs & Malaney, 2002).

Dengue

Dengue is mosquito-borne viral disease caused by one of four dengue viruses' serotypes (World Health Organization (WHO), 2021).

Each year 3.9 billion people are at risk of infection with dengue and an estimated 100-400 million infections occur, with a mortality rate of 0.8% to 2.5% (World Health Organization (WHO), 2020a).

Since this infectious disease is strictly linked with high density of urban population, the uncontrolled demographic rise of the latest years of specific regions has increased the frequency of dengue fever (DF) and dengue haemorragic fever (DHF) globally (World Health Organization (WHO), 2021), with a particular spotlight on low-income urban and peri-urban centres (Bhatt et al., 2013). Inadequate waste management, deterioration of health infrastructure and poor water supply management are exacerbating the situations, making Dengue a major public health problem (World Health Organization (WHO), 2020a).

Dengue has been for a long time in human history, but the first recorded outbreak was in 1897 in Australia, while the first confirmed epidemic was recorded in the Philippines in 1953-1954 (World Health Organization (WHO), 2020a).

The areas in which Dengue is present all year-round are countries in the Caribbean Basin and Puerto Rico, but also Argentina, Bolivia, Brazil, the Cayman Islands, Colombia and Paraguay (Centers for Disease Control and Prevention (CDC), 2021a). Major outbreaks have also taken place in the South-East Asia Region (India, Indonesia, Maldives, Myanmar, Sri Lanka, and Thailand), in the Western Pacific Region (Singapore, Cambodia, China, Laos, Malaysia, New Caledonia, Palau, Philippines, Tahiti and Vietnam) (Centers for Disease Control and Prevention (CDC), 2021a).

Also the Western Hermisphere has been touched periodically by Dengue: for example, it is present in an endemic form in at least 12 US countries (Centers for Disease Control and Prevention (CDC), 2021a).

Dengue is caused by a small, single-stranded RNA virus, which is transmitted by multiple species of mosquitoes to humans and other lower primates (World Health Organization (WHO), 2020a).

Currently no vaccines or other drugs for the prevention of Dengue exist (Bhatt et al., 2013). Moreover, despite numerous attempts to eradicate the diseases by extirpating the vector using chemical and biological means, no actual positive results were obtained (Tatem et al., 2006).

Dengue presence mainly manifests with a high fever, after 3 to 14 days after the human has been infected by the carrier (Centers for Disease Control and Prevention (CDC), 2021a). Other symptoms that can occur are headaches, myalgias, loss of appetite, nausea, vomiting and rashes (World Health Organization (WHO), 2021).

When a person is infected with one type of DENV and recover, becomes immune to that specific serotype forever, but can still be a subject for the other three remaining types (Centers for Disease Control and Prevention (CDC), 2021a). Some forms of the diseases can, instead, be extremely severe and bring to death (Centers for Disease Control and Prevention (CDC), 2021a).

COMMON

Monkeypox

Monkeypox is an infectious disease caused by one of the 10 known orthopoxviruses, which also generate smallpox (K. Brown & Leggat, 2016).

This disease emerged first in non-human hosts, in 1958, when a colony of laboratory monkeys was infected in Holland (Centers for Disease Control and Prevention (CDC), 2022b), while in 1970 it officially became a human virus, with the infection of an infant in the Democratic Republic of Congo (K. Brown & Leggat, 2016).

This virus is generally contained in tropical rain forests of the Congo basin (CB) and West Africa (WA) (human monkeypox) and previously to the 2022 outbreak, if found in other countries, was contained and related to international travel (CDC), 2022a).

It is not yet very clear how the initial infections occur: the Gambian pouched rat and rope squirrel are presented as the most likely subjects (Parker et al., 2007). From human to human this disease is spread through close, personal, often skin-to-skin contact (CDC), 2022a), since it is carried in exhaled large droplets, that are therefore incapable of remaining in the air for longer period of time (K. Brown & Leggat, 2016). It can also spread through touching objects, fabrics and intimate contact (eg. Sex, hugging, kissing) (CDC), 2022a).

The most common symptoms start with fever, fatigue and lymphadenopathy, headache (K. Brown & Leggat, 2016) to then develop acute skin rash or individual lesions (vesicles, then pustules and finally crusts) (Federal Office of Public Health (FOPH), 2022b) that start from the face and then spread over the body, reaching also oral mucosa, genitalia, and palms and soles (K. Brown & Leggat, 2016). Typically, monkeypox is considered a mild disease, though death can occur due to extremely virulent cases (K. Brown & Leggat, 2016).

Borrelliosis

Borrelliosis, also commonly known as Lyme Disease, is one of the most diffused vector-borne disease in the US and Europe (Centers for Disease Control and Prevention (CDC), 2021d). The former counts 476,000 cases a year, while the latter amounts to 200,000 (Marques et al., 2021). Endemic areas of Lyme Disease are, in fact, Europe (especially Scandinavian countries and Central Europe) and the United States, with New England, Mid-Atlantic states, Wisconsin and Minnesota as main hot spots (Shapiro, n.d.). The geographical constriction is mainly due to the fact that the species of thick which carries Lyme disease feeds of small mammals and ground-feeding birds native of these regions (European Centre for Disease Prevention and Control, 2018).

Lyme disease is caused by the bacterium Borrelia burgdorferi, transmitted to humans through the bite of an infected backlegged tick (Centers for Disease Control and Prevention (CDC), 2021d). In turn, the tick itself becomes a carrier when they feed of other animals with the pathogen in their blood (European Centre for Disease Prevention and Control, 2018).

When a human is infected and has Lyme Disease, the symptoms might be multiple and diverse. The most common include “erythema migrans”, rashes/skin lesions that appear from 3 to 30 days after the byte of the thick (Shapiro, n.d.), that expand gradually over several days (European Centre for Disease Prevention and Control, 2018) and fever, headache and fatigue (Centers for Disease Control and Prevention (CDC), 2021d).

In some other cases smaller rashes can develop, along with more severe factors, such as central nervous system disorder, facial palsy and meningitis (European Centre for Disease Prevention and Control, 2018). A later stage manifestation of the disease can also be arthritis (Shapiro, n.d.).

STDs

Sexually transmitted diseases or STDs are diseases caused by bacteria, viruses and parasites (World Health Organization (WHO), 2022b).

Currently, more than 30 different types of STDs are known (MedlinePlus, 2021c) and between them, eight are of relevance and have had a great impact in the last 50 years: syphilis, gonorrhoea, chlamydia and trichomoniasis (which are curable) and hepatitis B, herpes simplex virus (HSV), HIV and human papillomavirus (HPV) (which are not curable) (World Health Organization (WHO), 2022b).

In 2020, in the U.S. alone 2.4 million cases of STDs were reported[33], while worldwide the estimated infections reached 129 million for chlamydia, 82 million for gonorrhoea, 7.1 million for syphilis and 156 million for trichomoniasis (World Health Organization (WHO), 2022b).

STDs are spread from one individual to the other through sexual contact (eg. Vaginal, oral, anal sex), but occasionally also through other intimate physical, skin-to-skin contact (MedlinePlus, 2021c).

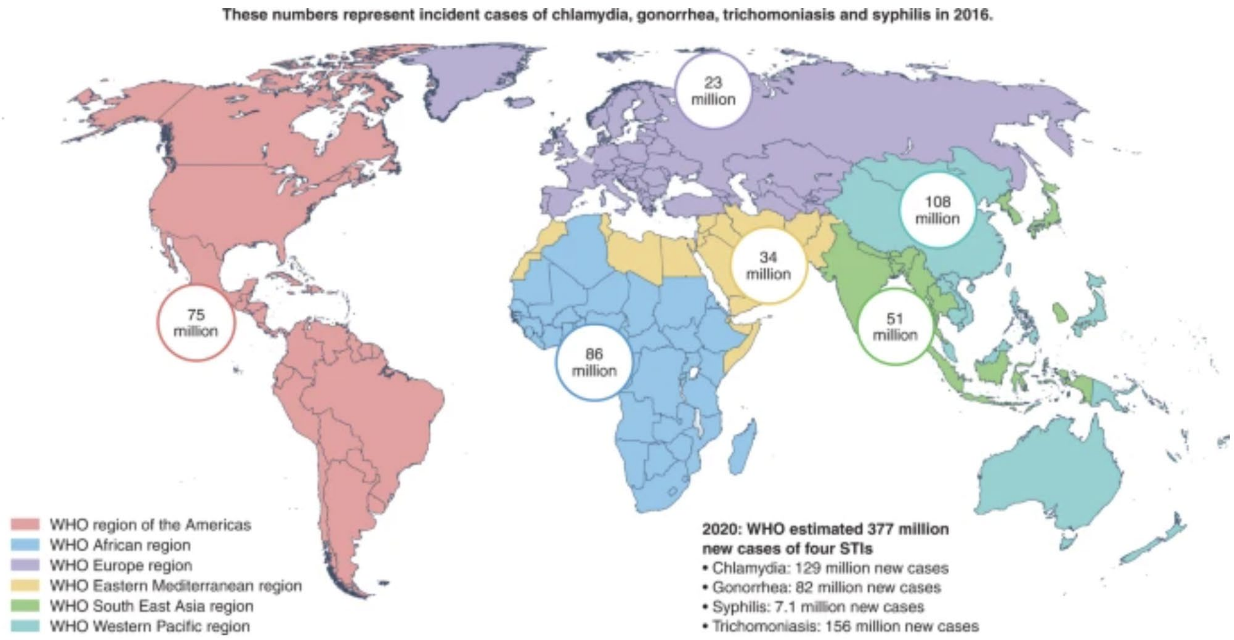


Figure 17 - WHO global regions and the incident cases of four STIs (chlamydia, gonorrhoea, trichomoniasis and syphilis) from 2016 estimates. Source: Gerwen et al, 2022.

Chlamydia

Chlamydia, an infection brought about by the bacteria Chlamydia trachomatis, is one of the most common STDs, which can infect both men and women (MedlinePlus, 2020). In 2020 it was the most common STD in the US, counting a total of 1,579,885 cases (Centers for Disease Control and Prevention (CDC), 2022a).

It is transmitted by having unprotected sex (sex with no condom) with an infected person (MedlinePlus, 2020), through contact with genital fluids (semen or vaginal fluid) (National Health Service (NHS), 2021a).

This disease might be present without symptoms, but still be passed to others (MedlinePlus, 2020). Common initial symptoms include abnormal vaginal or penis discharge, burning sensation when

[33] Announcement (cdc.gov)

urinating or pain during intercourse (National Health Service (NHS), 2021a), but they can worsen and reach abdominal pain, nausea and fever (MedlinePlus, 2020). Moreover, if not treated promptly and correctly it can lead to long-term health complications (National Health Service (NHS), 2021a).

Gonorrhea

Gonorrhea, also known as “the clap”, is an infectious disease of the genital tract, mouth, or anus brough about by the bacteria Neisseria gonorrhoeae or gonococcus (National Health Service (NHS), 2021b). It is the second most common STDs in the US and reports show that, since an historic low in 2009, cases have increased by 111% (Centers for Disease Control and Prevention (CDC), 2021).

As the other STDs, Gonorrhea is transmitted during vaginal, oral or anal sex (MedlinePlus, 2021) , because the pathogen is found mainly in penis or vaginal discharge (Centers for Disease Control and Prevention (CDC), 2021). It will infect the cervix, the urethra and the rectum, but occasionally also the throat and the eyes (National Health Service (NHS), 2021b). This disease can be transmitted from a pregnant woman to her baby and if not untreated, can lead the newborn to permanent blindness (MedlinePlus, 2021).

Similarly to other STDs, Gonorrhoea may not present any symptom (National Health Service (NHS), 2021b). The most common, though, are discharge from the vagina or the penis and pain when peeing (National Health Service (NHS), 2021b). Gonorrhea, if not treated leads to more serious complications, such as problems to prostate and testicles in the case on men, and pelvic inflammatory disease in women (National Health Service (NHS), 2021b).

HPV

Human papillomavirus (HPV) is a DNA virus, with more than 100 known genotypes, that infects skins or mucosal cells (World Health Organization (WHO), 2012).

Some of these genotypes are very common and do not cause any problem or symptom in people (Federal Office of Public Health (FOPH), 2022a), but at least 13 of them are known to be the cause of different kind of cancer (National Health Service (NHS), 2020) .

HPV is spread through direct sexual contact with an infected individual, or other skin-to-skin contact (MedlinePlus, 2021b). After contagion with low-risk HPV genotypes common symptoms are painless growths, lumps, warts around genitals, mouth or throat (MedlinePlus, 2021b).

DEVELOPING COUNTRIES

Infectious diseases also have a significant impact on developing countries, which often have weaker healthcare systems and limited resources to prevent and control the spread of diseases. The burden of infectious diseases in these countries is high, leading to increased morbidity and mortality rates, and hindering economic growth and development. For example, a study by Boutayeb (2010) found that communicable diseases such as malaria, tuberculosis, and HIV/AIDS are major contributors to morbidity and mortality in developing countries (Boutayeb, 2010). Additionally, these diseases can have a profound impact on healthcare systems and resources, further exacerbating the burden on these countries (Murray et al., 2014).

Many of these countries have limited resources and healthcare infrastructure, making it difficult to effectively manage and respond to outbreaks. Shortage of healthcare workers (both highly and less specialized) and little access to medical supplies, essential drugs and diagnostic tools are major challenges in managing infectious diseases, as well as limited hospital beds and adverse ambient conditions. This can further worsen the impact of infectious diseases, resulting in higher rates of morbidity and mortality.

Furthermore, infectious diseases can also impact the tourism industry in developing countries, which is often a significant source of revenue. Outbreaks of infectious diseases can lead to travel restrictions and decreased tourism, resulting in economic losses for the country. For example, the Ebola outbreak in West Africa in 2014 had a significant impact on the tourism industry in the affected countries, with estimates suggesting a loss of over $1 billion in revenue (World Travel & Tourism Council, 2018).

The impact of infectious diseases in developing countries is profound, with significant implications for healthcare systems and resources. Addressing these challenges will require a multi-pronged approach that includes improving healthcare infrastructure, strengthening healthcare systems, and investing in disease prevention and control programs.

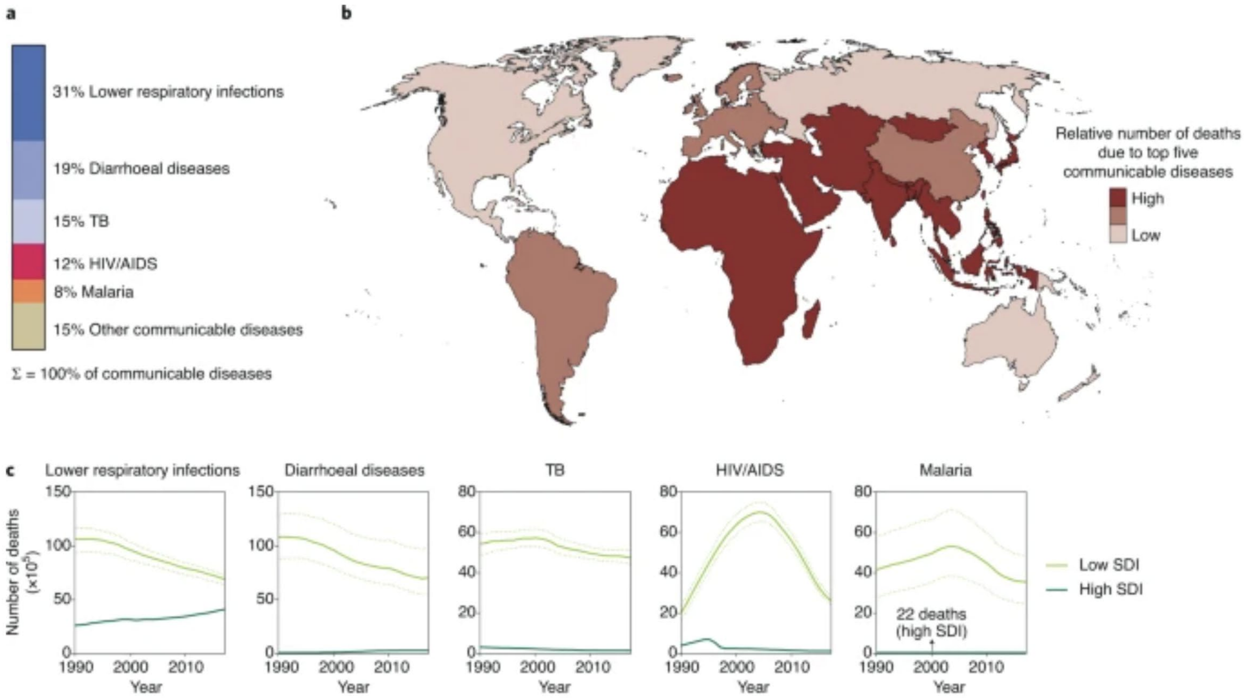


Figure 18 - Burden of IDs. Source: Kirtane et al., 2021.

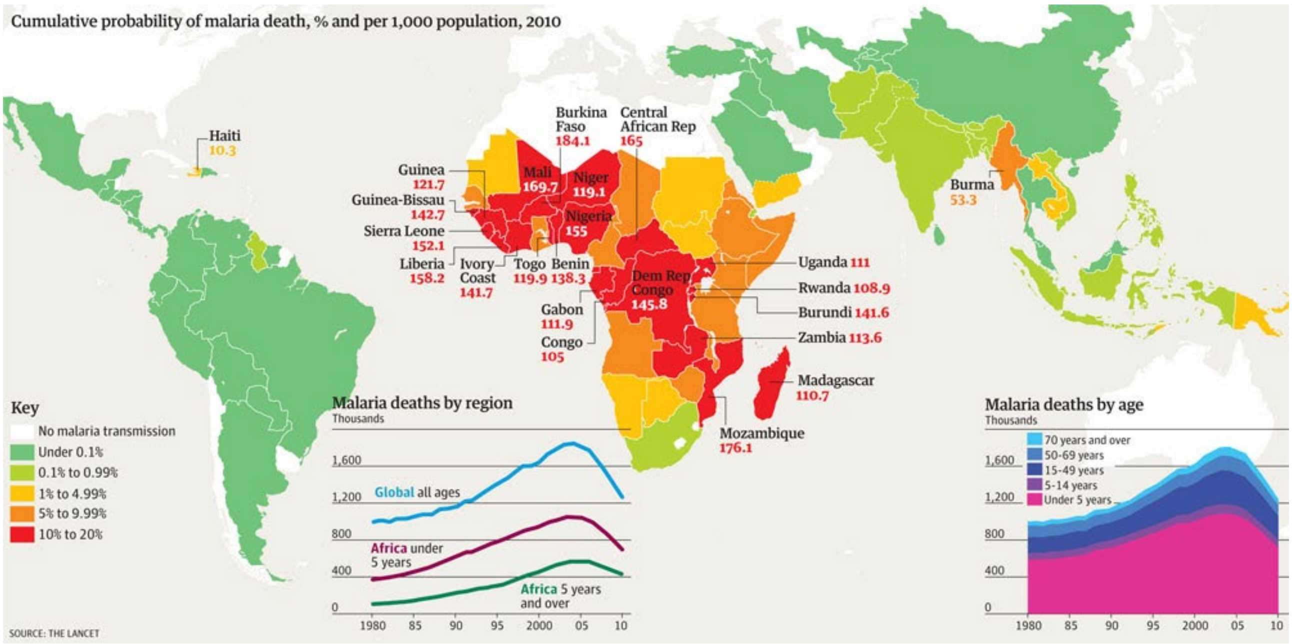


Figure 19 - Infectious diseases impact on developing countries: the case of Malaria. Source: The Guardian.

<u>*Schistosomiasis*</u>

Schistosomiasis is an acute and chronic parasitic disease caused by trematode worms and has been reported in 78 countries (World Health Organization (WHO), 2023).

Annually at a global level it is estimated that from 230 to 250 million people are infected and 280.000 individuals die because of it (Nelwan, 2019).

Schistosomiasis circulates predominantly in tropical and subtropical areas (World Health Organization (WHO), 2023). Endemic regions include Africa, the Caribbean islands and Asia (Southern China, Philippines, Laos) (Centers for Disease Control and Prevention (CDC), 2021b). Despite it being present in many countries, 90% of the infected are focused in African countries (World Health Organization (WHO), 2023). Schistosomiasis, in fact, mainly emerges in situations where there is frequent contact with freshwater, but also in locations where adequate sanitation is not present or water-based developments (such as dams and irrigations) in rural areas are not following proper techniques (Nelwan, 2019). This disease can also be spread in non-endemic countries, mainly by big movements of populations, such as immigrations and refugees flows (Nelwan, 2019).

Transmission of this disease happens through a vector, a parasitic worm, when human skin enters in contact with infected freshwater (Centers for Disease Control and Prevention (CDC), 2021b). Water can be contaminated either by some species of snails, which release larval forms of the parasite, or by other individuals who already have Schistosomiasis, through their bodily fluids or stool, which contain eggs that will hatch in the water itself (World Health Organization (WHO), 2023).

By swimming, bathing or wading into infested water the parasite can penetrate a person’s skin and subsequently mature and continue their reproduction into human blood vessels (World Health Organization (WHO), 2023).

Main symptoms of Schistosomiasis are fever, headache, myalgia, rashes and other respiratory problems (Nelwan, 2019). Repeated infection of this disease can bring an individual, especially children, to develop additional diseases and conditions, such as anemia, malnutrition and learning difficulties, other than create complications to other organs (mainly liver, intestine and lugs) (World Health Organization (WHO), 2023).

Despite not having a high death rate Schistosomiasis is still considered a relevant burden. The negative economic and health effects caused by this disease (such as development of disabilities and other severe illnesses, like HIV and paralysis) mostly affect poor, rural communities and their female and younger portions of the population, but also other regions and countries, due to migrations, populations movements, urban expansions and “off the beaten track” tourism (World Health Organization (WHO), 2023).

Zika

Zika is an infectious disease linked to a newly emerging mosquito-borne pathogen, part of the same genus as Dengue, West Nile and Yellow fever (Noorbakhsh et al., 2019), that was declared a Public

Health Emergency of International Concern by the World Health Organization in 2016 (Gulland, 2016).

The Zika virus was first isolated in 1947 in the Zika Forest of Uganda in a non-human host and for the subsequent 70 years remained dormant (Petersen et al., 2016). It remerged, suddenly, in 2007 with a 5000s infections' outbreak in the State of Yap (Federated States of Micronesia) (Duffy et al., 2009) and ensuing ones in other territories of the Pacific, between 2013 and 2014 (European Centre for Disease Prevention and Control, 2019).

After these geographically limited events, the situation worsened when, in early 2015, Zika emerged virulently in Bahia, Brazil (European Centre for Disease Prevention and Control, 2019) where the suspected cases reached 1.3 million (Petersen et al., 2016). This outbreak then spread along Central, South and North America (Noorbakhsh et al., 2019), reaching 33 countries and territories by March 2016 (Petersen et al., 2016).

From an epidemiologic point of view, therefore, Zika had its roots in East Africa, to then span to West Africa and Asia (Noorbakhsh et al., 2019). Only after it appeared as a new important human pathogen (Noorbakhsh et al., 2019), with a total of 84 countries reached worldwide (Baud et al., 2017). Today it poses as a particular threat to other regions of the world, such as the Eastern Mediterranean, due to the weakness of the health systems and disease surveillance systems (Noorbakhsh et al., 2019).

The Zika virus, being a Flavivirus, is originally spread through arthropod vectors (Noorbakhsh et al., 2019), meaning through bites of Aedes mosquitoes (Centers for Disease Control and Prevention (CDC), 2019) that have taken a blood meals from infected nonhuman primates (Petersen et al., 2016). In urban and suburban environments other than by mosquito bites, it can also be transmitted from other humans, mainly via sexual intercourse and blood transfusion (Centers for Disease Control and Prevention (CDC), 2019), but also during pregnancy from the mother to the fetus (Petersen et al., 2016).

The presence of this pathogen in the human body is shown mainly through an acute, febrile disease (European Centre for Disease Prevention and Control, 2019), with other common symptoms such as rashes, headaches, joint pain, red eyes and muscle pain (Centers for Disease Control and Prevention (CDC), 2019), but also vomiting and edemas (Petersen et al., 2016). One of the most critical aspects related to the diffusion of Zika virus it is that it creates serious and life-threatening congenital syndromes if a foetus is infected by the mother while pregnant (Baud et al., 2017).

Ebola

Ebola virus disease (EVD) is a rare and deadly diseases (Centers for Disease Control and Prevention (CDC), 2018), caused by Ebola virus (EBOV), one of the seven strains of filoviruses part of the genus

Ebolavirus (Jacob et al., 2020). Its recorded fatality rate is generally considered high and it can span from a 25% to a 90% (World Health Organization (WHO), 2022a).

It origin it is not yet clear (Centers for Disease Control and Prevention (CDC), 2018), but it is suspected that the virus, being a zoonotic pathogen, was maintained in the usual reservoir species, bats (Feldmann et al., 2020) and had a subsequent spill over into human through bats themselves or other infected animals (Centers for Disease Control and Prevention (CDC), 2018).

In 1976 Ebola was first discovered near the Ebola River in the Democratic Republic of Congo (World Health Organization (WHO), 2022a), with subsequent multiple outbreaks in African countries, mostly in remote villages of the central region, which are close to the tropical rainforests (World Health Organization (WHO), 2022a).

Totally, as of today the recorded amount of Ebola outbreaks where 43 (Jacob et al., 2020), most of which located in African regions close to the equator (central, western Africa) (Feldmann et al., 2020). Areas such as the Democratic Republic of Congo and Gabon are considered the main hot spots where, for example, human infections, between 2013 and 2016, reached numbers as high as 28,652 with 11,325 deaths (Jacob et al., 2020).

Initial transmission of Ebola virus happens via zoonotic route, meaning a human coming in contact with an infected animal (eg. Bat of nonhuman primate) (Centers for Disease Control and Prevention (CDC), 2018). Then the spread continues with a human-to-human link (Jacob et al., 2020). This second stage transmission occurs mainly when an individual comes into direct contact with a person sick or dead by EVD (Centers for Disease Control and Prevention (CDC), 2018) or with some of their infected tissues, bodily fluids (eg. breast milk, saliva, urine, semen, blood, tears, stool) or contaminated fomites (eg. Bedding, clothing) (Jacob et al., 2020). The spread of Ebola virus, in fact, start with the viral particles deposits themselves on mucous membranes (Feldmann et al., 2020) or penetrate the body through microscopic dermal injuries or broken skin (Jacob et al., 2020) or also sexual contact with someone who has recovered from EVD (Centers for Disease Control and Prevention (CDC), 2018).

EVD has numerous symptoms, some of which are fever, fatigue, muscle pain, headache followed by vomiting, diarrhoea, rashes (World Health Organization (WHO), 2022a).

2.4.4 Testing typologies

As it is outlined in the previous chapter, different kind of infectious diseases exists in the world and are brought about by either viruses, bacteria, or parasites. As data shows, the transmission of these diseases from one person to the other, in multiple cases, can happen in an extremely easily and rapid way (Chen et al., 2019). This easiness of transmission makes them a great threat to humanity as a whole when presented with infectious diseases the first step to approach the situation is obviously to provide fast and efficient treatment to the individuals affected, in order to stop the infection and allow the patient to be cured (Khabbaz et al., 2015)

Before being able to provide the correct treatment, though, another step is necessary: the diagnosis of the disease itself. Without being able to identify properly a pathogen incursion, in fact, it is not possible to both deploy an accurate and “personalized” treatment and prevent further transmissions (Chen et al., 2019). Therefore, as it was introduced in the chapter 2, the diagnosis is fundamental, and it occurs only through testing. Testing that allows for a proper diagnosis in today’s highly volatile contexts must be sensitive, specific and rapid (Chen et al., 2019).

In the case of infectious diseases as it is shown in figure multiple typologies of testing have been developed and for most of the diseases these methodologies of detection are recurrent (always the same).

These diseases are, in fact, recognized through common biomarkers (Everitt et al., 2021).

Biomarkers are defined as “objective indications of medical state, observed from outside the patient, that can be measured accurately and reproducibly” (Strimbu & Tavel, 2010).

During an infection process, that eventually will generate an infectious disease as an outcome, a lot of different biological “actors/elements” are involved, such as molecules, cells, etc. Some of these “actors/elements” can be used as biomarkers to objectively detect and/or measure the presence, the process and the phase of an infectious diseases in an individual (Everitt et al., 2021).

Biomarker #1 → Pathogen nucleic acids

All the pathogens that generate an infectious disease (viruses, bacteria, fungi, parasites) as we have seen in the previous chapters, have nucleic acids, either deoxyribonucleic acid (DNA) or ribonucleic acid (RNA), as it stands at the basis of biology.

Pathogen nucleic acids can be used as a biomarker for the diagnosis of an infectious disease (Chen et al., 2019).

Different methodologies are used to detect this kind of biomarker. The most common are NATs (nucleic acid tests), such as PCR tests and isothermal amplification, such as RPA and LAMP (Everitt et al., 2021).

Biomarker #2 → Antibodies

Antibodies are "protective proteins produced by the immune system in response to the presence of a foreign substance (antigen). The antibody recognizes and latches onto antigens in order to remove them from the body" [34].

During an infection process the immune system generates a lot of antibodies, that can be therefore used as biomarkers for the detection of an infectious disease (Chen et al., 2019). The level of antibodies during an infection, though, it is not always the same. Only in some cases the levels reflect the stage of the infection in a consistent way (Chen et al., 2019). The most common methodology to detect the presence and the level of antibodies is through immunoassay testing (Chen et al., 2019).

Biomarker #3 → Pathogen proteins (antigens)

As explained in the scientific background, pathogens have proteins, such as the capsid and the envelope proteins. They also can be utilized as biomarkers to detect infectious diseases (Chen et al., 2019). The most common methodology to detect the presence and the level of antigens is through immunoassay testing (Chen et al., 2019).

The test typology, therefore, depends on which biomarker is the most suitable to obtain an accurate detection of a specific disease. However, the golden standard to detect infections remains the nucleic acids amplification test (PCR/RT-PCR) (Everitt et al., 2021).

Regardless, Point-of-care (POC) testing has become increasingly important in the context of infectious diseases, as it allows for rapid diagnosis and timely management of patients. As explained in the previous dedicated chapter POC testing (for infectious diseases) has the potential to improve patient outcomes and reduce healthcare costs, by enabling healthcare providers to make quicker and more accurate diagnostic and treatment decisions.

Testing to be performed at the site of patient care, such as in a doctor's office, clinic, or hospital ward can greatly help to reduce turnaround time for test results, enabling healthcare providers to quickly diagnose and initiate treatment for patients with infectious diseases (Larsson et al., 2015). Rapid diagnostic tests, such as rapid antigen tests for influenza or SARS-CoV-2, can provide results in as little as 15-30 minutes, allowing for prompt management of patients and effective infection control measures to be implemented (Azzi et al., 2021).

Another advantage of POC testing for infectious diseases is that it can improve patient outcomes by enabling targeted treatment. For example, rapid molecular tests for sexually transmitted infections such as chlamydia and gonorrhea can provide same-day results, allowing for timely treatment and reducing the risk of complications such as pelvic inflammatory disease and infertility.

[34] Antibody | Definition, Structure, Function, & Types | Britannica

POC testing can also be useful in outbreak situations, such as in the case of a rapidly spreading infectious disease like Ebola or COVID-19. In such situations, POC testing can help to identify infected individuals quickly, enabling isolation and containment measures to be implemented promptly, which is crucial in reducing the spread of the disease.

POC testing for infectious diseases is an important tool for infectious diseases control, offering a range of benefits in terms of speed, accuracy, and patient outcomes.

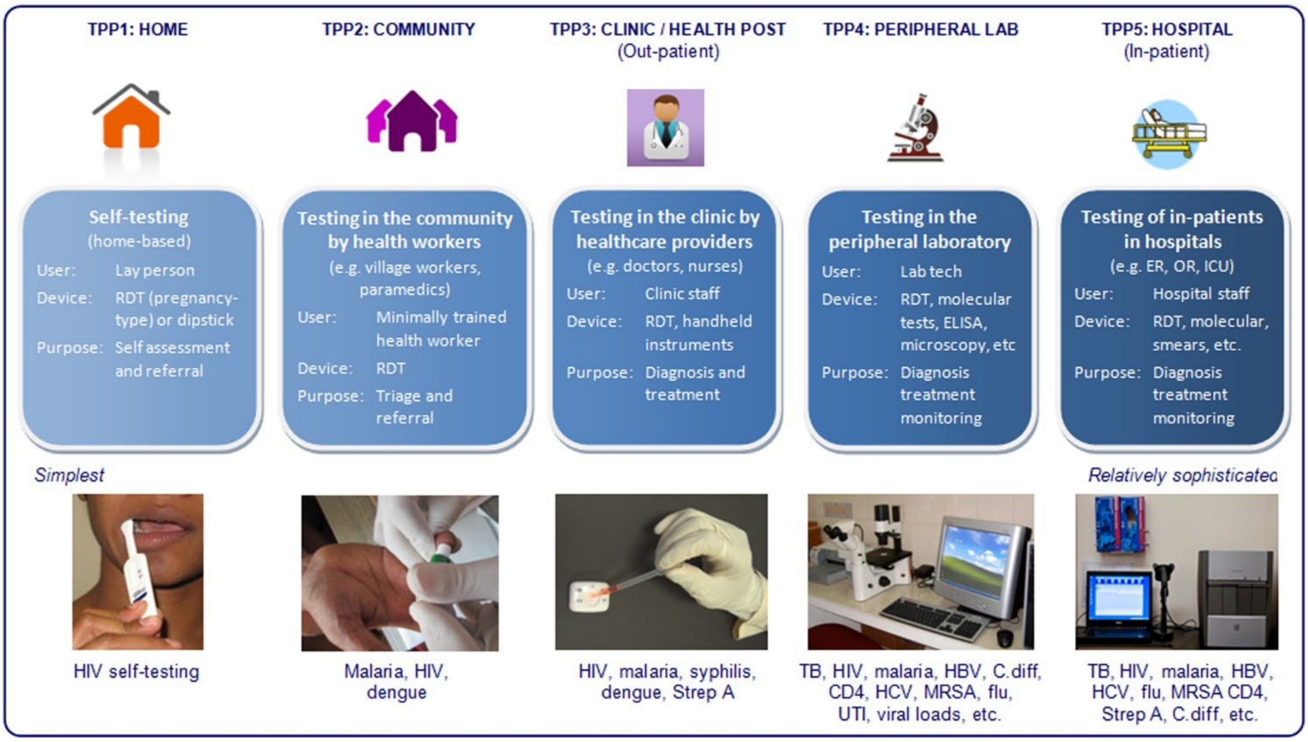


Figure 20 - Diversity of target product profiles, users, and settings within the spectrum of POC IDs testing. Source: Pai et al., 2012.

2.5 Diaxxo

2.5.1 Introduction

Diaxxo^{TM} ["Diaxxo" shortened] is a swiss medtech start-up focusing on diagnostics, founded in November 2020 by Michele Gregorini and Philippe Bechtold. Diaxxo was born as a spin-off of ETH (***E**idgenössische **T**echnische **H**ochschule)*, the Swiss Federal Institute of Technology in Zürich, and it is linked to its Laboratory of Functional Materials.

The startup's founders initially developed and prototyped an innovative Polymerase Chain Reaction (PCR) technology from which a series of products was subsequently generated.

<u>VISION</u>

“We envision a future where precise and reliable diagnostics can be accessed anywhere by anyone. We believe that thanks to our Point-Of-Care PCR tests, doctors will be able to identify and fight diseases faster, and experts will be able to perform much DNA analysis in a shorter time.”

Their vision is to bring the power of molecular diagnostics to every doctor’s office and clinic, through their devices which facilitate procedures, such as the new pre-loaded PCR test kits that allow for simpler and faster sample preparation steps.

MISSION

“Our mission is to enable DNA analyses to be widely diffused and adopted by professionals by manufacturing accurate, fast and effective POC devices at low cost.”

During 2020 their devices have been used by more than 250 laypeople for the rapid detection of COVID-19 in a field study that we ran at ETH Zürich, and their systems are currently being tested at the Swiss Tropical and Public Health Institute (Swiss TPH) and at the Tierspital Zürich. Several medical doctors have already expressed interest in their technology, and they are now working towards the In Vitro diagnostic (IVD) certification.

During 2021, diaxxoPCR was used in a project funded by the *Swiss National Science Foundation* to diagnose S. haematobium infections in individuals with mostly very light intensity infections in Zanzibar.

Diaxxo’s technology was implemented as novel diagnostic tool for surveillance-response in Point-of-Care settings. In as many as 15 low-endemic communities, school children have been tested with diaxxo’s rapid PCR technology, with a throughput of up to 500 children per day.[35]

This disruptive and unique project presented many challenges, such as the use of new equipment and material, IT, logistics, electricity supply and training of the local staff.

Value proposition

- Symptoms-to-therapy in one doctor’s appointment.

- New on-site diagnostic service.

- Broader access to top-standard diagnostic (decentralization).

[35] https://diaxxo.com/news/diaxxo-fighting-schistosomiasis-in-zanzibar/

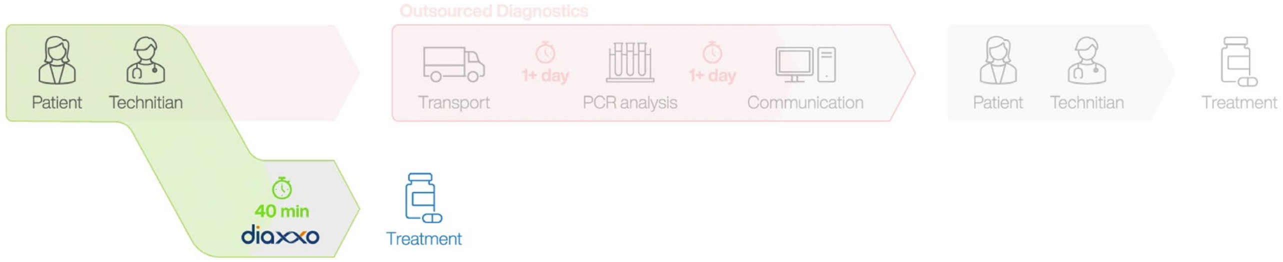


Figure 21 - Diaxxo's value proposition. Source: Diaxxo.

<u>Business model</u>

Based mostly on the consumables, the start-up produces and sells its own reagent kits (and pre-loaded or empty cartridges). The robots are sold for a low price or alternatively given for leasing.

<u>Assets</u>

Diaxxo is linked to the Functional Material Laboratory of ETH Zurich, and therefore it relies on its equipment. Aside from traditional and basic tools, the laboratory is equipped with CNC (**computer numerical control)** machinery, such as three axis milling machines and 3D printers (FDM and SLS). Moreover, the ETH Hönggerberg campus (where Diaxxo's offices are located) hosts workshops, and a specialized hardware store, where it is possible to produce single pieces for testing in a short time in-house without relying on external facilities.

2.4.2 The products

Multiple products are currently being developed and tested by Diaxxo.

<u>diaxxoExtractor</u>

DiaxxoExtractor is a DNA/RNA extraction device that processes a variety of samples (swabs, saliva..) with state-of-the-art magnetic beads extraction methods. It combines a simple workflow with a medium throughput (8 samples per run). Laboratory personnel or other operators can open the extraction cartridge package, load 8 individual samples into the cartridge, insert into the extraction device and press start.

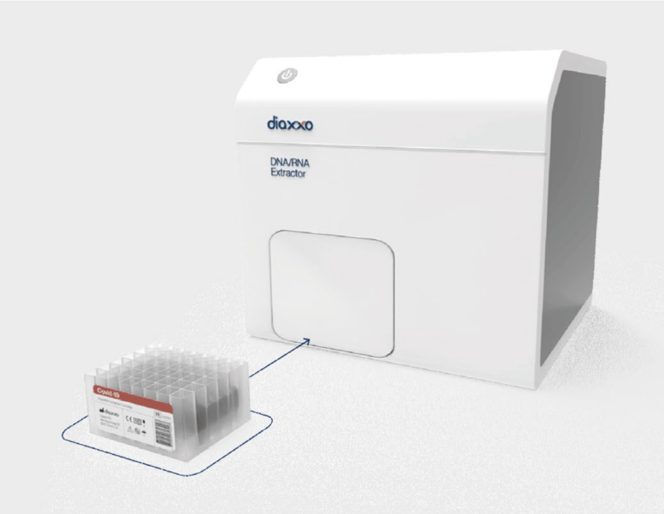


Figure 22 - DiaxxoExtractor. Source: Diaxxo

diaxxoPCR

The diaxxoPCR is the main product of the company. It is a fast, economical and resource-efficient device that run a Polymerase Chain Reaction (PCR) for DNA analysis. Its processing time is minimized thanks to the aluminium-alloy-bottomed cartridge, patented).

It provides a result in less than 30 minutes, with costs between 20-40 CHF per test and is as reliable as an external laboratory. Additionally, the cost of the overall machine is less than 2k CHF or can be given for leasing. Compared to the competitors, peakPCR's performances are unprecedented: other competitors' thermocyclers (RocheTM, e.g.) can detect the SARS-CoV-2 in ~ 1 h, 30 min, peakPCR takes only 25-30 min.

Thanks to the technological innovation of the machine this device is able to give the results directly to the patient in record time, while the traditional waiting time for a molecular test for SARS-CoV-2 is ~2 days, since the clinics still rely on external laboratories for the processing of the biological sample.

It features a very simple workflow: the medical personnel has to simply load the dedicated cartridge (diaxxoPod) into the machine, select the desired experiment and run it. The results will be displayed on the machine itself as soon as they are ready.

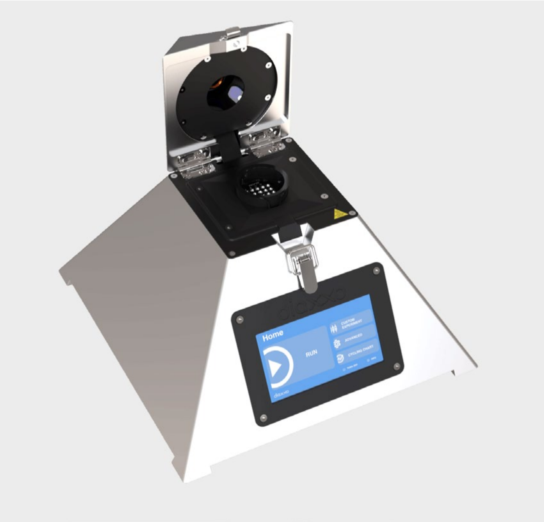


Figure 23 - DiaxxoPCR. Source: Diaxxo

diaxxoPod

The diaxxoPod is a patended in-vitro diagnostic test cartridge based on rapid Polymerase Chain Reaction (PCR) amplification technology, which contains all reagents pre-loaded in dry form.

It offers different advantages:

- Shelf-life at room temperature, no cold chain, no need for a fridge.

- Short amplification time (<30min).

- High throughout: 1 to 18 tests in parallel.

This cartridge is designed ad hoc to fit with diaxxoPCR and its workflow. In fact, the operator can load the samples directly onto diaxxoPod, load the control and cover fluid onto diaxxoPod and finally place it inside diaxxoPCR.

Figure 24 - DiaxxoPods. Source: Diaxxo

As of today, other than general purpose pods, the startup produces pre-loaded cartridges with the reagents needed to detect: SARS-CoV-2, SARS-CoV-2 variants, Dengue, Malaria, Schistosomiasis, Borrelliosis, Monkeypox, Avian, STIs,

With this kind of DNA/RNA analysis and consumables it is possible to design specific diagnostic tests and distinguish even amongst diseases that present similar symptoms. Moreover, each parallel test runs independently inside the cartridge giving specific and accurate positive/negative results.

diaxxoRod

It is a rapid and cost-effective nucleic acid extraction method for a wide variety of applications.

Shape and form allow a simple, rapid, and instrument-free procedure, that takes only three minutes. The purified nucleic acids can be used in downstream such as RT-qPCR.

These characteristics make it a viable solution for remote testing facilities and field laboratories allowing to extract nucleic acids from hard-to-lyse biological samples in a very fast and efficient way. No electricity required, external equipment or infrastructure are required and it is also low weight.

Figure 25 - DiaxxoRod. Source: Diaxxo.

<u>diaxxoSwab</u>

Similarly to diaxxoRod, diaxxoSwab is a rapid and cost-effective nucleic acid extraction method for a wide variety of applications, that brings state-of-the-art nucleic acid purification to remote testing facilities and field laboratories. The kit is designed to require no external electricity or infrastructure, making it an ideal option for settings with limited resources.

It is comprised of a small package with eight extractions, each allowing for the rapid extraction of nucleic acids from a sample. The workflow is simple and streamlined: the sample is collected by the operator using a diaxxoSwab, which is then inserted into the kit. The aluminium cover is pierced using a puncher, and the swab is stirred inside the reagents. The entire process, from sample-to-extracted nucleic acids, takes only three minutes, enabling rapid and efficient testing of infectious diseases.

Figure 26 - DiaxxoSwab. Sources: Diaxxo.

2.5.2 Current developments

Despite the innovative characteristics and wide possibilities of application and implementation brought about these products developed by Diaxxo, there still is a big limitation: constant human intervention. In fact, the platform and the single products require the presence and actions performed by a person, whether they be a trained laboratory personnel, a doctor, a nurse or an operator. Moreover, this fact also influences the actual times of processing: humans, prone to errors and unplanned issues, can make the overall procedure take longer than expected. The next ambitious achievement for diaxxo is to develop, then, a fully automatic platform, capable of managing without human intervention both the extraction and the DNA amplification, simplifying even more the workflow. This new product, diaxxoCare, has been in the workings for more than a year and it presented multiple automation and mechanical challenges, as well as the creation of new and ad hoc consumables that allow a smooth and efficient process and a reliable result.

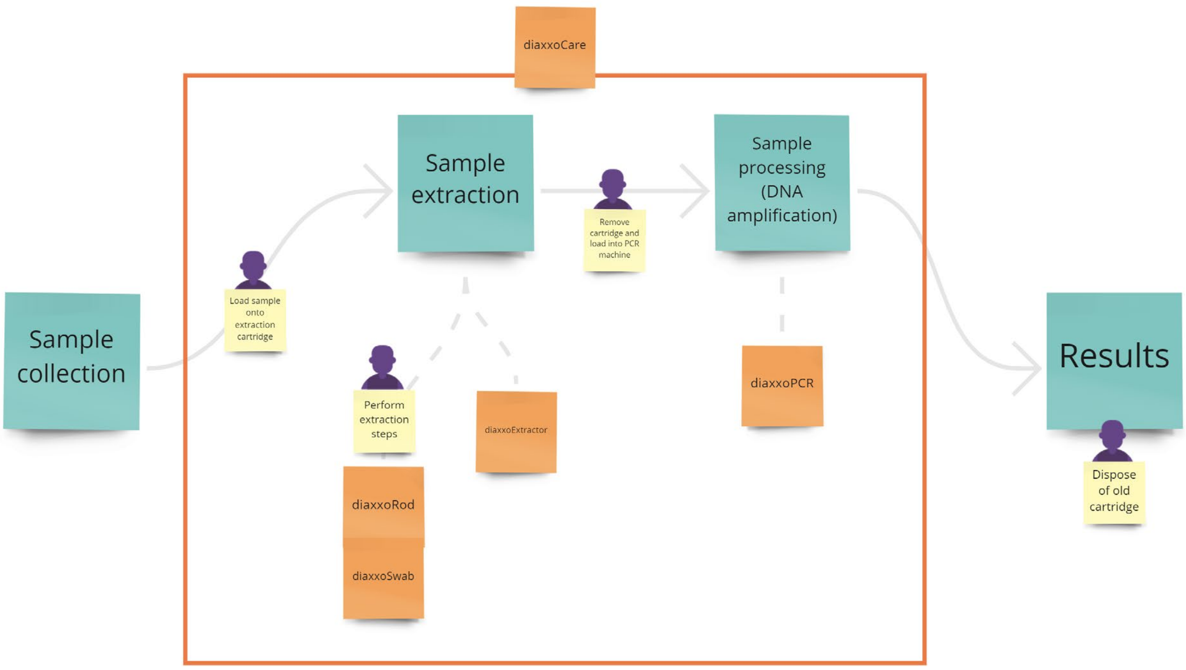


Figure 27 - Overview of Diaxxo's products.

It is exactly from the diaxxoCare vision and potential of implementation of this new device that this project was born.

3. DISCIPLINARY BACKGROUND

3.1 Service Design

3.1.1 Introduction

Before delving deeper into the discipline of Service Design, a brief overview of the practical and theoretical foundations that allowed it to develop will be outlined.

Today services account for the majority of economic activity in many countries around the world[36]: they are essential to our society and play a vital role in our daily lives and well-being. It is easy for us now to recognize their own raison d'etre, their characteristics, and their impact, and therefore also possibly understand the potential and importance of Service Design.

Service Design is as a fairly recent discipline (Moritz, 2005), as services themselves were only lately conceptualized by scholars (Foglieni et al., 2018b).

[36] https://ec.europa.eu/eurostat/databrowser/view/nama_10_gdp/default/table?lang=en

Economy (both in theory and practice) has, in fact, for the most part of its history, focused on material goods and their exchange (Vargo & Lusch, 2004). Services only started to be mentioned and more intentionally considered as a “third” possible field of economy starting only from the post-World War II era (Baumol, 1967). Increasing automation, changes in work and labor, and a renewed focus on knowledge and information, led to a gradual shift away from sole manufacturing of products (Bell, 1976).

During this period, a significant societal shift was underway: the emergence of the service economy. Coined by economist Victor Fuchs in his 1968 book "The Service Economy", this term refers to an economic system where the majority of economic activity focuses on the production and delivery of services, rather than physical goods. Fuchs predicted that the service sector would eventually become the dominant sector of the economy in the United States and other developed countries, driven by rising incomes, increasing levels of education, and changing consumer preferences.

The growing importance and focus on services sparked the emergence of new theoretical disciplines, including service marketing and service management, which delved into the emerging concept of "service" and its evolution (Foglieni et al., 2018). Their work eventually formed the foundation on which Service Design gained criticality.

Until the 21st century in these service sciences (and in practice), it was common to refer to services as “intangible products” or “add-ons” to material goods, a definition that implied a sort of subordination of services compared to such tangible goods (Lusch & Vargo, 2014). Other key aspects were outlined over time by scholars to characterize additionally the different nature of services, eventually creating what we now can call the HIPI paradigm (Edvardsson et al., 2005; Foglieni et al., 2018b; Lovelock & Gummesson, 2004).

Four main characteristics emerged as the most frequently used to describe services: intangibility, inseparability, heterogeneity, and perishability (Zeithaml et al., 1985). The concept of service continued to evolve, with various interpretations being proposed, gradually establishing services as fundamentally different from goods (Shostack, 1977).

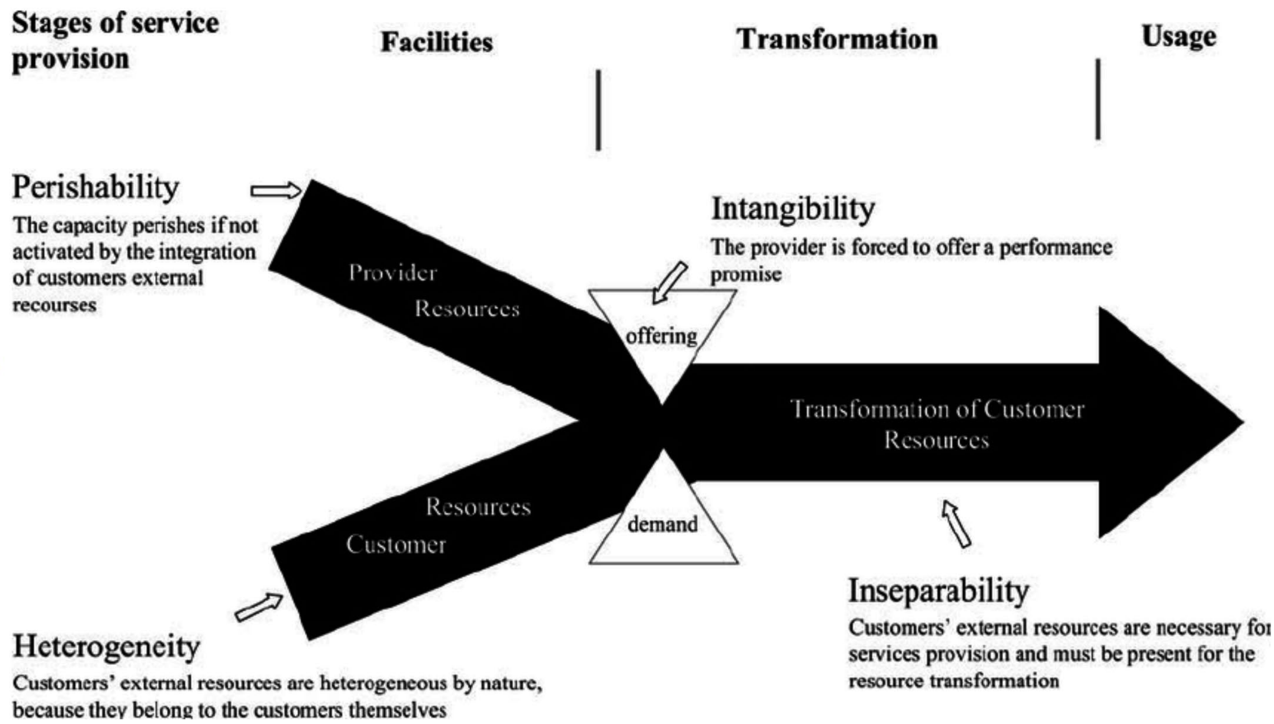


Figure 28 - Services and the IHIP model. Source: Moeller, 2010.

In the 1990s, service sciences became established disciplines, and their prolific research explored topics that formed the foundation for Service Design, such a as the definitions of services as performances, as a set of offerings, as a process, as a system or as an interface. Others, instead, proposed the impossibility to "structure" services in the HIPI framework alone (Lovelock & Gummesson, 2004) . Finally, concept such as servitization (Vandermerwe & Rada, 1988), servuction[37] and product-service system (Mark Jacob Goedkoop et al., 1999) started to emerge (Foglieni et al., 2018).

Some years later, this continuous evolution was upturned by with the introduction of the "Service-Dominant Logic" in opposition to the traditional "Goods-Dominant Logic" (Lusch & Vargo, 2014; Vargo & Lusch, 2004, 2008). This perspective presented a significant shift in the way services were conceptualized, leading to new implications for businesses and organizations and emphasizing the importance of services even further.

The Service-dominant logic (SDL) is a framework for thinking about the nature of value creation, proposed by Stephen Vargo and Robert Lusch in 2004. It states that economic activity is fundamentally service-based, and the focus of business should be on creating value through

[37] Eiglier P, Langeard E (1987) Servuction. Le Marketing des services. Wiley, Paris

relationships - the actual exchange process of goods and services from producers to consumers - rather than simply “selling” products or services (Lusch & Vargo, 2014; Vargo & Lusch, 2004).

The traditional view of value creation (based on firms creating products and services and then selling them to customers) was substituted by a new paradigm, the one of "co-creation," where customers are no longer passive recipients of products and services, but active contributors to their design and delivery (Prahalad & Ramaswamy, 2004).

Moreover, SDL also emphasizes the importance of understanding the customer's needs and preferences, and designing services that meet those needs (Vargo & Lusch, 2004).

At the same time, also the concept of a post-industrial society continued to grow in the decades since its inception and finally morphed into what we now call the “experience economy”. In a 1998 article, Joseph Pine and James Gilmore argued that economic value was shifting from pure goods and services the experiences they could provide to users (Pine & Gilmore, 1998). According the two scholars, experiences are more memorable, more emotional, and more authentic than basic products or services, and therefore have the potential to create greater customer satisfaction and loyalty.

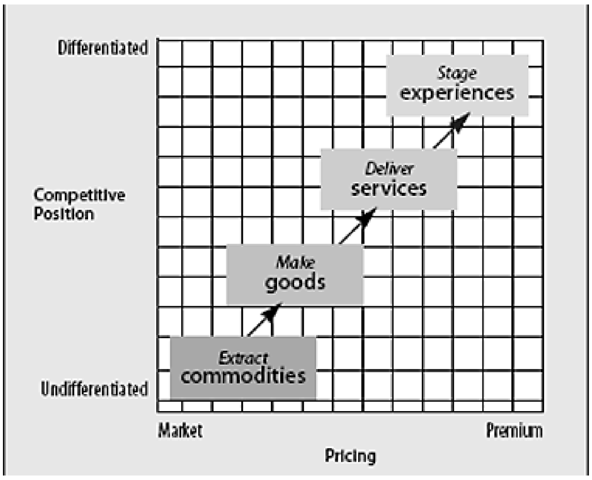


Figure 29 - Progression of economic value, proposed by Pine & Gilmore (1998).

Addressing service quality and customer satisfaction (Foglieni et al., 2018b), understanding and meeting the needs and desires of customers, collaborating with them to co-create value and orchestrate exceptional service experiences has become, then, a key priority and focus of all businesses, for them to differentiate themselves in the marketplace (Bitner et al., 2008).

Therefore, these fundamental concerns and challenges were some of the key drivers of Service Design, as they require a comprehensive and consistent understanding of how to effectively approach the design of services to achieve the desired outcomes.

The first official use of the term "Service Design" is attributed to Lynn Shostack, who used it in the 1982 article in the Harvard Business Review, "Designing Services That Deliver"[38]. However, this mention was still connected to service sciences research, as wells as some of the first foundational methods and tools which were subsequently developed, in the fields of service marketing and service management. Examples are service blueprinting (Bitner et al., 2008), customer journey mapping and Servicescapes (Bitner, 1992).

Only from the 2000s the practical application of these elements in service development and innovation, and especially in combination with a "design thinking" lens, brought Service Design to gain traction and finally become a field in its own right (Catalanotto, 2018), with dedicated academic courses, research and literature and design agencies (eg. Livework).

In recent years, an expanded and revised perspective on Service Dominant Logic (SDL), known as Service Logic (SL), has emerged and has played a crucial role in strengthening the theoretical foundations of Service Design (Foglieni et al., 2018b). SL places a strong emphasis on understanding the customer experience and creating positive experiences for customers as the key to success in service industries (Grönroos & Ravald, 2011). It highlights the importance of service quality and customer satisfaction (Grönroos & Ravald, 2011), as well as the need to understand the customer's perspective and context. SL suggests that value is created through a variety of interactions, experiences, and outcomes that occur throughout the service encounter (Grönroos & Voima, 2013). Additionally, SL recognizes the importance of customer engagement, ongoing dialogue and collaboration between service providers and customers, and the role of technology and other resources in facilitating value co-creation (Grönroos & Voima, 2013).

3.1.2 Nature and definition(s)

What is Service Design? In literature, no official and unified definition exists of this discipline. Service Design has been described in many ways and under multiple points of view, such as a mindset and a cross disciplinary language (Stickdorn et al., 2018), a field or approach (Blomkvist & Holmlid, 2010; Moritz, 2005; Ostrom et al., 2010; Patrício & Fisk, 2013), a mindset or approach (Sangiorgi et al., 2015; Foglieni et al., 2018b; Korper et al., 2020) or a process (Design Council, 2015) or set of activities[39].

The most common definition sees it as an emerging and creative approach that draws on an design thinking framework, to tackle the (re)design of service concepts (Korper et al., 2020; Moritz, 2005). Service Design has a particular focus on understanding user needs and preferences, in order to

[38] Designing Services That Deliver (hbr.org)
[39] Service Design: Study Guide (nngroup.com)

shape give shape to experiences that are “useful, usable, desirable, effective and efficient” (Moritz, 2005). In particular, this approach does not limit itself to the customer perspective only, but takes into consideration the plurality of actors involved, namely the customers, the clients, the employees, the business partners or other figures (Ostrom et al., 2010; Patrício & Fisk, 2013; Stickdorn et al., 2018).

Another important aspect of Service Design is the fact that it also foresees the definition of background operations, strategies and systems of the service that is being designed (Moritz 2005). It, therefore, works on different levels of orchestration (design of the service encounter, the service system and the service context) and addresses multiple service elements (such as touchpoints, cues and interactions, technologies, places, processes), keeping the vision of the holistic experience as the main guide (Patrício & Fisk, 2013).

An alternative way of interpreting Service Design is as “Design For Services” (Kimbell, 2011; Meroni & Sangiorgi, 2011), which can be defined as more investigative and preparatory (Foglieni et al., 2018b) . It focuses primarily on two main aspects: understanding the context in which services operate and the continuous involvement of people in multiple design activities preparatory (Foglieni et al., 2018b).

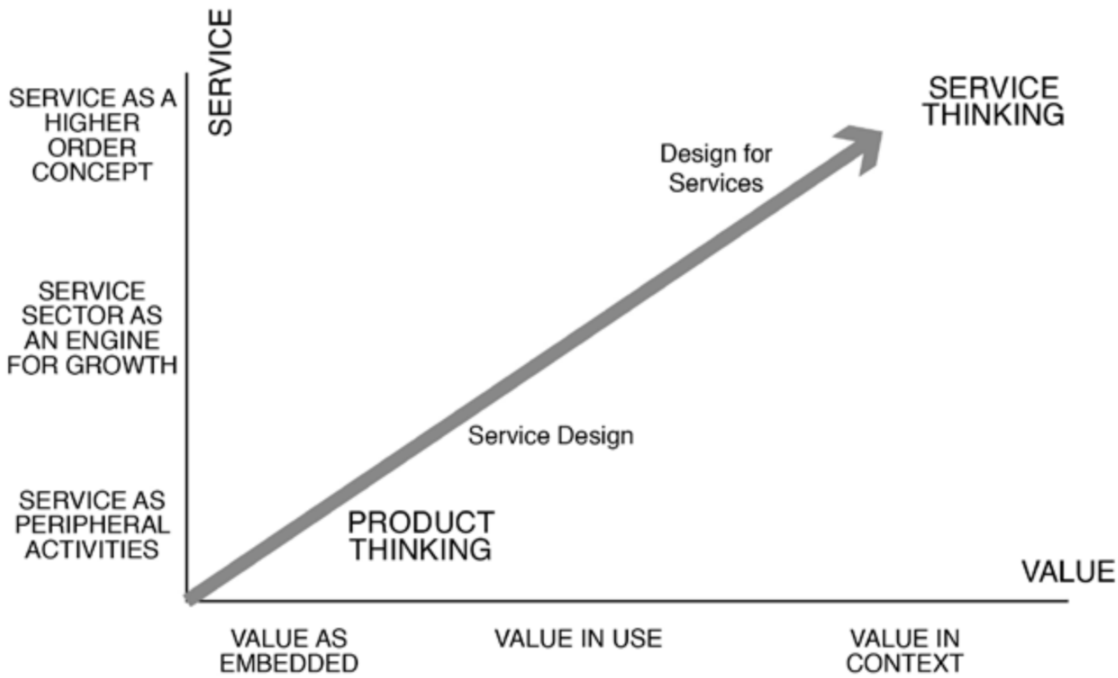


Figure 30 - Design for services evolution. Source: Sangiorgi (2012).

This perspective uses the preposition "for" because it accepts "the fundamental inability of design to completely plan and regulate services, while instead considering its capacity to potentially create the right conditions for certain forms of interactions and relationships to happen" (Meroni e Sangiorgi 2011, p. 35). Moreover, it goes along with the previously mentioned Service-Dominant Logic, which sees service as basic unit of economic exchange (Vargo & Lusch, 2004).

Within design for services practitioners focus on understanding and observing the user's experiences in a specific context and "at the time and place where value is co-created" (Wetter-Edman et al., 2014, p.107), with the aim to "create and develop proposals for new kinds of value relation within a socio-material world" (Kimbell 2011, p.49).

Finally, Service Design can also be approached from an expanded perspective that highlights its vast potential for action (Korper et al., 2020; Meroni & Sangiorgi, 2011). Service Design can range from the "simple" redesign of interactions and experiences to the redefinition of services on a wider level, that include new business models and value networks (Meroni & Sangiorgi, 2011). This understanding has therefore a broader scope and wider potential: it can support in shaping possible future scenarios, new behaviours, and collaborative service systems that can bring about real and powerful transformations in society (Meroni & Sangiorgi, 2011).

Figure 31 - Map of design for services, as proposed by Meroni & Sangiorgi (2011).

Notwithstanding variations in how scholars and practitioners approach Service Design's definition and conceptualization, there are commonalities that underpin the discipline's nature, such as its multidisciplinarity, its relationship with service innovation, and, notably, its principles and benefits.

MULTIDISCIPLINARITY

Service Design is considered multidisciplinary as it integrates knowledge and expertise from multiple fields (Blomkvist & Holmlid, 2010; Foglieni et al., 2018; Kimbell, 2009.; Meroni & Sangiorgi, 2011; Joly et al., 2019) which is fundamental to face the complex nature of services themselves and the implications that arise when developing them (Moritz, 2005). For example, areas that inform service design are HCI/interaction design (van Dijk, 2008; Blomkvist & Holmlid, 2010; Foglieni et al., 2018; Patrício & Fisk, 2013; Joly et al., 2019; Segelström, 2009), management and operations (Kimbell 2009; Patrício & Fisk, 2013; Joly et al. 2017; Foglieni et al., 2018), information systems (Patrício & Fisk, 2013; Joly et al. 2017; Foglieni et al., 2018;), marketing (Patrício & Fisk, 2013; Joly et al. 2017; Foglieni et al., 2018), psychology and graphic design (Foglieni et al., 2018).

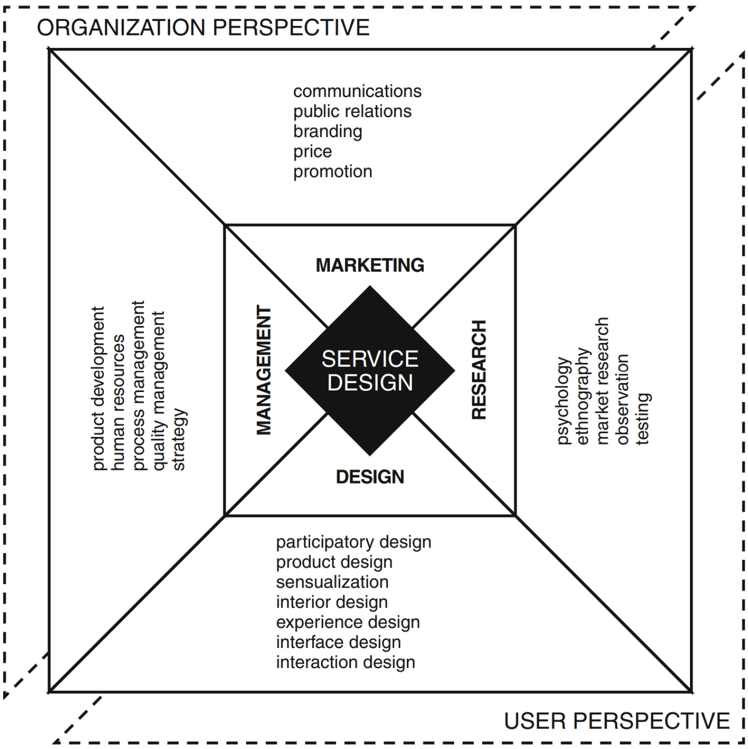


Figure 32 - Service design multidisciplinary nature, originally from Moritz (2005). Source: Foglieni et al. (2018).

SERVICE INNOVATION

Service innovation entails the proposal of new and/or improved service offerings, service processes, and service business models that can create value for the different stakeholders involved (Ostrom et al., 2010) and it has been linked with Service Design in multiple instances (Bitner et al., 2008; Grenha Teixeira et al., 2017; Mahr et al., 2013; Ostrom et al., 2015; Patrício et al., 2018; Yu &

Sangiorgi, 2018). Service Design is seen as a fundamental approach to make innovative service concepts and ideas a reality (Patrício & Fisk, 2013), due to the principles it follows and tools that it uses, which facilitate the thorough and inclusive examination of the individuals, resources, and actions involved in both the present and future utilization of the service (Karpen et al., 2017). In particular, the potential of service design has been seen when solutions are deeply technology-based (Patrício et al., 2018) and are born in a startup context (Korper et al., 2020).

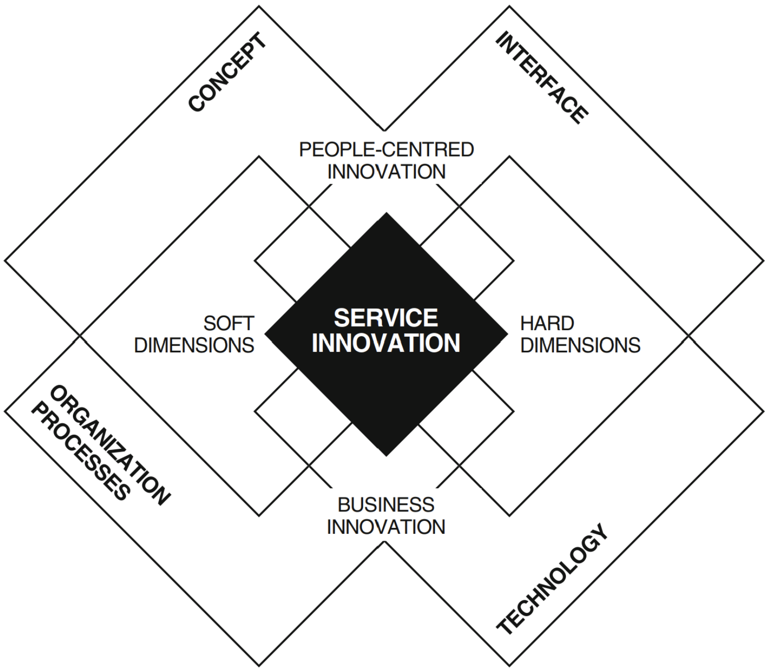


Figure 33 - A representation of service innovation. Source: Foglieni et al. (2018).

3.1.3 Principles

When discussing the Service Design approach and process, both in research and practice, there are specific words that emerge frequently, such as “holistic”, “human-centered”, “collaborative”. They are some of what we can consider fundamental characteristics, a sort of “core representation” of this mindset and the principles upon which all its related activities and processes are ruled and shaped.

Building on a first selection proposed by Stickdorn et al., (2018) I identified seven principles for Service Design:

Holistic

The holistic perspective sees Service Design as a discipline which takes into consideration the entire service ecosystem and seeks to create solutions that are empathetic and sustainable for all stakeholders involved by using a systemic approach (Karpen et al., 2017; Korper et al., 2020; Moritz, 2005). It does not focus only on a specific set of needs, but it aims to shape the entirety of a service by addressing all the different elements in the subject environment (Stickdorn et al., 2018) and "connecting the dots" between them (Karpen et al., 2017).

Moreover, "holistic" refers also to the fact that Service Design is contextual: when developing services it is always necessary to consider them in the specific social, technological and economic context they are set in (Blomberg & Darrah, 2014) . The service experiences and the service value will be, in fact, perceived by people in relation to particular environments, times and places and their social practices and structures (Maglio et al., 2019).

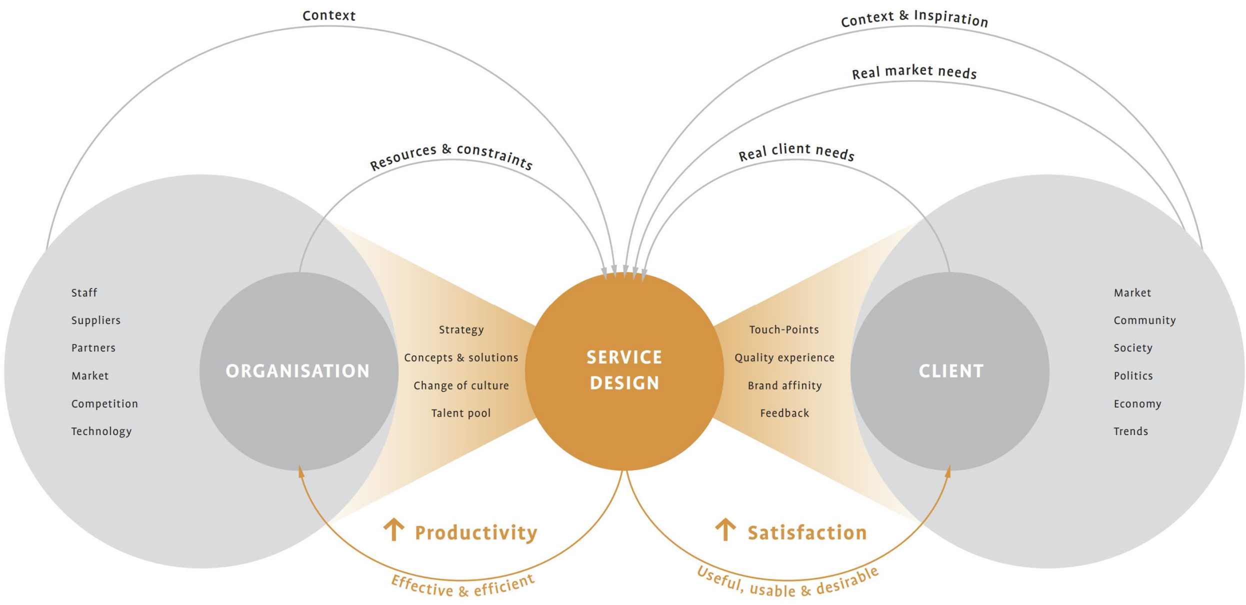


Figure 34 - Service Design overview model. Source: Moritz (2005).

Human-centered

Human-centered or people can be considered an evolution of user-centered (Stickdorn et al., 2018) and one of the most important and essential characteristic of service design (Holmlid, 2009; Foglieni et al., 2018; Meroni & Sangiorgi, 2011; Stickdorn & Schneider, 2011).

User-centered as a guiding perspective for design was firstly introduced by Don Norman in 1988, in his book The Psychology of Everyday Things. This concept underlines the importance of places the needs and preferences of the user at the forefront of decision-making in product development (Norman, 2013). A Human-centered perspective builds on these foundations but takes broader approach: it does not prioritize only the final user but considers all the experiences and values of the people that will be affected by the service design solution (Karpen et al., 2017; Korper et al., 2020; Stickdorn et al., 2018). On a deeper level, this engrained focus on people (their being users, staff, communities, organizations, companies) and the detailed understanding and respect for human behaviours, attitudes, dreams, and capacities, allows Service Design to bring to life actions that support and advance human dignity and sustain empowerment (Buchanan, 2001) (Buchanan 2001; Meroni & Sangiorgi, 2011).

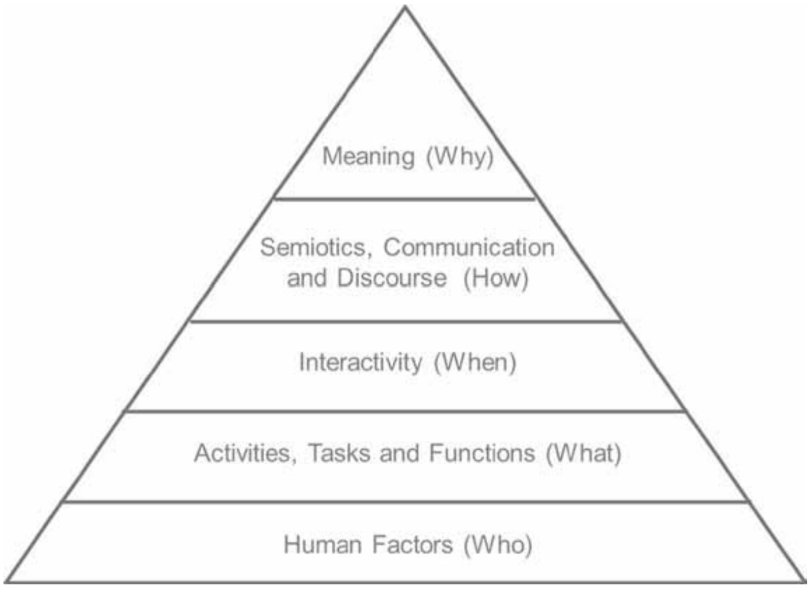


Figure 35 - The human centred design. Source: Giacomin (2014).

Iterative and experimental

This term refers to the “exploratory, adaptive, and experimental” (Stickdorn et al., 2018) set of activities that Service Design entails. Service Design, in fact, is not a linear approach with a clear endpoint, but rather a cyclical process (Blomkvist & Holmlid, 2010; Sangiorgi et al., 2015; Foglieni et al., 2018a; Stickdorn et al., 2018) where designers continually improve and refine their service through multiple rounds of iteration, that alternates research, insights development, ideation and testing (Kimbell, 2011). Through a continual evolution, a bounce between testing and refining, gathering feedback and implementing corrections, service designers can face ambiguity and complexity, can “play” with different service solutions and/or formulate bold and future scenarios (Karpen et al., 2017).

Co-creative and collaborative

Service Design is a collaborative practice as it involves the multiple service actors (designers, managers, customers, staff, citizens) in its processes (Kimbell, 2011; Korper et al., 2020; Stickdorn et al., 2018), drawing from the foundations posed by participatory design and co-design (Holmlid, 2009; Sanders & Stappers, 2008; Yu & Sangiorgi, 2018).

These perspectives see Service Design as an approach capable of creating spaces for deep empathy and constructive confrontation, by utilizing inclusive methods which facilitate the understanding of user’s real feelings and behaviours (Karpen et al., 2017; Korper et al., 2020).

Service Design makes sure that people are actively engaged in the proper shaping or redesign of services, but also directly included in the delivery and development of the solutions themselves (Meroni & Sangiorgi, 2011).

Transformative

Service Design is transformative and "betterment-oriented in nature" (Karpen et al., 2017). This because this practice does not approach services as a simple "design object", but as fundamental vehicles of change, that can drive wider societal evolutions (Sangiorgi, 2010). By considering the long-term impacts that the designed solutions will have on a specific ecosystem, service design and designer have the actual power of shaping a more collaborative, sustainable and creative society (Korper et al., 2020; Sangiorgi, 2010).

Service Design reflects this principle, in particular, in the area of future scenarios building: shared visions and alternative directions for the development of places and systems are generated by designers working with other stakeholders (communities, organisations), with the goal of guiding "strategic conversations" that can be the spark for more long-lasting change (Meroni & Sangiorgi, 2011).

Through this "transformative" lens Service Design is able to face the complex and volatile service contexts of today, leveraging these "desirable futures" (Meroni & Sangiorgi, 2011) and be free to explore different and bold solutions, actively seeking out and pursuing opportunities for improvement (Karpen et al., 2017).

Visual and creative

Relying on visual representations is a key aspect of Service Design, as they make complex aspects and multiple service levels more tangible and approachable to the different people involved in its processes (Kimbell, 2011; Korper et al., 2020). In keeping a creative and visual mindset, service designers are able to practically materialize the "relational and temporal natural nature of service" (Kimbell, 2011) and ensure that the perception of the service by different stakeholders is aligned (Karpen et al., 2017; Korper et al., 2020).

Creativity is intrinsic in the design nature of the Service Design discipline and manifests in the endless activities, tools and methods that are applied in the different Service Design frameworks.

3.1.4 Process(es)

With the increasing popularity and evolution of Service Design practices in the last few decades, also different design processes have been published by practitioners or described in literature (Stickdorn et al., 2018). Though the exact wording and number of activities, steps, or phases may vary, first of all, they all share the same mindset and principles that were previously described with a particular focus on exploration and iteration. In fact, it is clear that Service Design processes are not linear, but they follow an ”ongoing” flow, which constantly moves forward in repeating loops, that adapts and changes based on the specific circumstances it encounters on its path (Moritz, 2005; Stickdorn et al., 2018).

Secondly, Service Design builds on the more “traditional” design thinking logic, which champions an “abductive” reasoning, instead of the more traditional inductive and deductive model (Cross, 1982). Service Design processes show, therefore, recurring patterns of convergent and divergent thinking (Stickdorn et al., 2018) where designers dance between “deciding among existing alternatives” and “probing the future and creating new possibilities” (Brown & Katz, 2009).

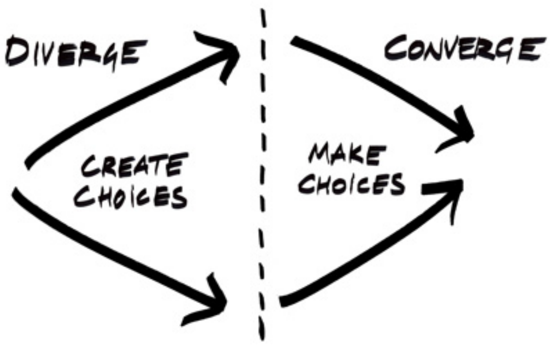


Figure 36 - Design thinking logic. Source: Brown & Katz (2009).

Service Design processes then, can be defined as an “open-ended inquiry” (Kimbell, 2011), where phases and activities can be carried out in different order, but also at the same time (Moritz, 2005).

The most frequently adopted Service Design process is the Double Diamond, which was outlined by the British Design Council in 2004 (Design Council, 2019).

This process involves four key stages - Discover, Define, Develop, and Deliver - each one of them with specific objectives, methods and tools (Design Council, 2015).

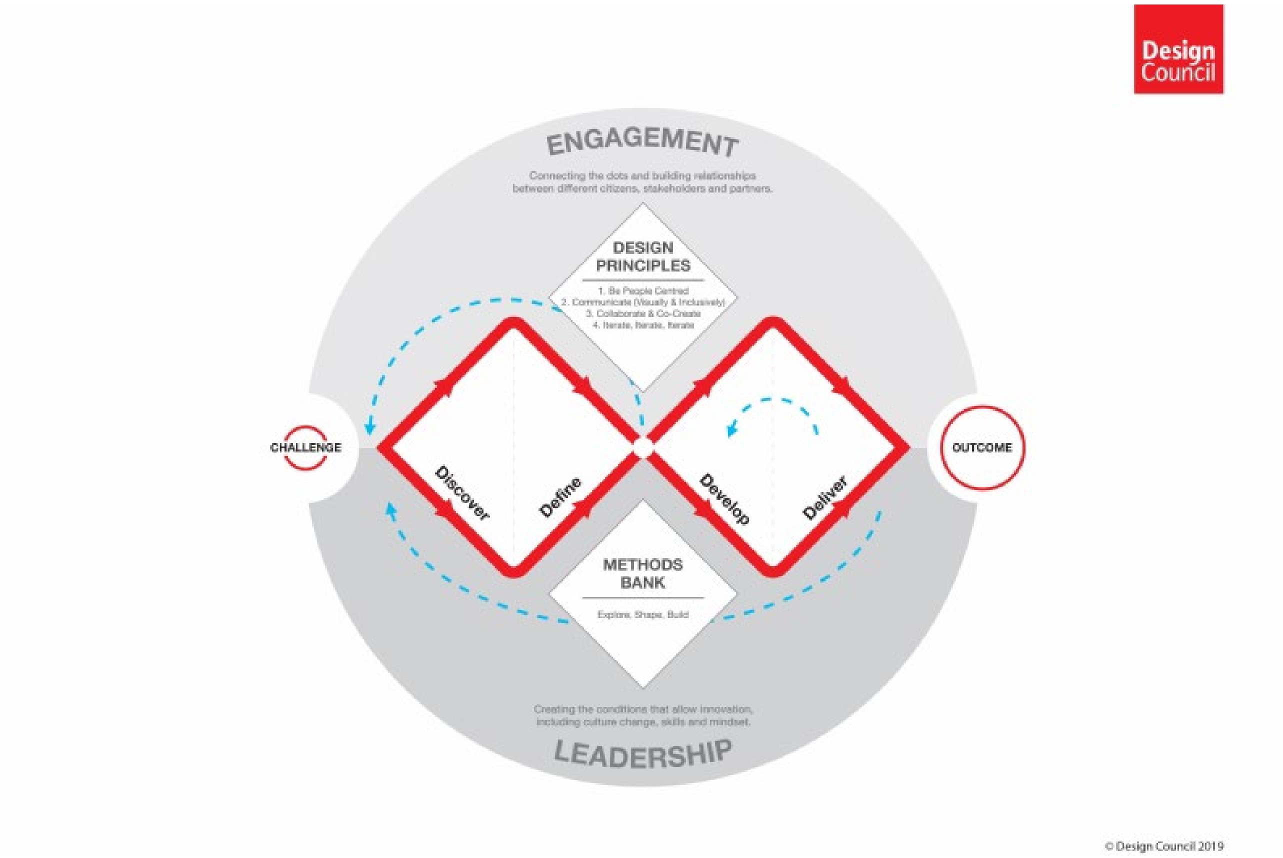


Figure 37 - The Double Diamond Process. Source: Design Council.

The first diamond involves the Discover and Define stages, which are focused on gaining a deep understanding of the problem or challenge at hand.

During the Discover stage, the goal is to gather information and insights through research and observation (Brown & Katz, 2009). In this moment designers create a knowledge base that will inform the subsequent stages, leverage different resources and taking into consideration aspects such as social trends, emerging technologies and new services (Design Council, 2015). The first boundaries of the solution are then set, as well as a very broad setting of the problem (Design Council, 2019).

In the Define stage, designers use these insights to outline the problem in a more specific way, identifying also the root causes and all the key stakeholders that might be involved (Brown & Katz, 2009). In this phase of the design process, designers analyze and structure the findings from the Discover phase into a reduced set of problem statements (Design Council, 2019) that are aligned with the organization's needs and business objectives, resulting in a shared definition of the challenges to be addressed and the opportunities that can be exploited (Design Council, 2015).

The second diamond includes the Develop and Deliver stages, which are focused on ideating and implementing solutions.

During the Develop stage, multiple solutions are generated, prototyped, tested and refined until a final solution is identified (Design Council, 2015). Design teams and partners use design and creative techniques to bring to life the product-service system concepts until they are ready for implementation, incorporating feedback from users throughout the process (Design Council, 2019).

Finally, in the Deliver stage, the solution is firstly tested again and evaluated to ensure that it addresses in the best way possible the user's needs (Design Council, 2019). The finalized service is then ready for launch.

As previously mentioned, the Double Diamond is only one of the endless processes that have been proposed.

Another one of the firsts was Moritz's (2005), who maps a higher number of stages; SD understanding, SD thinking, SD generating, SD filtering, SD explaning, SD realising (Moritz, 2005).

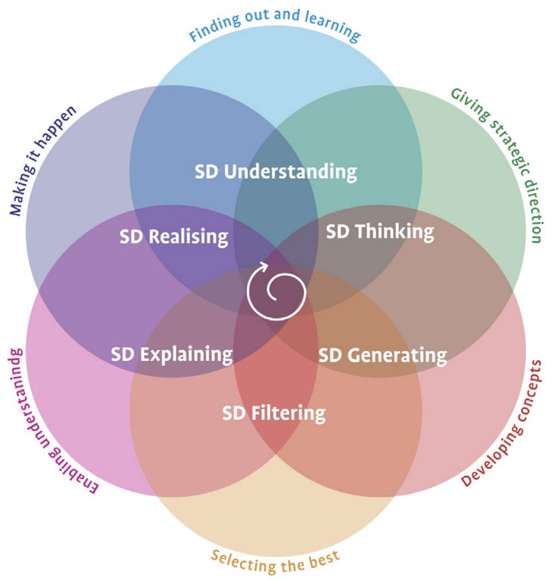


Figure 38 - Service Design process as proposed by Moritz (2005).

Meroni & Sangiorgi (2011) similarly utilize action verbs but reducing the steps. For them they are: "Analysing, generating, developing, prototyping" (Meroni & Sangiorgi, 2011). These are then expanded into a quadruple diamond process (Meroni et al., 2021).

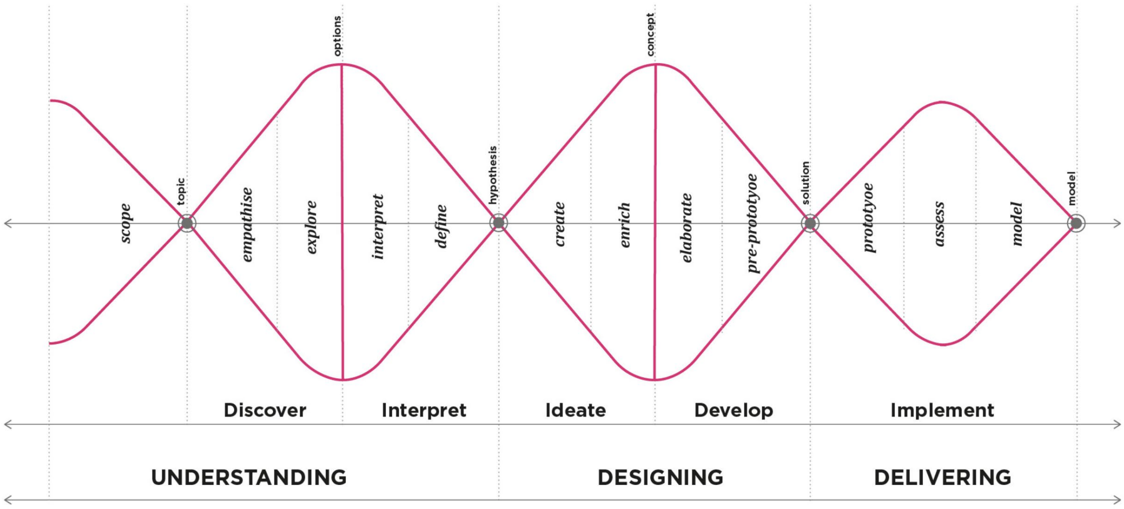


Figure 39 - Quadruple Diamond process. Source: Meroni et al. (2021).

Patricio & Fisk (2013) work with exploration, ideation, reflection through prototyping and testing, and implementation (Patrício & Fisk, 2013).

Recently, Stickdorn et al. (2018) shaped the process with “activities” rather than phases (Stickdorn et al., 2018). They outline four of them: research, ideation, prototyping, implementation.

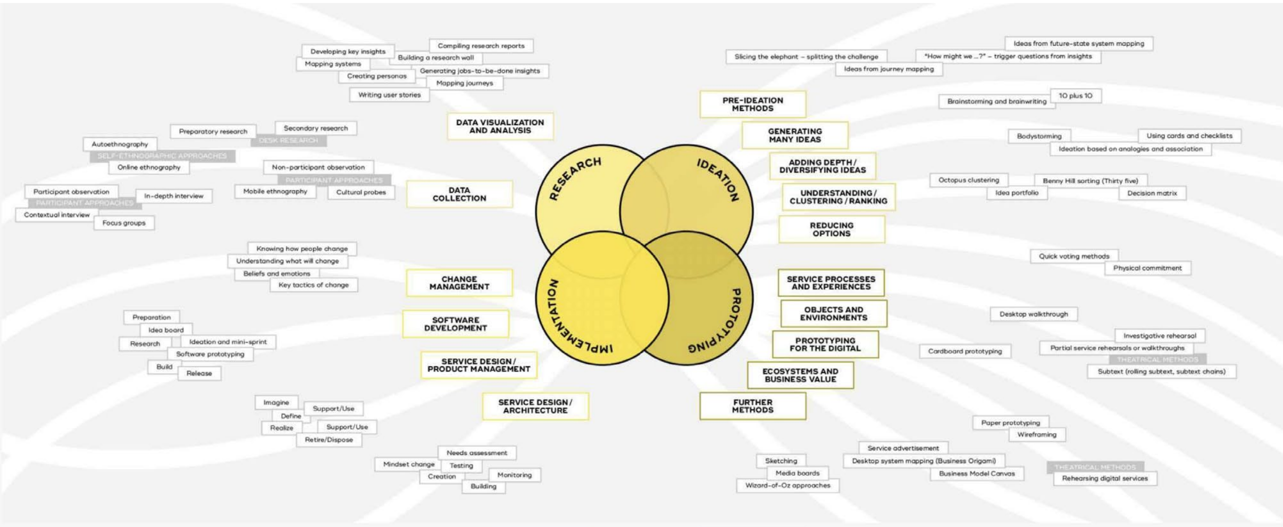


Figure 40 - Core activities of the Service Design discipline. Source: Stickdorn et. al. (2018).

Eventually, though, it is not possible (if not totally counterproductive) to apply the Service Design mindset/approach within a fixed and immutable structure and subjecting it to rigid rules (Moritz, 2005). As Meroni & Sangiorgi (2011) affirm, “services can differ significantly from each other and designers can approach services in diverse ways”, such as at different levels and breath, with different methods and with different end goals (Meroni & Sangiorgi, 2011).

3.1.5 Focus on: MEDGI process

Although the Double Diamond framework is the most commonly used in the Service Design discipline, as seen in the previous paragraph (3.1.4), there are other frameworks that exist. In this paper, we will focus on one particular framework, which served as a critical starting point for the development of the CHECKD. project: the MEDGI process. This structure was proposed by professor Edelman Jonathan Antonio and it proposes a particular Service Design approach with an emphasis on affordances and dimensions of engagement.

His views are based on the conceptualization of designing as

“Seeing the world as a *field of opportunities* for *skilled action* and *Acting* on the world with *skilled action* This means having the tools, skills and frameworks to *take the world* apart (meaningfully) and then put it back together (meaningfully) in a new way” (Edelman, 2021).

This approach builds on the idea that designers do not create just "ideas" but "culture," which is a conjunction of objects, behaviors, and narratives (OBNs), and its different dimensions.

OBJECTS

- Something material that may be perceived by the senses.
- Something that when viewed stirs a particular emotion.
- Something mental or physical toward which thought, feeling, or action is directed, an object for study.

BEHAVIOURS

- The way in which someone conducts oneself or behaves.
- Anything that an organism does involving action and response to stimulation.
- The response of an individual, group, or species to its environment.
- The way in which something functions or operates.

NARRATIVES

- Something that is narrated (story, account).
- A way of presenting or understanding a situation or series of events that reflects and promotes a particular point of view or set of values.

For example, when a coffee shop is designed, different elements are defined about its spaces, furniture, and materials. At the same time, what we "design" also includes how people act in it, what they wear, who they are with, who is serving, and the dynamics. Each different coffee shop, therefore, will offer a different story, a different experience, and a different "meaning." Meaning is a narrative in itself.

A key point expressed by Edelman (2021) is the perspective of design as a *performance*, a 'corpus of behaviors that increase the probability of finding a path to innovation in the face of uncertainty' (Leifer & Steinert, 2011). The performance of design uses brains and bodies interacting with a cascade of different kinds of media and tools, such as drawings, models, text, video, sounds, graphs, and charts.

He then proposes an innovation process for high performance, the MEDGI process. Fundamentally, this approach follows the translation of an old Object-Behavior-Narrative to a new Object-Behavior-Narrative, through different actions:

1 - MAPPING → user-interaction story = object + behavior + narrative (everything happens in time and space).

2 - EDUCING → uncovering implicit needs, goals, and values through observation and reflection

3 - DISRUPTING → exploring alternatives and questioning assumptions

4 - GESTALTING → generating and evaluating a range of solutions

5 - INTEGRATING → refining and implementing the chosen solution

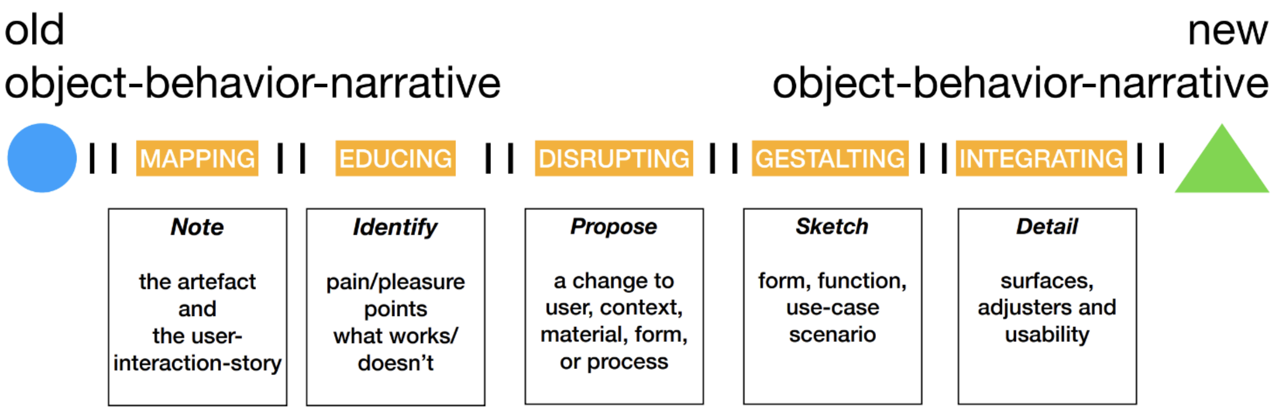


Figure 41 - MEDGI process. Source: Edelman (2021).

MEDGI can be considered both a macro process that spans over weeks and months and a micro process that happens in mere seconds or minutes.

One of the central aspects of MEDGI is Mapping, as it involves" taking the world apart, triangulating it, and putting it back together" (Edelman). Through mapping, designers can gain a comprehensive understanding of the object and its context, by examining what the object does, has, is used by, enables, causes, and is connected to. Thus, mapping plays a crucial role in identifying the core components of the design and in facilitating effective interventions that can lead to innovative and impactful outcomes.

Another important point of MEDGI, is that its underlying mechanisms reflect the kind of questions that designers need to ask and answer during the different phases of the process.

Analytic

This type of Q&As are what defines the work of engineers. They underline what is feasible, what is actually there and they stop from further exploration.

- Analytic questions have 'truth value', they ask about specification, comparison and verification. They address what is actual and often what is feasible.
- Analytic answers provide specifications, comparisons, and verifications.

Generative

These are fundamental exactly because they give space for exploration, the part lacking with analytic Q&As.

- Generative questions have no 'truth value', they are not looking for solutions, but to open up the field of inquiry with a range of possibilities for exploration. They are concerned with generating a field of possibilities.
- Generative Answers provide possibilities and directions for further exploration.

There are generative Q&A that matter "more". They are related to "reason".

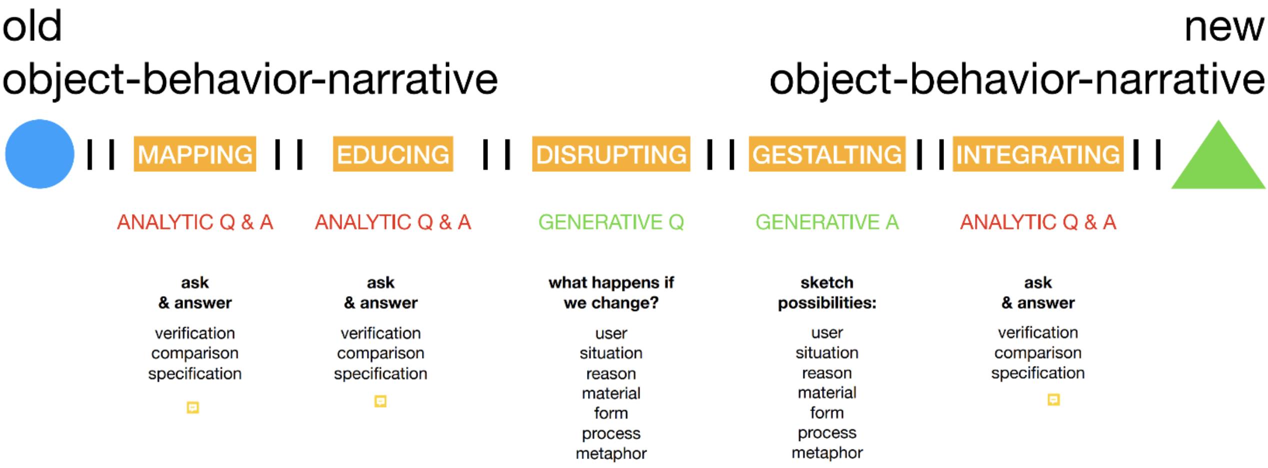


Figure 42 - MEDGI process and relationship with Q&A types. Source: Edelman (2021).

The MEDGI process is designed to destabilize an Oject-Behavior-Narrative and make it available for change by disrupting it and then putting it back together. To achieve this, the mechanism of change must be identified. One way to do this is by asking ourselves the question, "What happens if we change the user-situation-reason, material, form, process, or metaphor?" and acting on the four forces of change in design. These four forces are material, form, efficient, and final. Material refers to what something is made of, form relates to how it is shaped, efficient considers the processes required to make it, and final focuses on the "why," "for what," and "for whom" of the design. By focusing on these forces of change, designers can disrupt and destabilize an Oject-Behavior-Narrative, making it possible to create innovative solutions that meet the needs of users in new and exciting ways.

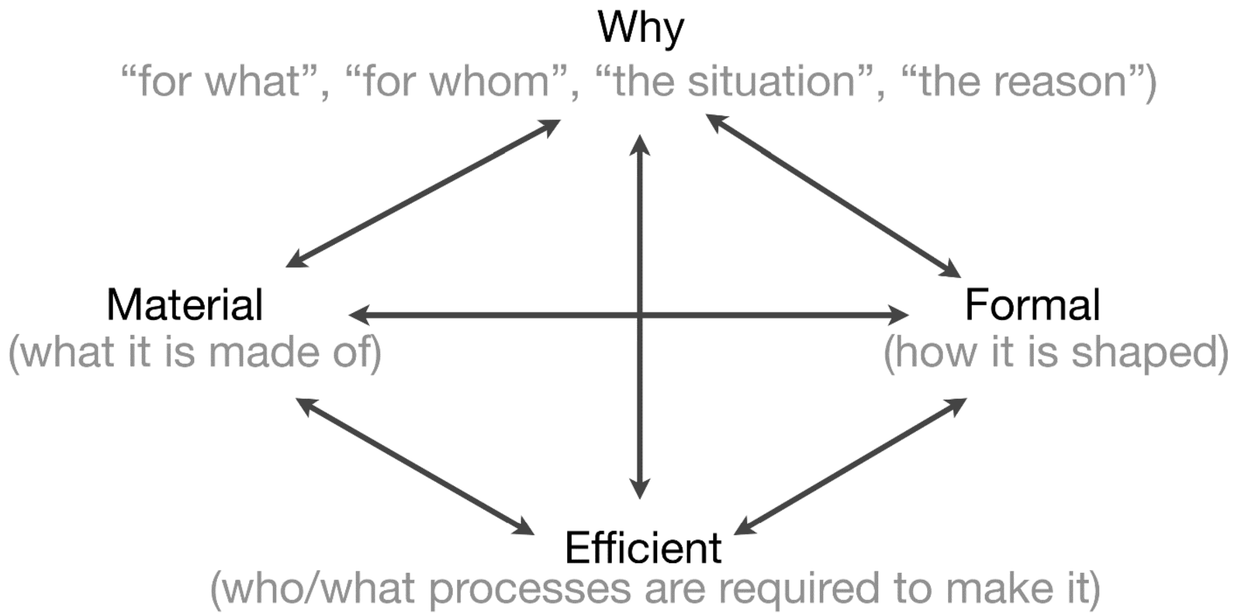


Figure 43 - Relationship between object-context. Source: Edelman (2021).

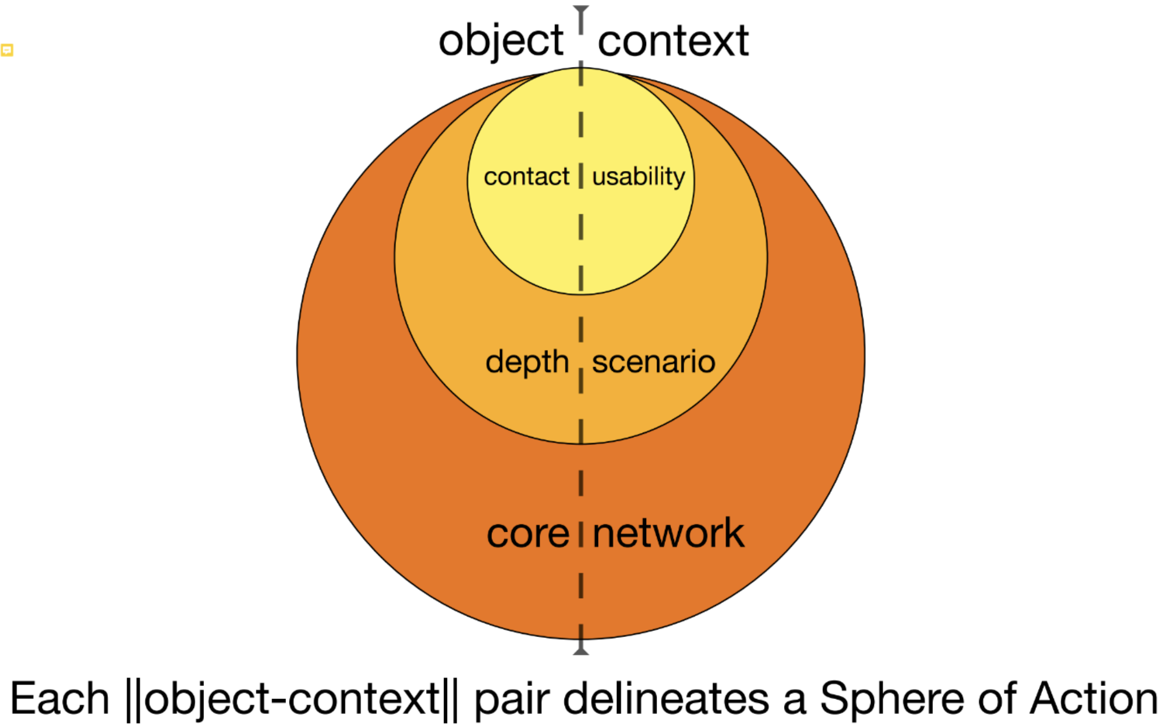


Figure 44 - Relationship between object-context. Source: Edelman (2021).

As previously mentioned, Edelman posits that designers do not solely create objects, but also generate behaviors, narratives, and opportunities. In essence, designers are creating a culture. Echoing the vision of Achille Castiglioni, Edelman emphasizes the idea that "designed objects are intimately connected to human gestures." Hence, designers are not solely responsible for designing the object, but also the gestures that accompany it. Similarly, this holds true for designing experiences as well.

An important concept that comes into play in this case is “affordances”.

“The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill. The verb to afford is found in the dictionary, but the noun affordance is not. I have made it up. I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment...”.

The concept of affordances was first introduced by psychologist James Gibson in his book "The Ecological Approach to Visual Perception," published in 1979. In this book, Gibson argues that perception is an active process in which the individual perceives opportunities for action or affordances in the environment. (Gibson, 1979).

Affordances refer to the characteristics or properties of an object or environment that suggest how it can be used or interacted with. In the context of design, affordances are the features or attributes of a product, service, or interface that communicate how it can be used or what actions it enables.

For example, a button on a website or app has the affordance of being clickable, while a door handle has the affordance of being pulled or pushed. In each case, the object communicates to the user how it can be used through its visual or physical properties.

The concept of affordances has been widely adopted in design, particularly in the context of user interface design. A 1988 article by Norman titled "The Design of Everyday Things" explores the role of affordances in the design of everyday objects and interfaces, arguing that good design should make the intended actions clear and intuitive through the use of perceptible affordances (Norman, 2013).

“The perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used. A chair affords (‘is for’) support, and, therefore, affords sitting.” (Norman, 2013).

Naoto Fukasawa also defines affordances:

“Observation connected to design ideas means discovering the kind of noticeable affordance people attain under a particular set of circumstances, such as hanging one’s jacket on the back of a chair or putting your hands on the desk when you stand up.”

He underlines how in design it is fundamental to watch people, see what they do and what they are missing: to sense the “unrequited gestures”.

Edelman affirms that all (designed) objects have affordances:

*There is a give and take, a play between object and action (E*delman, 2021).

Designers make changes to objects, behaviours and narratives so that they create affordances or more properly solicitations for experiencing the world as a field of opportunities for acting with skill (Edelman, 2121).

Designers can utilize dimensions of engagement as a tool to enact change in the world. These dimensions refer to the level at which designers enter into an object and the context in which it operates. By dissecting and analyzing these dimensions, designers can leverage effective tools to create well-tuned interventions, as suggested by Edelman. The dimensions of engagement also play a significant role in determining whether a new design will be radical, incremental, or somewhere in between. Thus, by carefully considering and working with dimensions of engagement, designers can create innovative and impactful designs that contribute to positive change in the world.

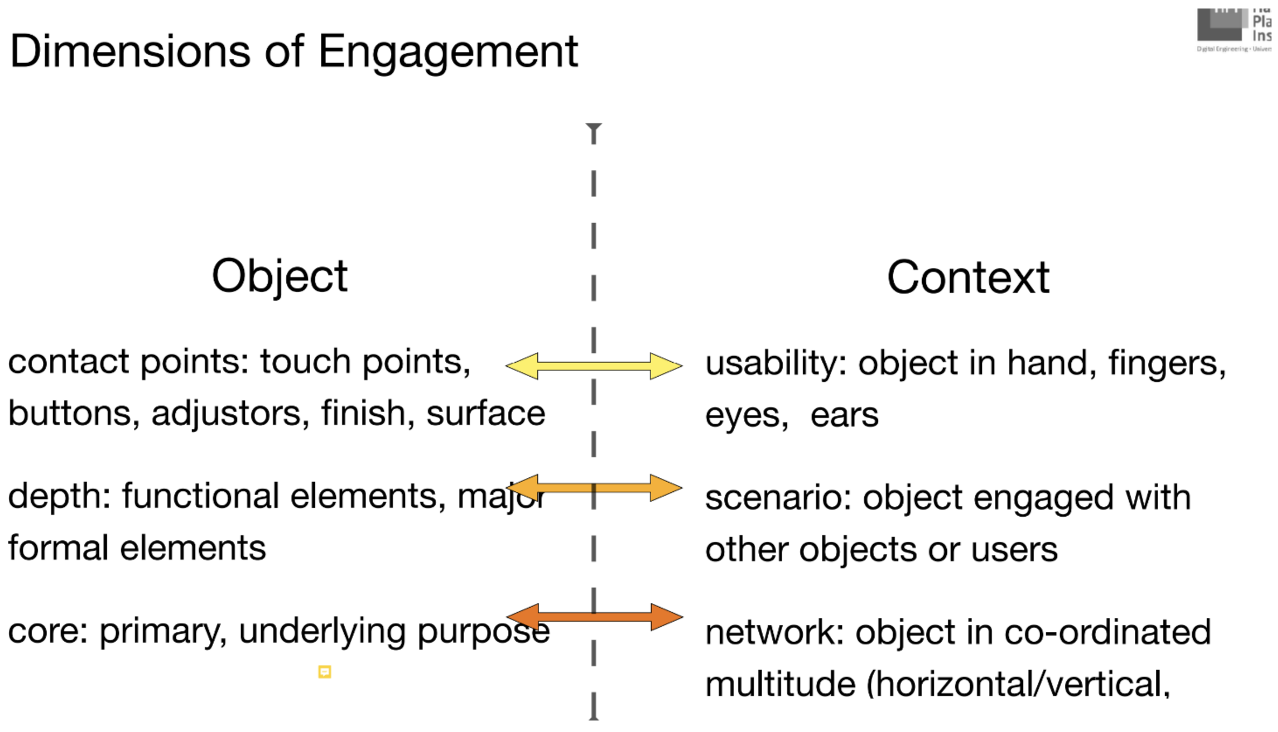


Figure 45 - Dimensions of engagement. Source: Edelman (2021).

3.1.6 Methods and tools

Other two complementary attributes linked to Service Design and its process need to be mentioned: methods and tools.

Methods (the "how") encapsule all the systematic procedure, techniques, or mode of inquiry employed40, that designers use to gain insights, generate ideas, and develop solutions for the design challenge at hand (Stickdorn et al., 2018) . Methods can be considered as framework, as main guidelines: they can be both followed precisely or modified based on the occasion (Stickdorn et al., 2018).

Tools (the "what"), on the other hand, are the specific materials and concrete models that designers use to apply methods and accomplish specific tasks during the design process (Stickdorn et al., 2018).

Tools can either be physical, digital or mixed in nature and they usually follow a specific structure, or a "template" (Stickdorn et al., 2018). Despite this they are highly creative and space from broad visualizations and sketches to more defined and detailed models (Stickdorn et al., 2018).

Tools and methods also materialize in a concrete and tangible way the multidisciplinary nature of Service Design: many of them are, in fact, inherited or inspired from other disciplines (Blomkvist &

[40] Method Definition & Meaning - Merriam-Webster

Holmlid, 2010) (Blomkvist, Holmlid, and Segelstrom 2010), such as ethnographic methods (Blomkvist & Holmlid, 2010; Segelström et al., 2010; Segelström & Holmlid, 2015).

Both methods and tools are organized into different stages or phases of the design process (Brown & Katz, 2009; Stickdorn & Schneider, 2011) and both are important for service designers. Through them, touchpoints, actors, activities, systems and relationships can be mapped, understood and analyzed deeply supporting in effectively solve complex design challenges and create solutions that enable real value co-creation (Čaić et al., 2019; Patrício et al., 2011; Teixeira et al., 2012).

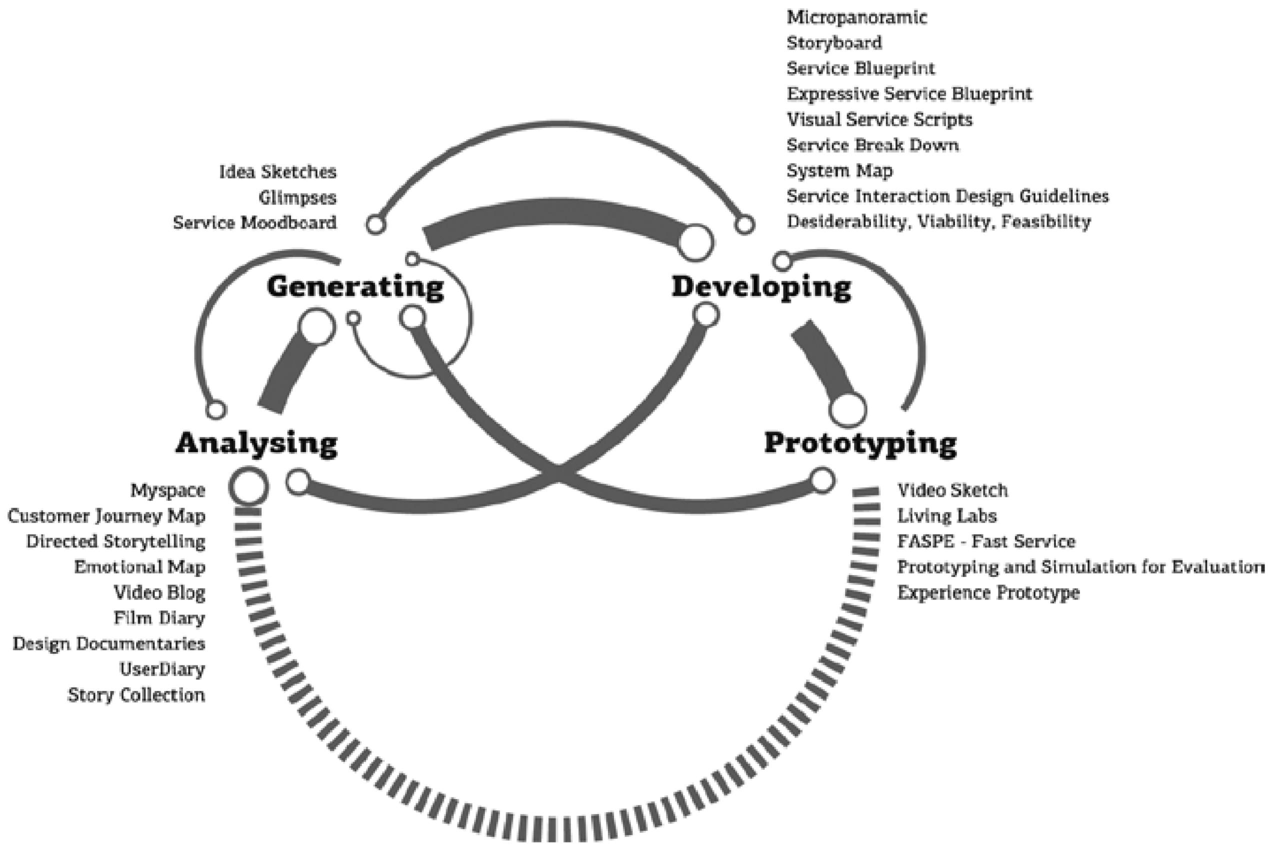


Figure 46 - Overview of Service Design tools. Source: Meroni & Sangiorgi (2011).

3.1 Co-design

3.1.1 Introduction

Co-design can be generally considered as a “a process of joint inquiry and imagination” (Steen, 2013) that includes users and other stakeholders involved in the delivery of a solution (Meroni et al., 2021). In this process, the actors discuss and define a problem and subsequently jointly explore, develop, and evaluate possible solutions (Steen, 2013).

Lately, the co-design approach has been largely debated and explored by designers, both in theory and practice, and under different perspectives. It is, in fact, increasingly seen as a potential solution for addressing significant societal issues and to tackle intricate design problems (Meroni et al., 2018).

The actual term “co-design” is of recent origin, as well as its conceptualization (massive codesign), but, as proposed by Sanders and Stappers (2008), it originally poses its roots into two well established approaches: user-centered design and participatory design (Sanders & Stappers, 2008).

User-centered design (UCD) originated in America in the field of computer-based industrial product design, and it operated successfully in this domain throughout the 1980s.

It was pioneered by Don Norman, who is often credited with coining the term in his 1986 book "User Centered System Design" [41] in relation to the design of effective and user-friendly computer systems. The philosophy of UCD took a step forward from traditional product development by considering a necessity the deep understanding of the users, their needs, goals, and behaviors. This requires designers to observe and listen to users in order to gain insights into their needs and preferences (Norman, 2013). Most importantly the UCD view proposes the idea of a design process where users are “studied” with more detail and consulted them during the design process, in different ways and levels, but mostly in the later or final stages (Abras et al., 2004). Another important aspect of UCD is iterativity: testing early and often with users to identify and fix problems as they arise and ultimately refine designs based on such user (Abras et al., 2004) . Finally, It introduced important methods such as field studies (including contextual inquiry), user requirements analysis, usability testing and evaluation, task analysis and heuristic evaluation (Mao et al., 2005)

Participatory design (PD), instead has its origins in Scandinavia, where it emerged in the 1970s. Similarly to UCD it was as a response to the growing recognition that traditional design processes often failed to take into account the needs and desires of users, and that designers needed to involve users more directly in the design process.

One of the key pioneers of PD was the Danish architect and planner Pelle Ehn, who was a central figure in the development of the "Utopia" project, which involved end-users in the design and development of computer support systems to enhance the quality of the resulting system[42]. The methodology used in this project, including low-tech prototyping and early design sessions with users paved the ground for participatory design and cooperative inquiry to develop (Bødker et al.,2000).

Participatory Design foresees actively involving stakeholders (including users, developers, and others affected by the design) in the design process: this means that not only users but also other

[41] What is User Centered Design? | IxDF (interaction-design.org)
[42] UTOPIA Project (perflensburg.se)

actors, such as developers and managers, have a role and a voice (Sanders et al., 2010). PD aims to empower users to actively participate in the design process, making them equal partners with designers and developers (Sanders et al., 2010).

It supports the idea that a fairly large group of “non-designers”, but directly involved in the context for which the product/service is being designed, know their needs better than an external designer/researcher, who has studied those needs in depth but has never had to deal with them in everyday life (Sanders et al., 2010).

The participatory view of design played a crucial role in the development of the co-design approach. By introducing and emphasizing a political aspect of design, it challenged the traditional idea of the designer as the sole holder of design expertise. Instead, it promoted a more democratic design culture where co-creation, or the act of collective creativity, is a key principle (Sanders & Stappers, 2008).

Users, from “passive object of study” become “experts of their experiences” capable of playing a key role in the development of solutions exercising their own creativity and becoming co-designers (Sanders & Stappers, 2008). Designers/researchers, instead, take on the role of “facilitators” that put to use their skills and capabilities to support the involved people and guide them through the whole design process (Sanders & Stappers, 2008).

3.1.2 Co-design and Service Design

Co-creation or more specifically, co-design can be considered as a key aspect of service design as it reflects and embodies fully two of its main principles: collaborativity and creativity (Stickdorn et al., 2018; Stickdorn & Schneider, 2011) (this is service design thinking and doing).

Co-design in service design can be defined as an “activity generating services, strategies and scenarios, which is conducted across the entire span of the creative process and, thus, not only in the moment of the exploration and generation of ideas, but also during the decision and deliberation processes” (Meroni et al., 2018), where customers, service delivery teams and other actors are actively involved in the design and improvement of services (Stickdorn et al., 2018).

This practice can cover different forms of participation in very different contexts. For example, it can be connected to community-wide and broader perspectives (Meroni et al., 2018), be focused on public services (Selloni, 2017), in product development process (Yu & Sangiorgi, 2018) or instead, refer to multiple levels of involvement (Holmlid, 2009).

Its end goal, though, is always the same: to help service providers create solutions that are more responsive to the needs and desires of users with customers, emphasizing collaboration and dialogue between all the involved stakeholders, and developing more effective and sustainable strategies for creating value (Wetter-Edman et al., 2014). It can also help to build stronger relationships between service providers and service users, which can lead to increased trust and satisfaction with the service (Meroni & Sangiorgi, 2011).

Moreover, multiple benefits can be identified when utilizing co-design methods in Service Design. Between the most important are: keeping the projects deeply rooted to reality, due to the “multidisciplinarity” of the team (Stickdorn & Schneider, 2011), empowering users (by involving them in the design process), giving them a voice in shaping the solutions that affect them (Steen et al., 2011) and foster creativity and innovation by bringing together diverse perspectives and ideas from designers, users, and other stakeholders (Stickdorn et al., 2018).

3.1.3 Co-design in practice

Co-design in service design involves a range of participatory-based methods and artefacts, called boundary objects, that are designed to facilitate collaboration and co-creation among stakeholders (Stickdorn et al., 2018). One of the most common way to co-design in Service Design is through organized sessions, which typically involve bringing together a diverse group of stakeholders to work together, in a specific moment of the design process (or more than one) to work on one or more specific aspect(s) of the service (Sanders & Stappers, 2008).

In a similar fashion to the service design process itself, workshops cannot be squared into a rigid set of rules, but hold an adaptive nature, which involves personalizing and reshaping the activities and tools to be deployed based on the specific instance and a series of variables (users, purposes, design fields, resources, etc.). Regardless, is indeed helpful to have guidelines that can be followed to initially frame the situation, without the need to start from scratch every time. In this paragraph a brief overview of how these workshops are structured will follow.

1. Definition of scope and purpose. This involves clearly defining the problem or opportunity the session will address, identifying the target group of participants, and envisioning the desired outcomes (Stickdorn et al., 2018).
2. Design of stages and materials. A detailed outlines of phases and activities and exercises to be undertaken during the workshop are drafted and designed. This includes selecting appropriate boundary objects (tools and prototypes) for each phase, defining the techniques and then produce them (Stickdorn et al., 2018). The main phases of a codesign sessions are three, beginning, core, end (Meroni et al., 2021). The beginning should include an icebreaker activity that promotes empathy and trust, even if it is not necessarily enjoyable (Meroni et al., 2018). The end should have a "wrap-up artifice" that allows participants to draw conclusions while the coordinator gathers relevant knowledge (Meroni et al., 2018).
3. Recruitment of participants. Participants who have relevant expertise and knowledge to contribute to the design process are identified and invited. It is important to consider specific project criteria when selecting participants taking into consideration that diversity and

differentiation are crucial factors (Meroni et al., 2018). All necessary information about the workshop, including the agenda and expected outcomes are provided (Stickdorn et al., 2018).

4. Execution of workshop. Facilitation of the sessions, following the agenda and encouraging active participation from all participants (Stickdorn et al., 2018). In this moment it is critical to keep the focus on more critical perspectives and debates and avoid do-goodism and optimistic/philantrophic attitudes (Meroni et al., 2018).
5. Documentation of the outcomes. Ideas, insights, and solutions generated during the workshop are recorded and summarized, as they are valuable resources for future design activities and project development (Stickdorn et al., 2018). This could be a challenging task as the content generated from the sessions themselves can be overwhelming and complex (Meroni et al., 2018).

3.1.4 The Collaborative Design Framework

The primary framework for the codesign sessions structure was as described earlier; however, to ensure comprehensive design and framing of the framework and its content, an additional set of guidelines was followed.

It is known, infact, that creating co-design sessions, especially in service design is it very complex as practitioners have to often face systemic and conflictual problems that require to work with ambiguity and engage in ongoing dialogue and negotiation with stakeholders (Kimbell, 2012).

The “Collaborative Design Framework”, developed by the POLIMI DESIS Lab, it is a co-design framework related to Service Design, outlined specifically to face complex social challenges with acts of “massive codesign”, that involve numerous actors along multiple and elaborated steps. Despite this framework’s original intention and field of application, it still renders as a critical guide and foundation by providing “actionable knowledge for supporting designers in aligning processes of co-design” (Meroni et al., 2018).

In fact, it covers and defines important building blocks of the co-design process, how to design them and also suggests solutions for problems that occur repeatedly when addressing service design projects, even of a different nature. For this reason it was integrated with the one from paragraph 3.1.3 in order to give more depth and detail to the workshops carried out for the development of this thesis.

STRUCTURE

This framework works along a set of quadrants defined by two main variables: design subject matter and style of guidance.

The “design subject matter” is connected to the phase of the Service Design process chosen to carry out collaborative practices. In this case, Service Design is displayed as linear process, even though it is specified that it is also iterative in nature due to the constant interaction between problem framing and solution finding.

When reproduced on a two-pole axis, we find on one side "topic-driven" activities, that focus on investigating the problem or situation that the project aims to address, while in the other "concept-driven" activities, that are guided by the problem-solving brief and aim to develop a solution-oriented approach to the design challenge.

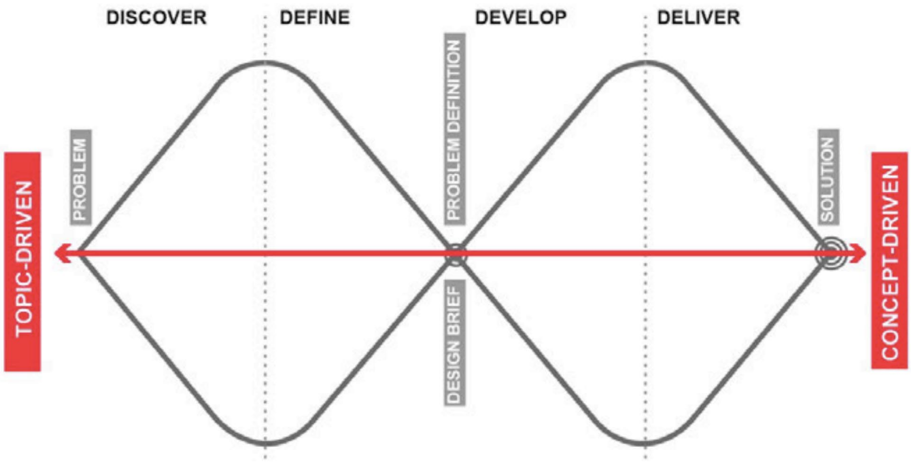


Figure 47 - Double Diamond and two polarities as presented by Meroni et al. (2018).

The “style of guidance”, instead, refers to how the session is facilitated and how the participants are encouraged to work together to explore, develop and evaluate creative solutions. The way the design is facilitated can have a significant impact on the participation and collaboration of the participants, and their ability to break away from their usual habits and boundaries.

When reproduced on a two-pole axis, we find on one side the style of "active listening", which fosters an open exchange of ideas and promotes the development of empathy and sympathy among participants. On the other, instead, there is “thought provoking”, where people are steered in thinking towards critical aspects or opportunities related to a particular topic or concept. This direction encourages participants to engage in speculative thinking and generate responses and reactions to a given situation.

QUADRANTS

When merged together, these two axis render the full framework:

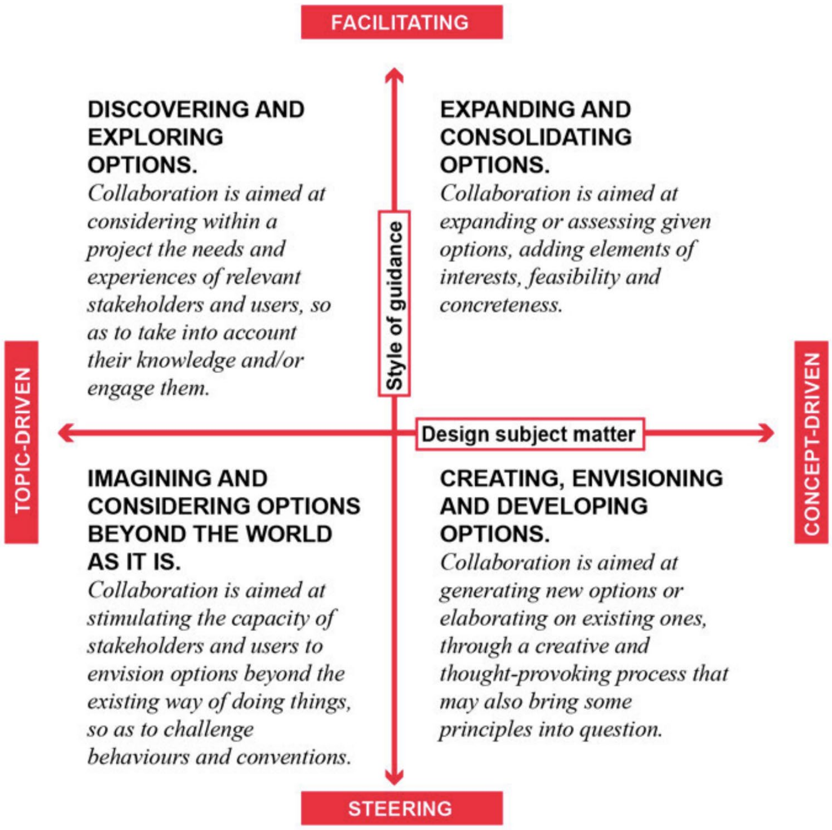


Figure 48 - The collaborative design framework. Source: Meroni et. al (2021).

3.1.5 Aspects and terminologies

From the presented frameworks, specific terminology has emerged. Some of these key aspects will be described in the following section, to define a common understanding of them, as they will be mentioned multiple times throughout the thesis.

BOUNDARY OBJECTS

The concept of boundary objects was first introduced by Susan Leigh Star and James R. Griesemer in their 1989 paper titled "Institutional Ecology, 'Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology." They introduced the concept to describe the ways in which objects or artifacts can act as a bridge or interface between different social worlds, allowing people with different perspectives and expertise to communicate and collaborate effectively (Star & Griesemer, 1989). These objects or concepts are shared, but they have different meanings or interpretations within each world (Star, 2010): they are, in fact, understood in terms of their "plasticity," meaning that they can be adapted and interpreted in different ways by different communities to serve their specific needs (Star & Griesemer, 1989).

They play a key role in mobilizing for action and legitimizing design knowledge and therefore can be leveraged as main a component of co-design processes by acting as facilitators of “dialogical exchanges” between different parties (Star, 2010).

Their main and most important characteristic is their “interpretive flexibility” (Star & Griesemer, 1989). This means that their own design must be such that they can be interpreted and understood in different ways by various communities of practice, enable them to overcome fundamental differences in interpretation and support them in collaborating on a specific task (Meroni et al., 2018).

Another important factor is creativity. In collaborative design projects designers need to be able to think creatively in order to create artifacts that are meaningful and effective for different stakeholders (Vines et al., 2013).

In practice, boundary objects are design artefacts that embody design concepts and ideas, and that can be manipulated and experimented with by designers and stakeholders. Design things are not just static representations of design concepts, but rather they are interactive and allow for exploration and experimentation (Ehn, 2008).

Boundary objects in service design are designed to help align different views and expectations, clarify assumptions and requirements, and co-create solutions that are meaningful and relevant to all stakeholders involved.

They therefore aid in the imagining, conceiving, and creating of solutions by allowing for iterative development and exploration of potential approaches, but also expanding and transforming design concepts by enabling their evaluation, manipulation, and development in greater detail and complexity (Meroni et al., 2018).

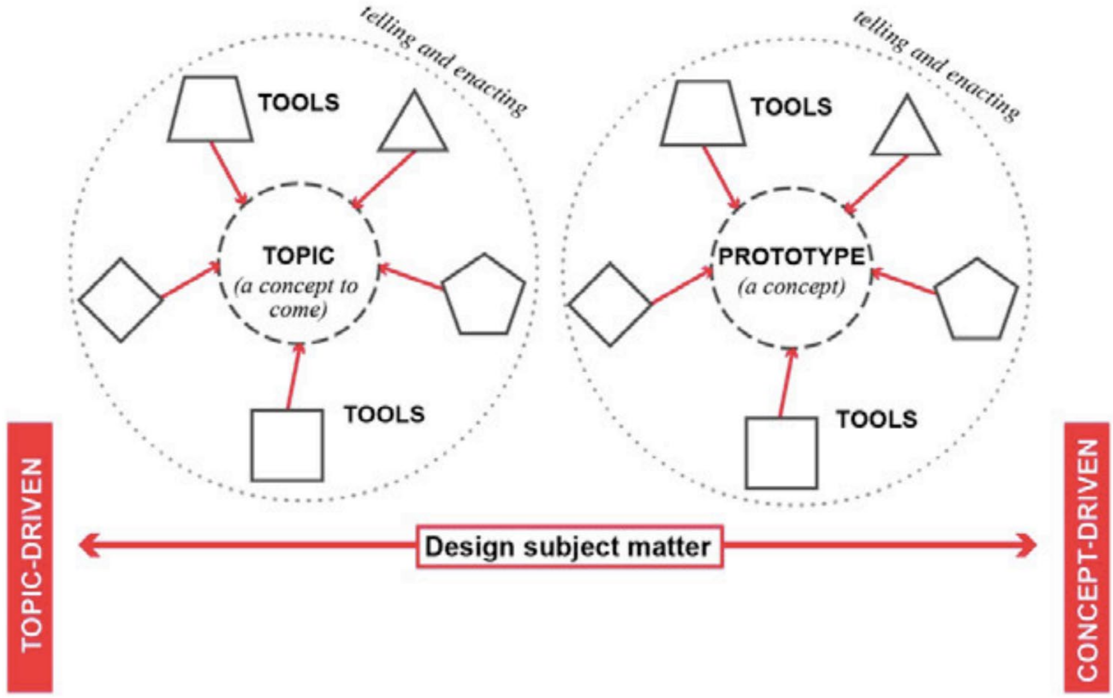


Figure 49 - The relationship between tools, topic, concepts and prototypes in codesign actions along a design process. Source: Meroni et. al (2021).

Boundary objects in service design are physical or digital artifacts, that are combine in a complex way both tools and prototypes as they complement "diverse forms of verbal and body telling/enacting" (Meroni et al., 2018).

They are therefore different from "individual" tools and prototypes.

TOOLS

Tools can be considered as visual and conceptual "aids" that are employed to support the participants in understanding their needs and preferences, identify pain points, but also exploring, defining and creating design options (Sanders & Stappers, 2014; Stickdorn et al., 2018).. They are applied in all collaborative activities, regardless of their position in the process (Meroni et al., 2018).

Examples for early stages of design process are interviews and probes, case study discussion, storytelling, while for more advanced ones are customer journey maps, sketches, blueprints, storyboards (Sanders & Stappers, 2014).

PROTOTYPES

Prototypes, instead, are physical or visual representations of service or scenario concepts and they provide a manifestation of the main evidence and interactions taking place within a system (Meroni et al., 2018).

Prototypes usually are primarily employed in the “concept-driven” sections (massive codesign), but they often cross boundaries and mix together (Sanders & Stappers, 2014) and therefore, in certain situations, cannot be quite clearly defined.

3.3 Prototyping

3.3.1 Prototyping: brief overview

The use of prototypes in design can be traced back to the early 20th century, when designers began creating three-dimensional models to test and refine their ideas (Buxton, 2007). However, it wasn't until the 1960s that prototyping became a more formalized part of the design process, with the development of computer-aided design (CAD) tools and the emergence of rapid prototyping technologies (Buxton, 2007).

As of today, prototyping is a well-established area of the design practice and process (Budde et al., 1990; Floyd, 1984; Kelley, 2010; McElroy, 2017). Design research approaches the subject in different ways and levels, proposing a variety of perspectives and frameworks that also vary based on the specific discipline.

Prototyping practices vary across different design disciplines (Buchenau & Suri, 2000; Martin & Hanington, 2012).

For example, in product design, physical prototypes are commonly used to test the form and function of a design (McElroy, 2017; Ulrich & Eppinger, 2012), while in interaction design, digital prototypes can be used to simulate user interactions with a system (Houde & Hill, 1990; McElroy, 2017). In architectural design, prototypes can take the form of scale models or digital simulations that test spatial relationships and material properties (Schon & Wiggins, 1992).

Prototyping in design can be considered both as an "activity” as well as a "mindset” or “approach" (Houde & Hill, 1990). Prototypes, instead, are a more complex item to describe, as countless definitions of it exist. This thesis will base itself on Blomkvist's (2014) description of prototypes as: “Any shared physical manifestation externalising an otherwise internal or unavailable vision of a future situation”, which is overarching and complete.

More in detail, prototyping as an “activity” sees physical or digital representations of design concepts (the prototypes) used to test and evaluate ideas, gather feedback, make improvements, communicate (Brown, 2008).

As a mindset and approach, prototyping is a way of thinking about design that emphasizes experimentation, iteration, and a willingness to fail and learn from mistakes. This mindset encourages designers to be flexible and adaptive, to remain open to new ideas and feedback, and to continuously refine and improve their designs based on what they learn through the prototyping process. As Norman & Verganti (2014) point out, prototyping is a key part of the design thinking process in general, which is focused on understanding and solving complex problems through a human-centered perspective.

Despite its multiple applications and angles, prototyping in design (and therefore in service design) remains a critical practice. It allows designers to create and test new ideas in a quick and cost-effective manner (Buxton, 2007), to gather feedback from users and identify problems with the design before it goes into production (Snyder, 2003) and in general to reduce the risk of failure, save time and money, and ensure that the final product meets user needs and expectations (Dorst, 2011).

It is also worth mentioning, for clarity, that prototyping in design has a different meaning from prototyping in engineering, despite they originally share some similarities.

Prototyping in design is primarily focused on creating and testing visual, interactive, or experiential representations of a product or service that often involves creating low-fidelity mockups or sketches to quickly iterate and refine ideas, followed by higher-fidelity prototypes to test and validate design decisions (Gero & Kannengiesser, 2004; McElroy, 2017). The goal of prototyping in design is to better understand user needs and behaviors, and to create a more effective and engaging user experience (Cross, 1982).

In contrast, prototyping in engineering is focused on creating and testing physical or functional prototypes of a product or system. Engineering prototyping involves creating prototypes that closely resemble the final product in terms of form, fit, and function, and that can be tested to ensure that they meet performance, safety, and reliability requirements (Ulrich & Eppinger, 2012). The goal of prototyping in engineering is to validate the design, identify potential issues or weaknesses, and optimize the product or system for manufacturing (Ulrich & Eppinger, 2012).

To further emphasize the differences between design and engineering prototyping, research by Landay & Myers (1995) explains that design prototyping focuses on creating a better user experience, while engineering prototyping focuses on verifying the design's functionality and performance. They highlight how design prototyping emphasizes exploration, creativity, and user engagement, while engineering prototyping emphasizes precision, accuracy, and feasibility (Landay & Myers, 1995).

Before delving deeper into how prototyping and Service design merge, a few key concepts and frameworks related to both worlds will be discussed briefly, as they are they will be later reproposed in the actual practice of this thesis' project.

PROTOTYPES

Anatomy

The "anatomy" of prototypes is a concept advanced by Lim, Stolterman, and Tenenberg (2008): it refers to different components that make up a prototype (both metaphorically and literally) (Lim et al., 2008).

They do this to provide a framework for understanding prototypes and their fundamental nature: it is crucial for designers, as it helps them think about the different dimensions they need to consider when approaching them and the possibilities for designing them. The metaphor of "anatomy" is used to describe how different parts of a prototype can be organized, but it does not provide a rigid prescription for how a prototype should be designed.

Their proposed anatomy of prototypes includes:

1. Filtering dimensions ("what" to filter in a prototype):

- Appearance dimension. Physical properties of a design (forms, colors, textures, sizes, weights, and shapes, proportional relationships among these elements) that refer to all senses (sight, touch, smell, …)
- Data dimension. Information architecture and the data model of a design (include the size of data, the number of letters to be shown in each label, the amount of visible and invisible data on screen, the semantic organization of the contents, the ways of labeling and naming, the levels of privacy of data, and the types of information)-
- Functionality dimension. Functions that can be performed by the design.
- Interactivity dimension. Methods or modes of engagement that individuals have with various components within a given system (eg. feedback, input behaviors, operation behaviors, and output behaviors).
- Spatial structure dimension. Manner in which the different parts or elements of a system are integrated or linked together (eg. placement, arrangement, and hierarchy of the components, as well as the relationships and connections between them in/of both tangible and intangible environments).

2. Manifestation dimensions ("how" to form a prototype):

- Material. Medium (either visible or invisible) used to form a prototype" (lim et al) (eg. paper, wood, and plastic; tools for manipulating physical matters, computational prototyping tools, available existing artifacts).
- Resolution. Level of detail or sophistication of what is manifested.

- Scope. Broader range of the aspects that the prototype aim to cover (not related to the filtering dimensions).

The manifestation dimensions may alter or enhance the prototype's ability to filter the desired dimensions to varying degrees: they can influence how people perceive and respond to a given prototype (Lim et al., 2008). This means that they are fundamental for determining "how well a prototype performs as an informing tool in the design process" (lim et al 2008) in terms of how effectively it can be used to evaluate and improve upon design ideas while maintaining the chosen filtering dimensions (Lim et al., 2008).

Fidelity

Fidelity in prototyping is a highly discussed and sometimes controversial topic, especially when put into comparison with resolution, but at the same time is crucial for prototyping.

This thesis supports Houde & Hill (1990). They define resolution as the "amount of details", meaning a property of the prototype's design (Houde & Hill, 1990). Fidelity, instead, as the "closeness to the eventual design", meaning a property of the prototype's relationship to the intended system (Houde & Hill, 1990), similarly to the concept of "fidelity of emulation" proposed by Schneider (1996).

Prototypes can vary in fidelity: a very common distinction is between: "low fidelity", "medium fidelity", "high fidelity" or "no-fidelity" (Houde & Hill, 1990).

- Low fidelity: rough, quick, and simple representations of the final product, often created with materials such as paper, cardboard, or digital wireframes (Buxton, 2007). They are useful for exploring and communicating design ideas early in the process and for testing basic functionality and user flow (Snyder, 2003).
- Medium fidelity: more detailed than low-fidelity ones but still less the high fidelity and they are useful for testing and refining specific features and interactions (Buxton, 2007).
- High fidelity: High-fidelity prototypes are very detailed and realistic representations of the final product (Snyder, 2003), they can be functional prototypes or simulations (Lim et al., 2008).
- No-fidelity: not physical or digital representations of the final product, but rather verbal or written descriptions, sketches, or storyboards (Houde & Hill, 1990). They are what Blomkvist (2014) considers "static prototypes". They are useful for exploring and communicating design ideas early in the process and for testing user needs and requirements (Snyder, 2003).

Two main problems are related to fidelity: using it to define prototypes and choosing the right level (considering the moment in the process, the resources, the goal, etc.).

Regarding the first, it is argued that generalize the concept of fidelity and use it as an umbrella term is too simplistic and could bring to misunderstandings (Bryan-Kinns & Hamilton, 2002; McCurdy et al., 2006).

McCurdy et al. (2006) proposed a framework for understanding prototypes based on five orthogonal axes, or dimensions, that prototypes can vary along and it will be briefly introduced here, as it will be a key step for the prototyping practices of this thesis. This framework, in fact, provides a more nuanced understanding of the strengths and weaknesses of different prototypes, and helps designers make informed decisions about which type of prototype to use for a given design problem.

These five axes are not mutually exclusive, and a prototype can be described by its position along each of them, allowing designers to tailor their prototypes to meet specific project goals and user needs.

These dimensions include:

1. Level of visual refinement (degree of visual fidelity). Level of detail and sophistication in the appearance and aesthetics of the prototype. At the high end of the axis, the prototype may be highly polished and realistic, while at the low end, it may be crude and sketch-like.
2. Depth of functionality. Extent to which the prototype's functionality is implemented/extent to which the prototype emulates the final product in terms of the range and complexity of its functions. A low-depth prototype may only implement the core features (limited subset of the final product's functions) , while a high-depth prototype may include all possible features (the prototype may offer a comprehensive range of functions).
3. Breadth of functionality. Rrange of functions (variety and number of functions) the prototype supports. A narrow prototype may focus on a specific use case (broad range of functions), while a broad prototype may support multiple use cases (narrow set of functions).
4. Level of interactivity. Degree to which the prototype allows for user interaction → degree to which the prototype allows users to interact with it, and to what extent it simulates the experience of interacting with the final product. A low-interactivity prototype may only allow passive viewing (static and non-interactive), while a high-interactivity prototype may allow for complex user input (interactive and responsive).
5. Depth of data model. Extent to which the prototype represents the underlying data model (level of detail and accuracy in the underlying data model used to generate the prototype). A shallow prototype may only show a simplified representation of the data (simplified or incomplete), while a deep prototype may model the data in detail (highly detailed and accurate).

How to choose the right level of fidelity is also a frequently discussed topic. Higher fidelity prototypes are said to provide more accurate feedback from users, but may also require more time and resources to create (Blomkvist, 2014). Low-fidelity prototypes can be useful for exploring design alternatives and getting early feedback, while high-fidelity prototypes are better suited for testing detailed interactions and validating design decisions (Rudd et al., 1996).

SERVICES

Service as Design material

When designing services, and therefore also prototyping them, it is necessary to take into consideration their multiple dimensions as “design objects”.

A useful framework that explains and simplifies this is given by Secomandi & Snelders (2011), in their paper "The Object of Service Design". It will be briefly explained and expanded with other definitions that will be useful for the shared understanding of this thesis.

They define three types of objects that always need to be considered: service experiences, service systems, and service processes.

1. Service processes. Series of steps and activities that are involved in the delivery of a service (eg. everything from the initial customer contact to the post-service follow-up) (Secomandi & Snelders, 2011). It is an “idealised version of the service”, meaning a series of expectations for how the interaction should proceed and the desired outcome of the exchange (Blomkvist, 2014). A breakdown of service processes, from smallest element to wider element, would be:

    - Touchpoint: contact point between customers and organisations (Blomkvist, 2014; Clatworthy, 2011; Secomandi & Snelders, 2011).
    - Journey: a set of touchpoints together through the interface (Parker & Heapy, 2006).
    - Interface: ensemble of resources (products, information (visual and verbal), people (appearance and behaviour) and environments (physical and virtual) that support exchanges between stakeholders (Blomkvist, 2014).
    - Interactions: actual exchange that takes place between the user and the service provider, which can include both verbal and nonverbal communication (Carbone & Haeckel, 1994).
    - Service encounter: different and sequential moments when a customer interacts with a service provider and its dimensions (social and physical environment) (Bitner, 1990). It can be considered a series of “stages”: pre-encounter, encounter, and post-encounter stages, which are important for understanding the overall service experience and the customer's perceptions of the service provider and the service itself.

2. Service experiences. Subjective perceptions and interpretations of users during their interactions with a service: the result of the interactions between the user and the service provider (Secomandi & Snelders, 2011).
3. Service systems. The collection of resources and actors that are involved in the delivery of a service (eg. physical infrastructure, technology, human resources, policies, and procedures) (Secomandi & Snelders, 2011).

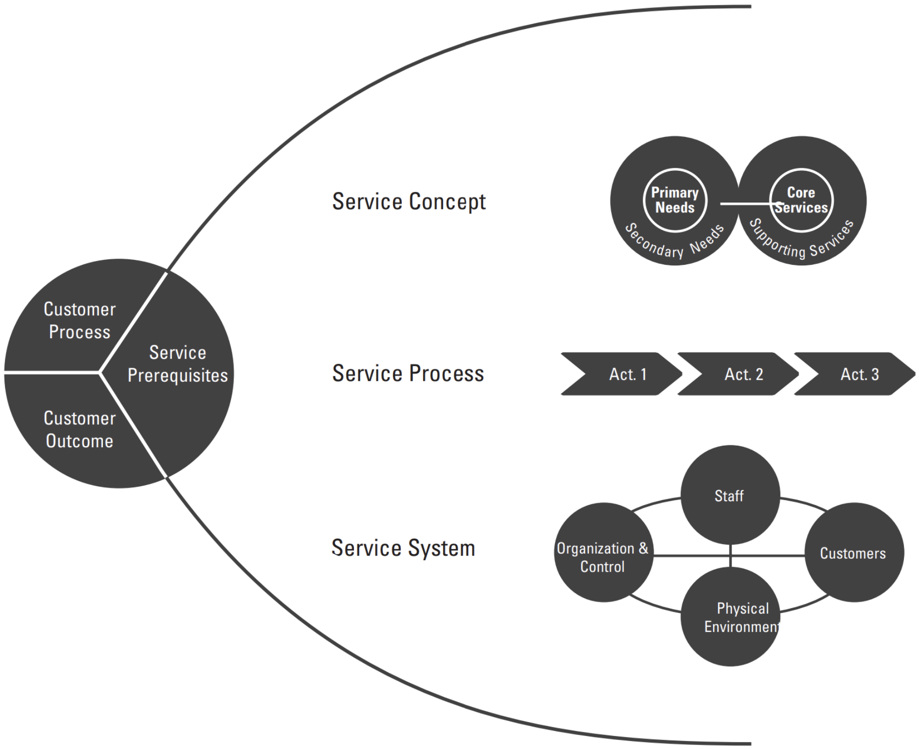


Figure 50 - Visualization of service development framework. Source: Secomandi & Snelders (2011).

Servicescapes

Finally, it is important to mention the idea of servicescapes.

Servicescapes are an expansion of Bitner's (1990) conceptualization of service encounters briefly described before, that specifically refers to the dimensions of "physical environment".

The physical environment refers to the tangible aspects of the encounter, such as the setting, layout, design, and ambiance of the service delivery location Bitner's (1990).

In general, when talking about services, the servicescape plays a crucial role in shaping the customer's experience and perception of the service being provided and therefore can influence customer behavior, emotions, and attitudes, and can affect the customer's overall satisfaction with the service (Bitner, 1992).

The framework she proposes (Bitner, 1992) can be a useful guide to structure some aspects of service prototypes. They do in fact entail creating a physical or digital representation of the service environment where designers can test different layouts, designs, and decor options to see how they affect the user experience and how they can be re-organized to allow value creation.

Three main dimensions of a servicescape exist:

- Ambient conditions. Physical aspects of the environment that contribute to the customer's sensory experience (eg. lighting, temperature, and noise level)

- Spatial layout and functionality. Physical arrangement of the space (eg. seating arrangement, the flow of traffic, and the location of service counters)

- Signs, symbols, and artifacts (eg. visual elements of the environment, including signage, decor, and other design elements)

The service environment should supply users with the necessary signs for the comprehension of behaviour expectations, how to find services and critical infrastructures (spatial orientation) and of how the organisations works (functional orientation) (Sangiorgi, 2021).

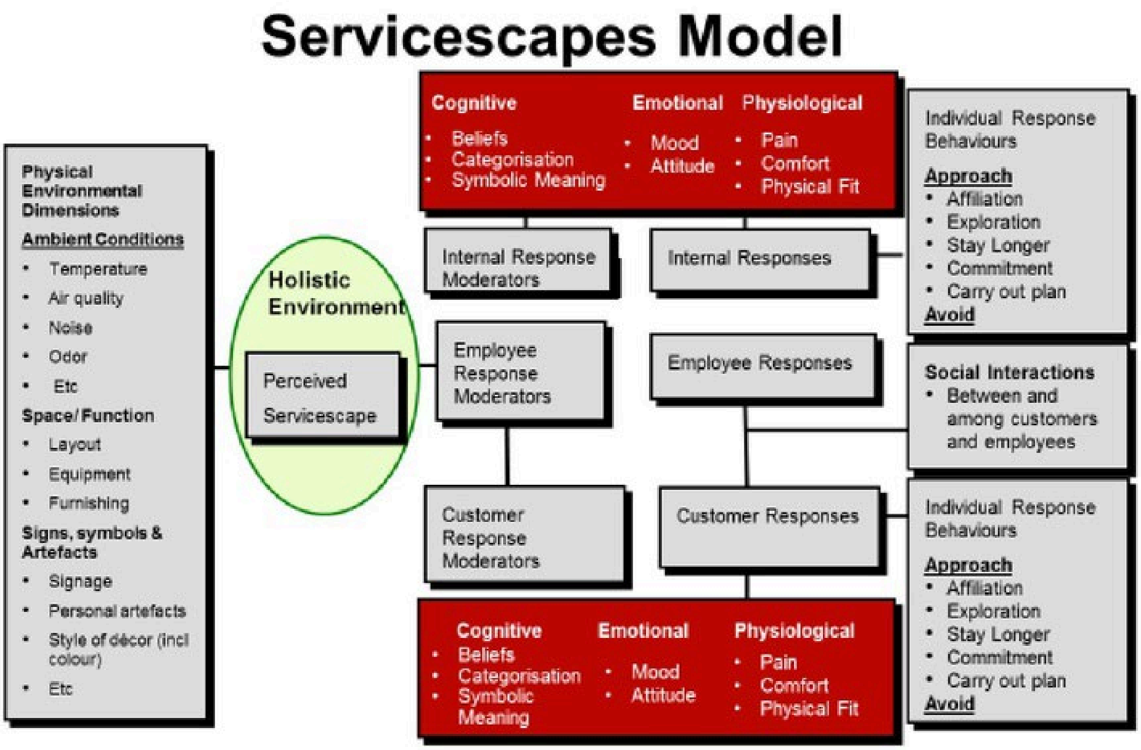


Figure 51 - Serivcescape model. Source: Bitner (1992).

3.3.2 Prototyping in Service Design

Prototyping, as mentioned, is a deeply explored area in design, both in practice and theory, but most of the available resources focus either on product (both physical and digital) and interaction design (McElroy, 2016). Less explored, instead, is prototyping in the service design field (Blomkvist, 2011; Passera et al., 2012), despite it being considered crucial for the practice itself (Patrício & Fisk, 2013; Yu & Sangiorgi, 2018). Most of the existing knowledge comes from the dissertations of Blomkvist (2011, 2014) who reflects on this practice and focuses on its conceptualization.

Prototyping in service design can be considered as method for exploring and representing potential service futures, which involves creating representations ("anything perceivable that is used or made for the purpose of representing something else.") of possible future service situations that can be used to explore and test different service concepts and ideas (Blomkvist, 2014). Service prototypes, instead, are defined as any representation of a future situation, either of them being sketched ('definite') or enacted ('ongoing') and considered as surrogates that exists in a liminal state, that can be tested and explored freely and without time limitation (Blomkvist, 2014).

Prototyping services it is not as straightforward as traditional prototyping: it in fact entails the act of replicating complete, holistic experiences, where highly elaborated systems of both tangible and intangible elements come together (Blomkvist, 2011, 2014; Passera et al., 2012).

The complexity of prototyping is therefore higher than traditional situations and it presents multiple challenges (Blomkvist, 2011). Some are related to the nature of services themselves, meaning their being intangible, inconsistent, inseparable and perishable (Blomkvist, 2011; Zomerdijk & Voss, 2010).

Other are related to the way the prototype is rendered. In this case we have the problems of authenticity and validity (Blomkvist 2011). Ensuring authenticity involves using realistic people and techniques to generate data that accurately reflects the intended implementation context, while validity refers to the fact the test situation should closely reflect the real-world context in order to produce meaningful results (Blomkvist 2011, 2014 + Passera et al., 2012).

3.3.3 Frameworks for Service Prototyping

The first framework for service prototyping was developed by Blomkvist (2011) and expanded by Passera et al.(2012). The latter, building upon Blomkvist's work, propose the 'Service Prototyping Practical Framework', which is a more applied perspective. They provide a series of guidelines, defining them as an "aid for thinking and asking fundamental questions when prototyping" (Passera et al., 2012, p.5). The combination of the two will be described briefly in this next section as it will be used as main guide to describe and analyse the prototyping activities carried out for the development of this thesis project.

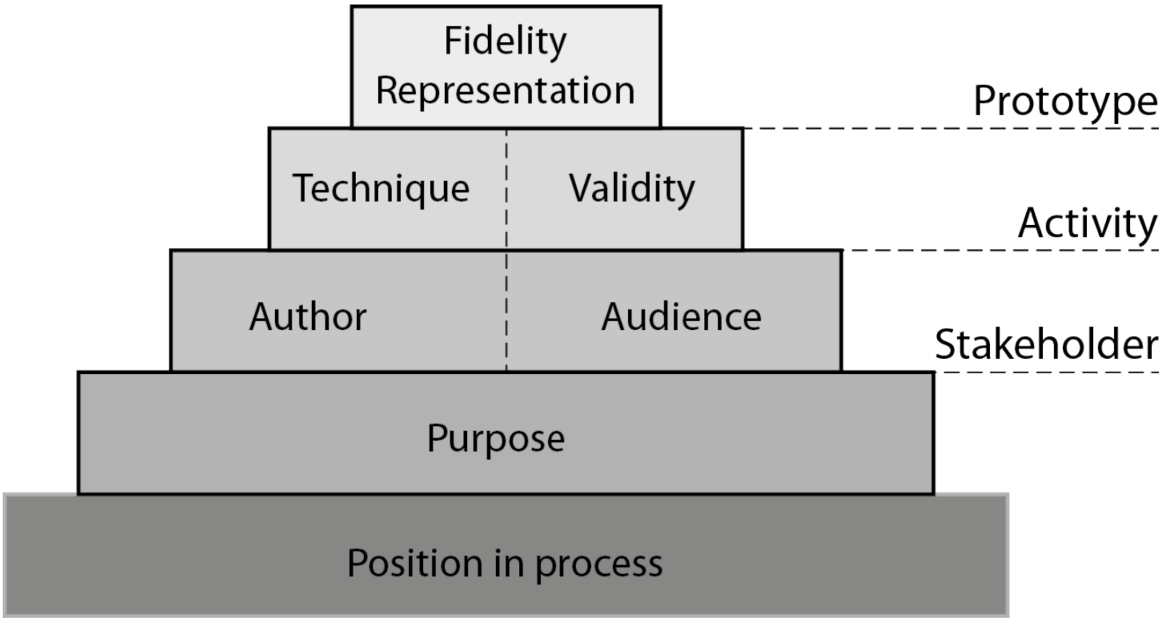


Figure 52 - Original Service Prototyping Framework by Blomkvist (2011).

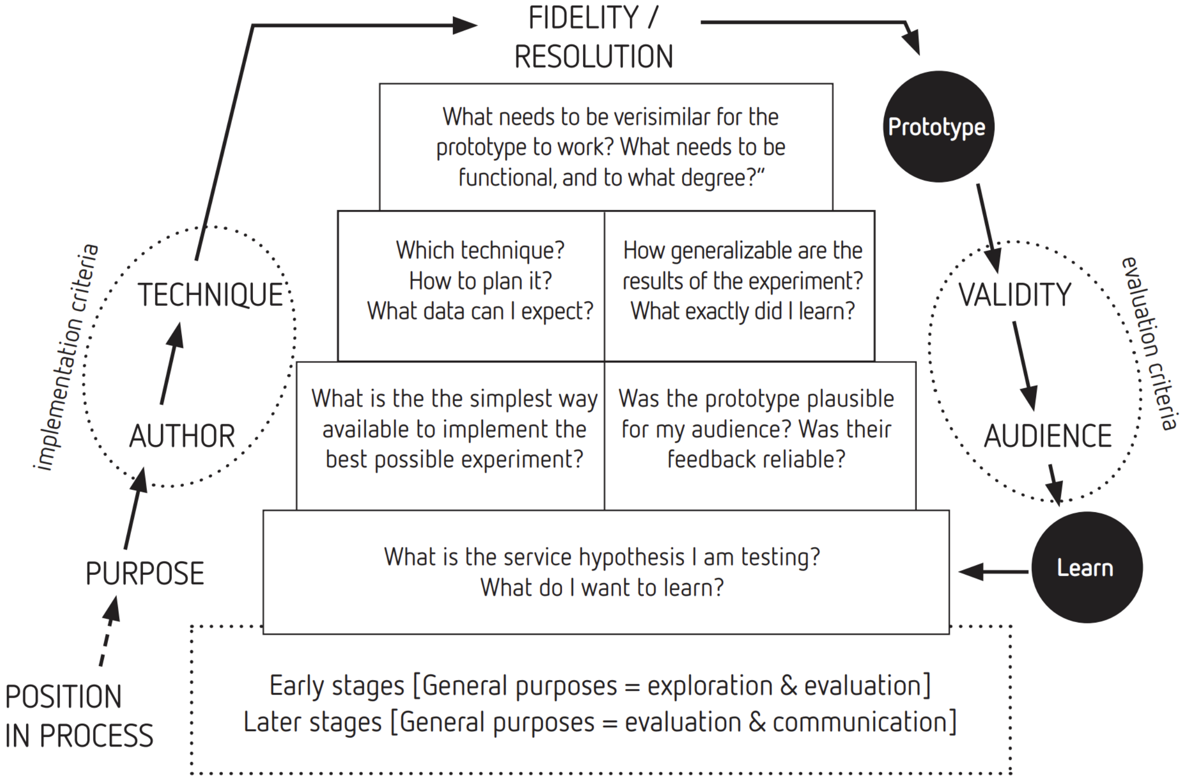


Figure 53 - The Service Prototyping Practical Framework by Passera et. al (2012).

This framework highlights the multiple dimensions of Service Design prototyping, specifying their interconnections (Blomkvist 2011, Passera et al., 2012). They are: position in process, purpose, audience, technique, fidelity and representation (Blomkvist, 2011).

<u>Position in process and purpose</u>

'What is the service hypothesis I am testing? What do I want to learn?'

The position in the process, as the words itself explain, refer to the moment of the Service Design in which the prototyping happen, and it is the starting point of all activities. The purpose of prototyping, instead, is a crucial perspective that dictates how prototypes are constructed.

They are strictly connected: each purpose is distinct and can relate to a specific point in the process itself. Explorative prototypes are used in early stages of a project and are well-suited for rapid prototyping projects, while evaluation prototypes are based on more elaborate design ideas and generally have a more explicit hypothesis. When prototypes are used as tools for communication, the purpose may be more focused on presentation and persuasion. In this case, prototypes suggest new project directions, ensure stakeholders are on the same page, or receive input on improvements. Regardless of the purpose, it is essential to be clear about it to make evaluation possible.

Author and resources

'What is the simplest available way to implement the best possible experiment? To what resources do we have access?'

The author is the person who defines and plans the prototype set up (Passera et al., 2012). The Author plays a significant role in determining the appropriate technique to use, how to represent the prototype, and the context in which it should be tested.

The resources are physical items (eg. Money, materials, tools, equipment) or intangible assets (eg. Human, time, knowledge) available to carry out the prototyping activities. Passera et al. (2012) present a set of heuristics (location, users, staff, props) that can help to frame and assess them.

Technique

'Which technique? How to plan it? What data can I expect?'

The available resources and the Authors' skills mostly dictate which techniques it is used (Passera et al., 2012). There are categorized technique repositories available to development teams (eg. Moritz, 2005; Segelström & Holmlid, 2009; Stickdorn & Schneider, 2018; Service Design Tools[43]), but a more precise approach is to understand the purpose of each technique and the results it can provide, so to personalize and customize each of them or create new ones (Passera et al., 2012). It is also important to ensure that the chosen testers or audience can understand and relate to the experiences created by the technique.

[43] Tools | Service Design Tools

Fidelity/resolution

"What needs to look and feel verisimilar for the prototype to succeed? What needs to be functional, and to what degree?"

Regarding these concepts the frameworks builds on theories described previously (paragraph 3.3.2). According to it fidelity ought to be employed to depict individual features of a prototype, whereas resolution (as the combination of the fidelity of separate features) can reflect the overall degree of authenticity of the service prototype. A "resolution graph" allows to regulate the level of implementation quality across various service aspects (Passera et al., 2012).

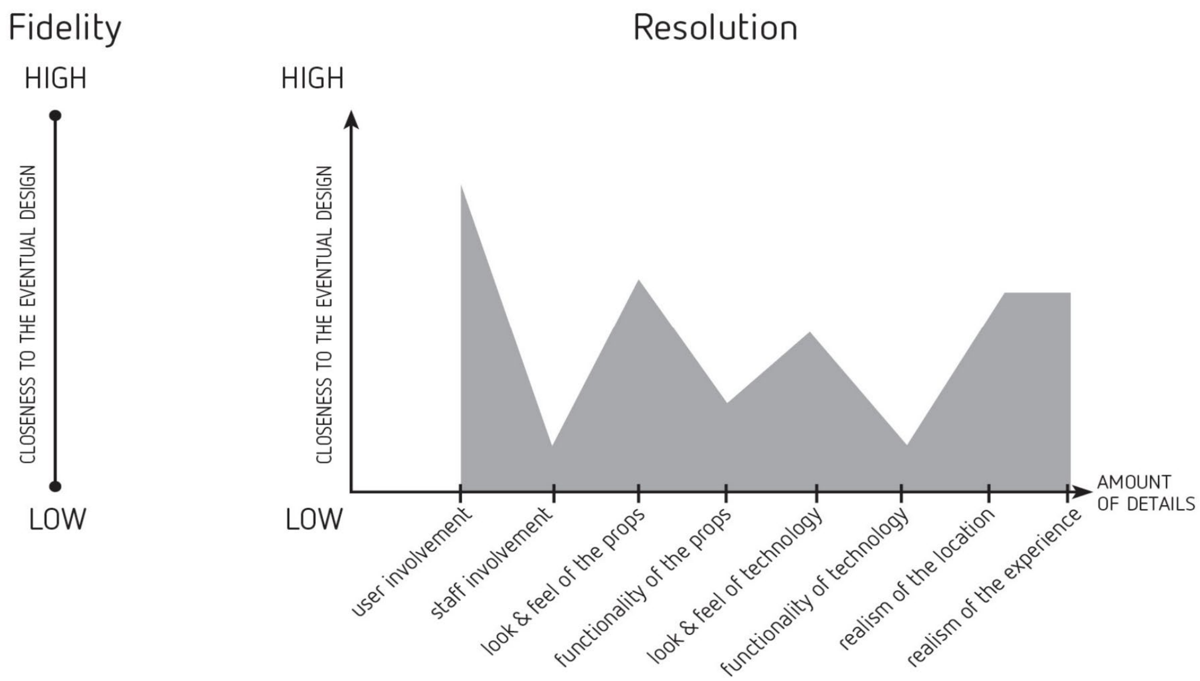


Figure 54 - Fidelity/resolution graph as proposed by Passera et al. (2012).

Moreover, fidelity/resolution are strictly related to representation (Blomkvist, 2011). The representation perspective refers to how they are materialized and what they look like and it is certain service categories, particularly those that heavily rely on physical or visual elements such as servicescapes (Blomkvist, 2011).

Validity

'How generalizable are the results of the experiment? What exactly did I learn from what I tested?'

The concept of validity relates to *"the context in which the prototype is used or evaluated."* (Blomkvist, 2011). It *is* closely linked to the technique and is contingent upon the nature of the prototype and the type of service it represents. (Blomkvist, 2011). Moreover, it is a crucial aspect of the evaluation process and involves being honest about whether the prototype achieved its purpose, if it was well received by the audience and if it generated new valuable insights (Passera et al., 2012).

<u>*Plausibility*</u>

"Was the prototype plausible for my audience? Was their feedback reliable?"

Plausibility is an experiential quality arising from the user encounter with the prototype" (Passera et al., 2012). A prototype that is plausible can help testers imagine and understand the service hypothesis, leading to more trustworthy feedback.

3.3.4 Service Prototyping process

As for the codesign sessions, also for creating and defining prototyping moments it is necessary to follow a process.

In the case of evaluative prototyping the sessions should first of all based on data coming from a research phase and a subsequent conceptualization phase before it can begin (Blomkvist, 2011). This means that the process starts by using an existing service visualization (a shared understanding between the stakeholders) to determine which areas need to be designed or improved (Blomkvist, 2011).

In this paragraph a brief overview of how this process can be structured will follow.

1. Analysis of Service (whole and in detail). The process begins with a visualization of an existing service, typically using data collected during the research phase and codesign activity of service design projects (Blomkvist, 2011). From these designers can analyse the details of the service and their correlation with the overall service proposition by viewing the service in its entirety and by zooming in and out to comprehend the specifics of what happens (Blomkvist, 2011).

Examples of these visualizations are customer journey maps (Følstad & Kvale, 2018; Stickdorn & Schneider, 2011), service blueprints (Bitner et al., 2008), storyboards (Stickdorn et al., 2018).

2. Selection of what can/should be designed/redesigned. After defining the service category, based on the service representation, necessary parts of exploration and modification (whole phases, steps, encounters, touchpoints, interactions) are identified (Stickdorn et al., 2018), as well as crucial points of the service that are essential for the experience and valued by the stakeholders (Blomkvist, 2011).

3. Definition of the goal. A clear goal or assumption about how the behavior will change with the new prototype are outlined, so to have a basis to which evaluate the prototype to (Blomkvist, 2011).

4. Design of the necessary parts. The variety of designed materials and interactions referred to the specific sections defined in point 2 is produced (Stickdorn et al., 2018). All the physical evidence (props), immaterial artefacts and the environment with which the customer and other stakeholders

interact (Patrìcio & Fisk, 2013), such as face-to-face interactions, behaviors, scripts, signs, colors, interfaces, furniture, sound, smell, etc.. When designing these parts, the prototyping perspectives framework can be used to consider the prototype's fidelity and representation, content, audience, and other aspects (Blomkvist, 2011).

5. Service and prototype evaluation. Sensemaking activities are carried out, which involve combining and analyzing the data to draw meaningful conclusions about both the future service situations and the prototype itself (Stickdorn et al., 2018).

6. Iteration. Ideally, the prototype should be flexible enough to allow for changes to be made from one day to the next, incorporating feedback from each version of the prototype (Blomkvist, 2011).

3.3.4 The Service Walkthrough technique

Many techniques for prototyping exist and could be potentially used in conjunction to prototype services (Blomkvist, 2011, Stickdorn et al., 2018).

A specific and more precisely service focused technique, though, exists and it is called "service walkthrough". Service walkthrough (Arvola et al., 2012; Blomkvist, 2011, 2014, p. 20; Blomkvist et al., 2012; Blomkvist & Arvola, 2014, 2014; Blomkvist & Bode, 2012.) is built on already existing techniques: experience prototyping (Buchenau & Suri, 2000), bodsytorming (Schleicher et al., 2010) and pluralistic walkthrough techniques. This paragraph will briefly explain its origins and outline a brief description, as it is the main techniques applied in the prototyping activities of this thesis project.

EXPERIENCE PROTOTYPING

Buchenau and Suri (2000) introduced the concept of experience prototyping as a method for exploring the user experience of a service through the creation of "quick and dirty" prototypes. According to Stickdorn and Schneider (2011), experience prototyping in a service design context "creates a near-real environment in which the service is performed or experienced, allowing the designers to empathize with the users and gain a deeper understanding of their needs and behavior."

This technique involves prototypes that are mainly low-fidelity or abstract, but designed to be experienced by users in order to elicit feedback and insights (Buchenau and Suri, 2000). Another key point to mention Is that experience prototyping can be particularly useful in the early stages of a design process, where there may be a lack of clarity or agreement about user needs or specific requirements (Buchenau and Suri, 2000).

BODYSTORMING

The term was first coined by Allison Druin in the early 1990s (Druin & Solomon, 1996). Bodystorming is a prototyping technique that involves physically acting out a service or experience in order to gain a better understanding of how it might work in practice (Buchenau & Suri, 2000).

During bodystorming, participants take on the roles of different users, and physically move through the space in which the service or experience would occur. This can help designers to identify potential issues or challenges, and to generate ideas for how to improve the service or experience.

PLURALISTIC WALKTHROUGH

Pluralistic walkthrough was first introduced by Hughes et al. in 1995. In pluralistic walkthrough the aim is to identify potential usability issues and generate design ideas, bringing together stakeholders with different backgrounds and perspectives to review and critique a design (Hughes et al., 1995). By playing different roles in the process (eg. users, developers, and designers), and each brings their own expertise and insights. The technique involves a structured walkthrough of the design, with the stakeholders taking turns to comment on different aspects of the design (Hughes et al., 1995). The facilitator guides the process and ensures that everyone has the opportunity to share their feedback. The feedback is then synthesized and used to inform design decisions (Hughes et al., 1995).

SERVICE WALKTHROUGH

Service walkthrough, by drawing on the previously described tehcniques, can be considered a participatory and iterative process that includes several rounds of testing and evaluation of service prototypes (Blomkvist & Bode, 2012.). It is considered an “ongoing” representation on/of service: it is interactive and responsive to actions because they involve humans and instantaneous, spontaneous, and fleeting because it exist only in the present moment and disappear soon after (Blomkvist, 2014).

The service walkthrough technique is scenario-based, meaning that a service scenario or a sequence of service touchpoints is used as a starting point for the walkthrough (Blomkvist et al., 2013; Sangiorgi, 2011). Then service walkthrough can bring to life, in a somewhat realistic way, a service in its completeness (end to-end) by having people physically enacting the sequence of carefully orchestrated steps of the service journey and live the experience as close as possible to the ideal version (Arvola et al., 2012; Blomkvist, 2011; Blomkvist et al., 2012; Blomkvist & Bode, 2012; Blomkvist, 2014; Blomkvist & Arvola, 2014).

It is a visual and tangible approach that helps stakeholders to understand the service concept and experience and supports the co-creation of services (Blomkvist & Bode, 2012) and the development of a shared understanding of the service concept among stakeholders (Blomkvist et al., 2012.

Finally, it is worth mentioning that service walkthrough technique is an iterative process, where the scenario is revised and refined based on feedback and insights from stakeholders, to ensure that the service meets the needs and expectations of all stakeholders (Blomkvist et al., 2013; Sangiorgi, 2011).

4. CHECKD. DESIGN PHASES

4.1 Project methodology

Every service design project requires a unique and tailored approach that is specific to its context, goals, and stakeholders. Service design is a highly iterative and human-centered process that involves exploring, understanding, and solving complex problems in collaboration with stakeholders. Therefore, the process for each project must be flexible and adaptable, allowing for ongoing feedback and refinement based on the insights and discoveries made throughout the project.

Chapter 3 discusses one of the most popular frameworks for iterative design: the Double Diamond. However, another approach to service design, the MEDGI process, was outlined. Both the approaches, at times merged, served as a starting point for structuring a personalized take of this thesis project.

A three-macro phases process was carried out:

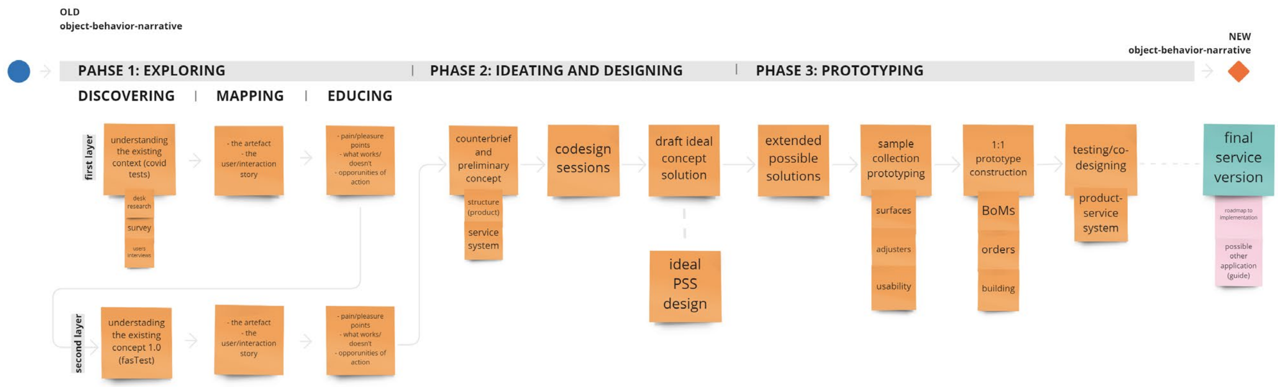


Figure 55 - Process overview.

PHASE ONE: EXPLORING

The exploring phase consisted of a series of “sub-phases”: discovering – mapping – educing. These three activities were applied to two distinct layers of the project in the same manner: the context and the existing concept (fasTest).

LAYER #1: The context

During the discovering phase, the goal was to gain a deeper understanding of the problem or situation that was being addressed and its wider context, including factors such as infectious diseases, testing options, and wider impacts. To achieve this, desk research was conducted on more general topics that were then funneled into a selection specific to COVID-19.

In the mapping phase, the results of a survey were elaborated and integrated with the information gathered during the initial research to create multiple "testing experience maps." These maps were visual representations of the "old" object-behavior-narrative drafted as a starting point. The maps captured the people's perceptions, behaviors, and feelings related to multiple experiences linked to the testing process.

Finally, in the educing phase, a further layer of analysis was added to the testing experience maps, showing pain and pleasure points. This layer of analysis helped to extract insights and ideas from the data, which could be used to inform and guide the design process.

LAYER #2: fasTest

In parallel with user research, a thorough exploration of the existing idea was carried out. The project proponent had, in fact, already autonomously drafted a rough product for implementing the technology, in a draft called “fasTest”. I analyzed and mapped the user “experience” associated with this concept, and subsequently expanded on it. Through this process, I was able to identify what worked and what did not, as well as potential future opportunities for action.

PHASE TWO: IDEATION AND DESIGN

The second phase included seven co-design sessions, which involved a total of 16 people who were identified among the possible user categories, the latter defined in collaboration with the project proponents and their vision for the project in previous discussions, despite the fact that, in this particular case, the user could virtually be “anyone”.

By using different types of tools, the co-design sessions aimed to expand on the service system's essential framing and start a discussion around the different facets of the booth structure, such as the look and feel, the spaces, and the interactions with the machines inside.

Following the co-design sessions, a comprehensive experience map/customer journey map was constructed based on the insights obtained during the discussions concerning the service system. Furthermore, requirements for the physical product (i.e., the booth) were specified, and three distinct structure concepts, along with optimal swabbing procedure steps, were formulated. Through stakeholder deliberation, one of the proposed concepts was designated as the preferred solution based on specific criteria.

PHASE THREE: PROTOTYPING

The final phase of the project encompassed various prototyping activities. The first prototyping session focused on the sample collection procedure, using an experience prototyping technique. The insights gleaned from this session were subsequently analysed and integrated into the existing knowledge base, thus guiding the next stage of prototyping. The second session involved a complete service experience and utilized the service walkthrough technique. The data obtained from this session yielded several distinct insights, which were then clustered and analysed in order to identify possible future implementation steps.

Prototyping is a crucial tool to explore and communicate the ideas in a tangible form, and to get feedback from users and stakeholders, as early as possible in the design process (Stickdorn et al., 2018). It is fundamental, in fact, to test and refine specific solutions before investing significant time and resources in developing a full-scale service.

4.2 Phase one: Exploring

4.1.1 Introduction to the process

In late April 2022, a “kick-off meeting” was conducted by the CEO of the startup and another employee to introduce the project. During the meeting, the CEO presented a preliminary brief that outlined the primary direction that the startup and other stakeholders intended to follow. The brief consisted of a conceptual proposal with inspirational pictures that were broadly presented and described: the main goal was to develop a sort of “vending machine” or “photo-booth”-like structure for diseases self-testing. Keeping in mind this context and objective, a semi-structured brief was created during the meeting, to include the core aspects in need of a first review and potential final outputs.

Starting from the core aspects was critical, because it was their definition that would give a specific direction to the project.

CORE ASPECTS

Target environment

- Airports, shopping malls, universities, convention centers, hospitals, squares/streets, municipalities.

Target application

- Saliva-detectable diseases (Covid, Flu, RSV..)

- Nasal/Mouth swab-detectable diseases

- Intimate-swabs (e.g. vaginal)

- Blood (e.g. Malaria)

Target user

- Anybody
- Potentially also developing countries

POTENTIAL OUTPUTS

Service

Offering, Stakeholders, Personas, How to approach the service, Working principle, Interface + Sample collection.

Communication

Brand identity, Communication strategy, Marketing, Signage.

Interior

Booth, Shape, Material, Dimensions, Components.

Business

Business Model, Value proposition, Competitors.

For my first task, I was asked to write a *counter brief* that would identify primary opportunities and issues about the project's core aspects, draft a possible process to follow, and provide a practical starting point. Unlike a traditional SD process, this was a departure from the norm as the original concept idea was already formulated, but had to be expanded and deeply refined.

To solidify the project's framework and provide valid counterpoints, I explored each aspect in detail, seeking to expand on each point, identify potential challenges and opportunities, and gain a comprehensive understanding of the subject matter. This involved delving into complex and technical topics related to testing typologies, infectious diseases, and their scientific background, origins, and mechanisms, as well as the broader context of diagnostics and the impact of such diseases. A key aspect was the distinctions between testing typologies, which required careful attention and clear understanding to determine the potential value of the proposed Product-Service System.

To achieve this, I conducted desk research or secondary research, which involved analyzing previously published or collected data and literature.

The insights gained from the preliminary research were presented in a counter brief proposal during a subsequent meeting, which defined the guidelines for the project more officially.

This initial work was carried out from Italy. In fact, the collaboration with the different stakeholders started, for organizational purposes, started in remote and continued for the whole month of May 2022.

CORE ASPECTS – REVIEWED

One very important premise made was that target environment, target application and target user were fundamentally interlinked and dependent from each other, therefore defining one or more would influence critical decisions also on the remaining.

Target environment

From the proposed locations, only "indoor" spaces were deemed optimal. In fact, compared to outdoor locations, they can support a smooth functioning of the booth in its different aspects:

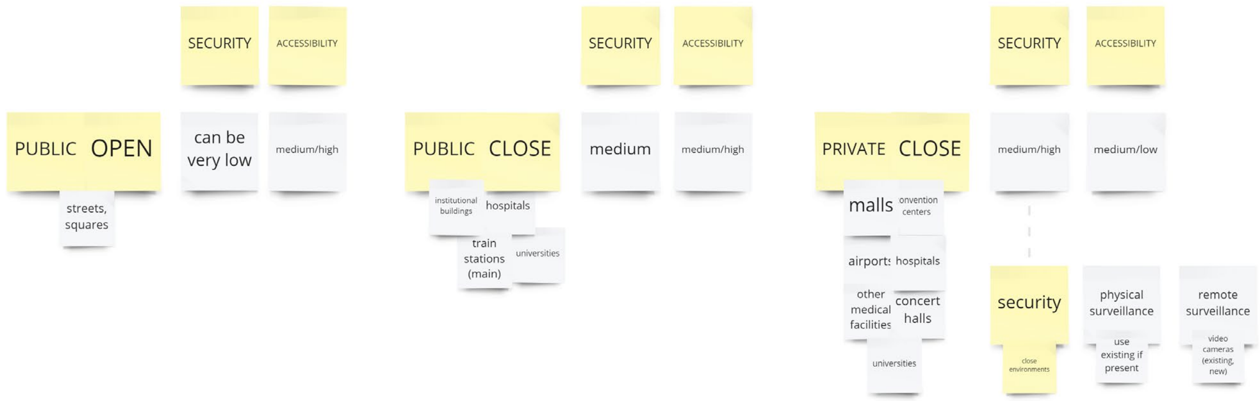
- Operational side. Indoor locations can avoid complications due to adverse weather, that could make the waiting time difficult (and thus reduce the accessibility). Moreover, placing this kind of booth into a public location might require long times and processes to acquire the necessary permissions. Finally, the complexity level of the servicescape and flows managements could be too high and therefore not manageable.
- User experience. Indoor locations offer more opportunities to create a welcoming environment with seatings (especially if already present) and more easily support the journey with signage and wayfinding.
- Accessibility. This is critical, given that the booth's services are oriented towards "anyone." Indoor locations can be more accessible than outdoor locations, which are often full of architectural barriers. The booth must be easy to reach for all categories of users and easily accessible through public transportation. Additionally, having more "stations" in different parts of a city can improve this aspect, as their increase in number and differentiation in position can make them more easily reachable.
- Security. It is also crucial, given the handling and general presence of biohazard material. Therefore, there is a need for video or physical surveillance to ensure compliance with regulations and laws in specific environments. Having a robust security system can create trust in the customer/user and show reliability. Leveraging an existing security systems that are installed in the cited indoor locations (eg. airports) can be a convenient solution, but it depends on the allocated space inside different facilities.

Criticalities of indoor spaces, though, are also mentioned:

- Available space inside the location. This needs to be enough to accommodate the testing station and do not stand in the way of the other activities happening in the building. This might prove a challenge.
- Necessity of a safe distance between people waiting, as the main topic is infectious diseases.

Based on these aspects, proposed environments for the booth were put in a priority order: transportation hubs, with airports as main location, then train and bus stations. Following, malls, hospitals, and other medical facilities, universities, and convention centers.

Figure 56 - Overview of environmental aspects.



Target application

In terms of the target application, a counter-proposal was made to reduce the scope to a specific category of diseases. This was because the significant difference in their nature led to implications that were too diverse and incompatible with each other, making it impossible and impractical to develop a truly one-size-fits-all solution.

Intimate swabs, body fluids, and blood would require additional design complexity for both the booth's architecture and service, such as lock-secured space for privacy, a full/automatic sterilization system, and different interior and sample processing components. Moreover, from the perspective of defining the user and conducting user research, this would involve an almost infinite pool of users with profoundly different and disconnected categories.

As a result, the initial focus was on diseases detectable through saliva and nasal/mouth swabs. Ultimately, the decision was made to mainly structure the project on Covid-19 since it was still a relevant topic at the start of the project (spring 2022) and due to its strong connection with the prioritized locations (target environment).

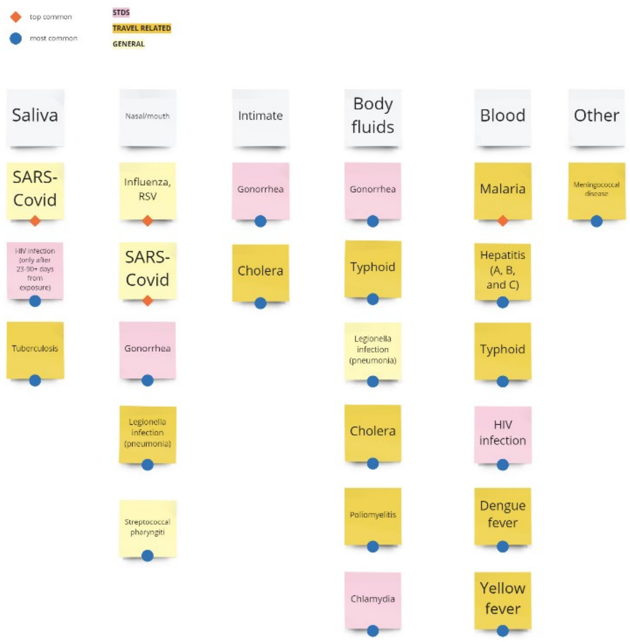


Figure 57 - Overview of potential applications

Target user

The main nature and function of an "automatic testing station" could hypothetically be really for "everyone". Having "anyone" as a user, though, it is not feasible in a SD project. One of the first and necessary steps that had to be taken, in fact, was to define the user in greater detail. Who will be using the automatic booth? And what is their specific contex and situation and broader everyday-life needs? Answering these questions is critical in order to shape the product-service system itself and an accurate value proposition. With "anyone" as audience, with no minimal specifications, the possibilities would be infinite and therefore impossible to manage properly with only one solution.

Figure 58 – Relationship between the core aspects of the project, with the user as main shaper of the product-service system.

Regardless, three main universal/horizontal “categories” to take into consideration were identified:

- Layperson (general user).

- Child/minor (accompanied by an adult/parent/caregiver).

- Persona spectrum (characterized by permanent, temporary or situational factors that bring about certain constraints which may affect the user’s interactions with the product/service).

A broad version of the possible process to follow was also outlined, including potential next steps. Further desk research was needed, first to explore the newly established boundaries in greater detail and refine the project's focus accordingly. Second, and most importantly, to understand and define the potential user categories and their implications, as this would be a crucial milestone for the project's future development. After this a thorough investigation of the existing concept (fasTest), developed by Diaxxo AG, was planned.

4.1.2 Layer #1: the Context

Following the preliminary research and core aspects discussion, the initial “stage” for the project became much narrower, creating a less “expansive” environment for analysis: this marked the real beginning of the exploring phase. In particular “layer #1-the context” aimed to gain a deeper and more detailed understanding of the contextual basis for the future Product-Service System.

In practical terms, this implied investigating the topic of Covid-19, including its connection to and impact on travel and the current Covid-19 testing typologies. Understanding the latter was critical to the success of the proposed system, as it could directly impact its value and feasibility.

DISCOVERING

Covid-19, travelling and pandemics

COVID-19 is an infectious disease caused by the novel coronavirus SARS-CoV-2 that first emerged in Wuhan, China, in December 2019[44]. The virus quickly spread to other parts of China and eventually worldwide. On December 31, 2019, the World Health Organization (WHO) was informed of a cluster of cases of pneumonia of unknown cause in Wuhan, China[45]. By January 7, 2020, Chinese authorities had identified the virus as a new coronavirus (Zhu et al., 2020). This agent, known as SARS-CoV-2, is similar to the virus that caused the SARS outbreak in 2003. However, SARS-CoV-2 is more contagious and has spread rapidly worldwide, resulting in over 40 million confirmed cases and 6 million deaths as of March 2023, according to the World Health Organization[46].

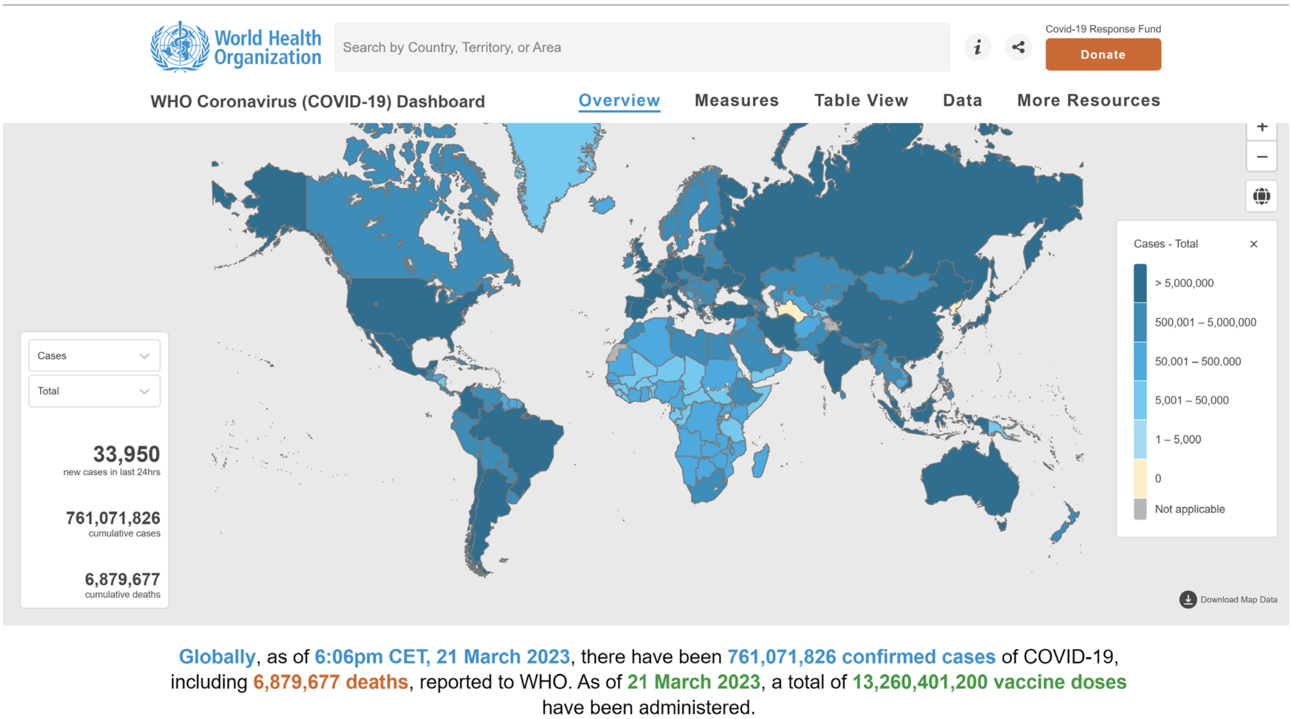


Figure 59 - Covid-19 in numbers. Source: World Health Organization.

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44 A Virus Outbreak, Netflix's Oscar Nod Dominance, and More News | WIRED
45 Statement on the meeting of the International Health Regulations (2005) Emergency Committee regarding the outbreak of novel coronavirus 2019 (n-CoV) on 23 January 2020 (who.int)
46 WHO Coronavirus (COVID-19) Dashboard | WHO Coronavirus (COVID-19) Dashboard With Vaccination Data

The disease is primarily transmitted through respiratory droplets, and symptoms can range from mild to severe. Common symptoms include fever, cough, and shortness of breath[47]. The virus can also cause more severe illness, including pneumonia, acute respiratory distress syndrome (ARDS), and multi-organ failure, particularly in older adults and those with underlying medical conditions (Eastin & Eastin, 2020; X. Yang et al., 2020). COVID-19 can also cause long-term symptoms, known as "long COVID," including fatigue, shortness of breath, and cognitive impairment, among others (Nalbandian et al., 2021).

In March 2020, the WHO declared COVID-19 a pandemic. Pandemics are defined by as "an epidemic occurring worldwide, or over a very wide area, crossing international boundaries and usually affecting a large number of people" (Kelly, 2011). The declaration of a pandemic is a significant event that often triggers a coordinated international response to control the spread of the disease and mitigate its impact. The COVID-19 pandemic was one of the most relevant after the Spanish flu (1918-1920) pandemic, caused by the H1N1 influenza virus, that killed an estimated 50 million people worldwide, making it one of the deadliest pandemics in history (Johnson & Mueller, 2002).

Significant social, economic, and health consequences were brought about by the pandemic, as many countries imposed lockdowns and other restrictions to slow the spread of the SARS-CoV-2 virus. Increase in mental health issues were registered[48], as wells as job losses, and healthcare system strain (Karan & Wadhera, 2021) . It has also highlighted existing health disparities, with marginalized and disadvantaged populations being disproportionately affected[49].

The COVID-19 pandemic has had a major impact on travel, with many countries implementing travel restrictions, quarantines, and other measures to slow the spread of the virus. This has led to widespread disruptions in the travel industry, including flight cancellations, border closures, and decreased demand for travel.

Governments around the world have imposed different restrictions on travel, including entry bans, quarantines, and testing requirements. These measures can vary depending on the severity of the COVID-19 situation in different countries, and are subject to change at any time. Travelers should stay informed about the latest restrictions and requirements for their destination and plan accordingly. In addition to government restrictions, airlines, hotels, and other travel-related businesses have implemented new health and safety protocols to protect travelers and reduce the

[47] Symptoms of COVID-19 | CDC
[48] COVID-19 pandemic triggers 25% increase in prevalence of anxiety and depression worldwide (who.int)
[49] Social Determinants of Health and Impact on Marginalized Populations During COVID-19 (uspharmacist.com)

spread of the virus. This can include enhanced cleaning and disinfection, physical distancing measures, and mandatory mask-wearing.

Travel started to gradually resume in late 2021 but travel was still strictly linked with constant disruptions and changes, especially related to entry requirements, flight cancellations or quarantine guidelines.

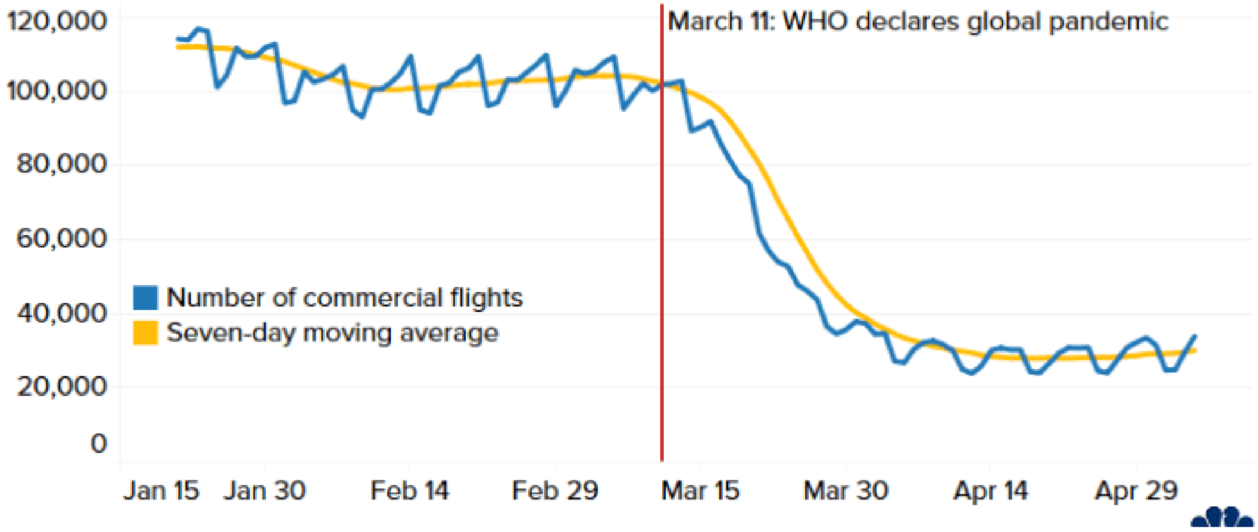


Figure 60 - Drop in travel from the start of the pandemic. Source: Flightradar24.

Governments and health organizations around the world have responded to the pandemic with a range of measures, including lockdowns, travel restrictions, and widespread testing and vaccination programs. These efforts have helped to slow the spread of the virus and protect public health, but the pandemic continues to evolve and has had significant impacts on the global economy, public health systems, and daily life.

Testing remains one of the most critical tools for reducing and controlling pandemics, such as the Covid-19 one. Some key reasons why testing is important:

1. Early Detection: Testing can help detect cases of infectious disease early, allowing for prompt isolation and treatment of infected individuals. This can help to prevent further spread of the disease (Lai et al., 2020).
2. Contact Tracing: Testing can be used to identify and trace contacts of infected individuals, enabling public health officials to contain outbreaks and prevent community spread[50].

[50] Contact Tracing for COVID-19 | CDC

3. Monitoring Disease Spread: Testing data can provide valuable insights into the spread and severity of a pandemic, helping public health officials to make informed decisions about resource allocation and public health interventions (Camille, 2020).
4. Disease Surveillance: Testing can be used to monitor the prevalence of a disease over time, allowing public health officials to track the effectiveness of interventions and adjust strategies as needed[51].

Covid-19 testing typologies

Since Covid-19 is an infectious disease, its testing options reflect what already described in chapter 2, paragraph 2.4.4.

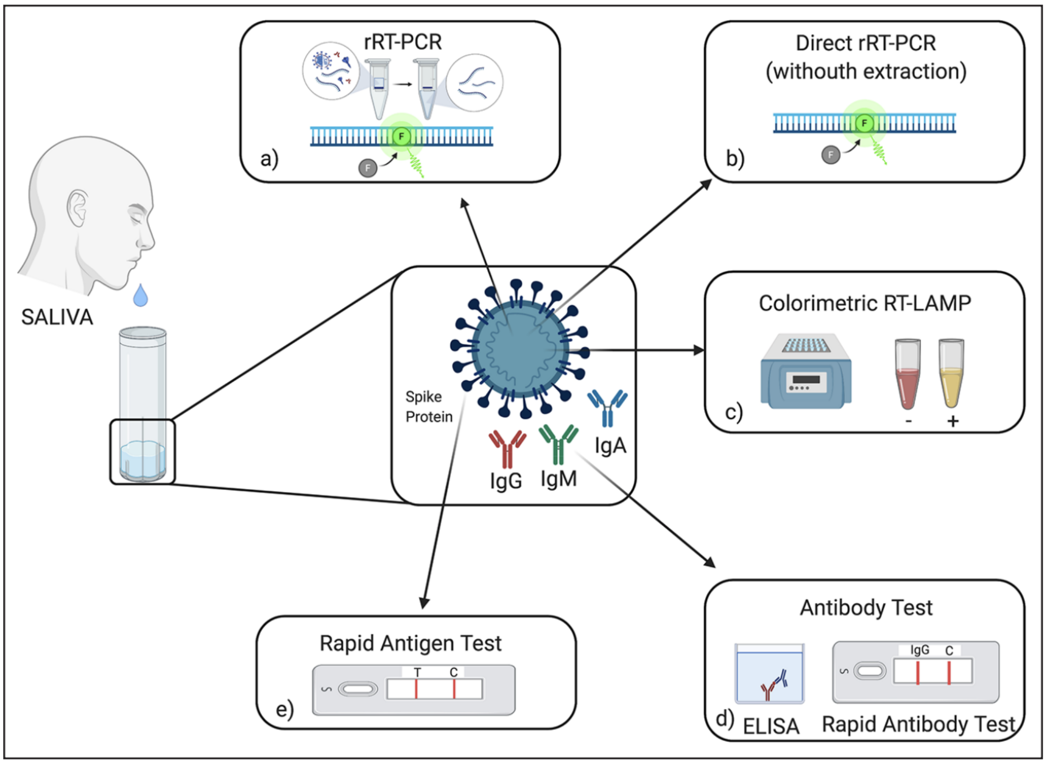


Figure 61 - Overview of Covid-19 testing typologies. Source: Azzi (2021).

A. MOLECULAR TESTS (PCR)

[51] Diagnostic testing for SARS-CoV-2 (who.int)

The Polymerase Chain Reaction (PCR) is the gold standard for detecting infections and diseases caused by viruses, bacteria, or parasites (Everitt et al., 2021). PCR is a technology that allows for the direct detection of the genetic material (DNA or RNA) of these pathogens in a patient's biological sample. RT-PCR (Reverse-Transcriptase Polymerase Chain Reaction) is a variant of PCR that is used specifically to detect RNA. PCR is widely used testing to combat pandemics and for detecting infectious diseases (Everitt et al., 2021).

It works by amplifying a specific section of DNA or RNA through multiple cycles of heating and cooling, resulting in billions of copies of the targeted sequence [52]. When the starting genetic material is RNA, it must first be converted into a complementary DNA copy before amplification, which is called reverse-transcriptase PCR (Farrell, 2010). There are two types of PCR: qualitative and quantitative. Qualitative PCR is used to detect the presence or absence of a pathogen by producing a specific DNA product, while quantitative PCR not only detects but also measures how much of a specific DNA is present in the sample in real time.

RT-PCR is considered the gold standard for SARS-CoV-2 diagnosis, but it has some limitations such as a high false-negative rate and the need for specialized laboratory equipment and trained personnel. (Kevadiya et al., 2021; Song et al., 2021).

[52] Polymerase Chain Reaction (PCR) Fact Sheet (genome.gov)

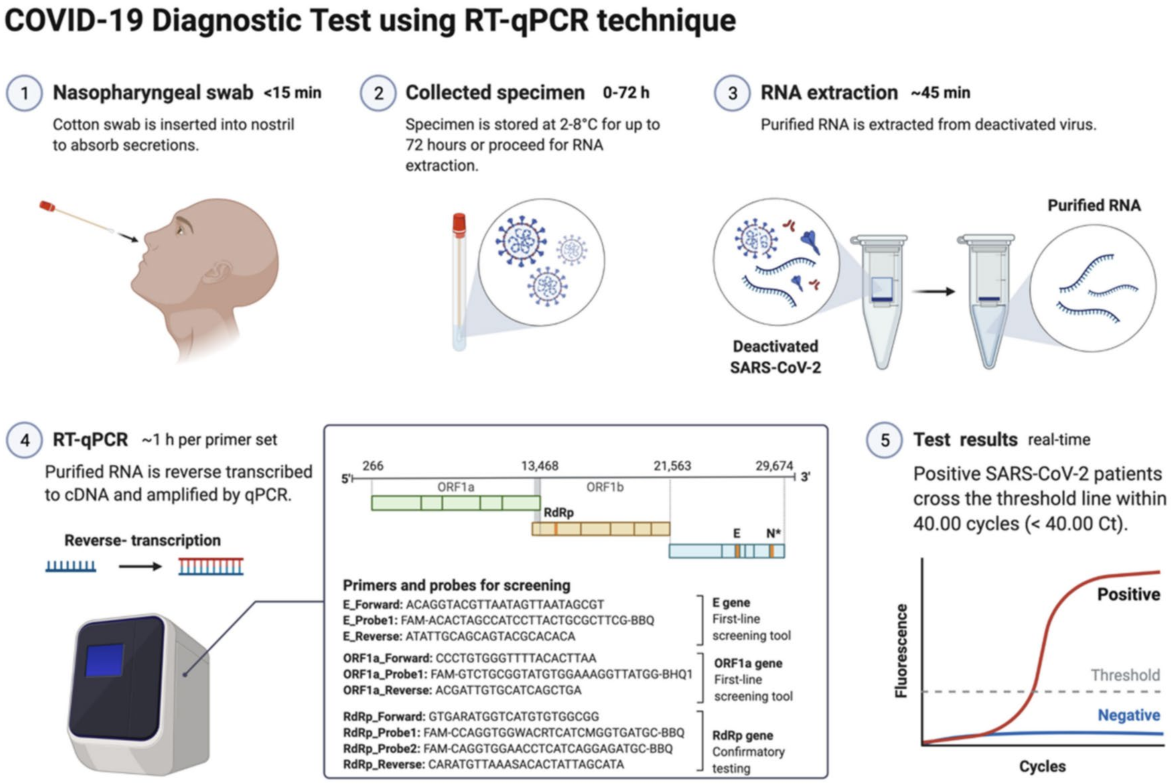


Figure 62 - Overview of PCR technique. Source: Dutta et. al. (2022).

1. Collection of a sample [up to 3 minutes]. The first step in a PCR test is to collect a biological sample from the patient, typically using a swab. In standard procedures for viral detection, clinical samples are collected using nasopharyngeal swabs (NPS) and/or oropharyngeal swabs (OPS) and placed in a sealed container with viral transport medium or isotonic saline. This is done to preserve the sample's integrity and ensure accurate viral detection (Gao & Quan, 2020).
2. Isolation of genetic material/sample preparation [This step can take up to several hours, depending on the specific protocol and the type of sample being prepared. For example, RNA extraction from a nasal swab sample can take approximately 30 minutes to 1 hour.]. Once the sample has been collected, the next step is to isolate the genetic material from the virus (in this case, RNA) using a process called RNA extraction. This involves breaking open the virus particles and extracting the RNA using various chemicals and mechanical techniques (Song et al., 2021).
3. Reverse transcription [1-2 hours]. RNA needs to be converted into DNA before it can be amplified. This is done using a process called reverse transcription, which uses an enzyme called reverse transcriptase to create a complementary DNA (cDNA) strand from the viral RNA (who doc).

4. Amplification of genetic material [The amplification step usually takes around 2-4 hours, depending on the number of cycles required and the equipment used.]. Once the viral RNA (or cDNA) has been isolated, the next step is to amplify it using the PCR process. This involves using special enzymes (such as Taq polymerase) and primers (short, specific pieces of DNA or RNA that bind to the viral genetic material) to repeatedly heat and cool the sample, which causes the viral RNA to be replicated millions of times, creating millions of copies of the original genetic material (Song et al., 2021; Dutta et al., 2022).
5. Detection of amplified genetic material [For example, gel electrophoresis can take several hours, while fluorescence detection can be completed within a few minutes.]. After the genetic material has been amplified, it needs to be detected. There are various methods for detecting amplified DNA or RNA, including gel electrophoresis, hybridization, and fluorescence-based detection. In the case of most PCR tests for SARS-CoV-2, fluorescence-based detection is used. This involves using a fluorescent dye that binds to the replicated viral RNA, which emits a fluorescent signal that can be detected and measured by a special instrument (Dutta et al., 2022)
6. Interpretation - Interpretation of the results usually takes only a few minutes, once the detection method has been completed.

Advantages:

- It can be automated (Everitt et al., 2021; Murari, 2022).
- Fast test to develop, it can take as little as a week (Everitt et al., 2021).
- Premade reagents kits are available (Murari, 2022).
- High-throughput robotic sample handling (Everitt et al., 2021).
- Very early detection is possible, even from one strand of DNA/RNA in sample (Everitt et al., 2021).
- Very good sensitivity and specificity, meaning that it is very reliable (Camille, 2020).

Disadvantages:

- Difficult handling of samples: there is the need for a trained user (Everitt et al., 2021), meaning personnel trained for nuclear-acid manipulation (Gao & Quan, 2020). This especially to avoid false positive due to background contamination (S. Yang & Rothman, 2004).

- Multiple steps are required (Everitt et al., 2021), complicating its use on a massive scale (Camille, 2020).
- Instruments size and cost, such as thermal cyclers and other equipment, is relevant (Azzi et al., 2021.; Everitt et al., 2021).
- Singular test cost is high (Murari, 2022).
- Some essential testing materials (e.g. reagents, nasal swabs, transport media, etc.) can be in limited supply (Camille, 2020).
- Only centralized and/or done in commercial laboratories (Everitt et al., 2021).
- Long turnaround time: for testing results often exceed 48 h, which may be further delayed by the daily testing capacity of a laboratory (Gao & Quan, 2020). Logistics of sample collection, transport to a central laboratory, analysis of the sample and return of results cause a long lead time between when a sample is taken and when the results are available and communicated (Camille, 2020).
- Non-negligible risk of viral transmission for the operator who performs the procedure (Azzi et al., 2021).

B. Lateral flow immunoassays – rapid antigen tests

LFIA stands for Lateral Flow Immunoassay **and** are commonly delivered through two main systems: either a dipstick system or a cassette system, to make them portable (Everitt et al., 2021). They are, in fact, considered a Point of Care testing methodology. Their characteristics, in fact, makes them useful for quickly identifying infected individuals and for mass screening in settings such as schools, workplaces, and airports.

They detect antigens, meaning viral proteins (Everitt et al., 2021). Those are a different part of the SARS-CoV-2 virus, which is the protein coating surrounding the RNA genome (Camille, 2020) . Like molecular tests, antigen tests are used to detect the presence of the virus in symptomatic or asymptomatic individuals, and they are carried out using samples collected from the respiratory tract (eg. nasal swabs or saliva).

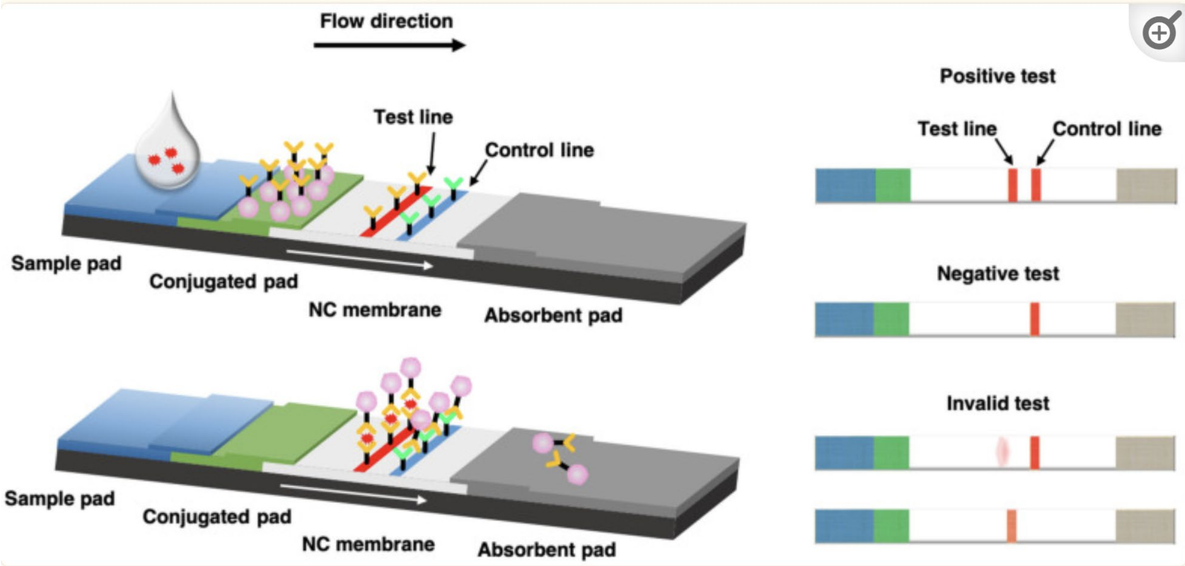


Figure 63 - Cassette system of antigen test. Source: Hsiao et al. (2021).

1. Sample collection [up to 5 minutes]. Nasal or nasopharyngeal secreation or saliva sample are collected either with a swab or a funnel.
2. Lysis buffer [up to 3 minutes]. Sample is mixed with lysis buffer (different techniques depending on sample origin).
3. Discard of parts [instant]. Parts that are not necessary anymore are removed and thrown away.
4. Sample in well. Three drops of sample mixed with lysis buffer are placed into the well.
5. Sample pad. The sample pad collects the sample and begins the process of the lateral flow test, distributing evenly the sample and ensuring an accurate and controlled flow throughout the device.
6. Conjugate pad. The liquid moves from the sample pad to the conjugate pad which stores conjugated labels and antibodies until the test begins (conjugate buffer preserves the conjugate particles). If the target analyte is present in the sample, the conjugates will bind to it and move along with it as it flows through the conjugate pad toward the rest of the device.
7. Membrane. The sample then moves to a nitrocellulose membrane that contains binding reagents at the test lines. The membrane also includes a control line at the end. This line contains specific detection antibodies that bind with the sample to indicate that the test performed correctly.
8. Absorbent pad. It sits at the end of the device and wicks moisture through the membrane, aiding in sample flow and absorbs the sample once it reaches the end of the device.
9. Results reading [results are available after 15 minutes and no more than 20 minutes]. Positive result: If the target analyte has bonded with the conjugate particles in the conjugate pad,

those particles will attach to these binding reagents and form the line. Negative result: if there is no target analyte present, there will be no conjugate particles to bind to the test line, creating a negative result.

Advantages:

- Simplicity of use, as they can be performed at the point of care by placing a swab in contact with the reagent (Camille, 2020)
- Cheap: from USD 15 to less than USD 50.6 (Camille, 2020).
- Speed of the result: most producing a result in 15 to 30 minutes (Camille, 2020)
- Suitable for large-scale testing as there is no instrumentation to use and still have a high number of samples processed quickly (Everitt et al., 2021).

Disadvantages:

- Low sensitivity: false-negative results are frequent (Camille, 2020)
- Samples are directly tested without processing, some interfering substances may prone to lead to false positive or negative results (Song et al., 2021)

C. SIEROLOGICAL TESTS - ELISA

ELISA stands for Enzyme-Linked Immosorbent Assay. This test methodology is a type of immunoassay (a subset of infection diagnostics) that allows to detect antibodies against SARS-CoV-2 in blood samples (or biomarker #2) (Everitt et al., 2021; Kevadiya et al., 2021) or in other bodily fluids (Camille, 2020).

They determine whether a person has developed antibodies against a particular pathogen due to exposure or infection (Camille, 2020). However, they are not suitable for early diagnosis of SARS-CoV-2 infection as antibodies take time to develop. (Kevadiya et al., 2021; Camille 2020).

Generally, immunoassays are test that use a “linear amplification scheme”, which means there is no positive feedback to label the immune detection of a biomarker at a surface (Everitt et al., 2021).

To carry out the detection of an antibody it is possible to use different types of ELISA tests, either an indirect ELISA or a sandwich ELISA[53].

[53] Enzyme Linked Immunosorbent Assay - StatPearls - NCBI Bookshelf (nih.gov)

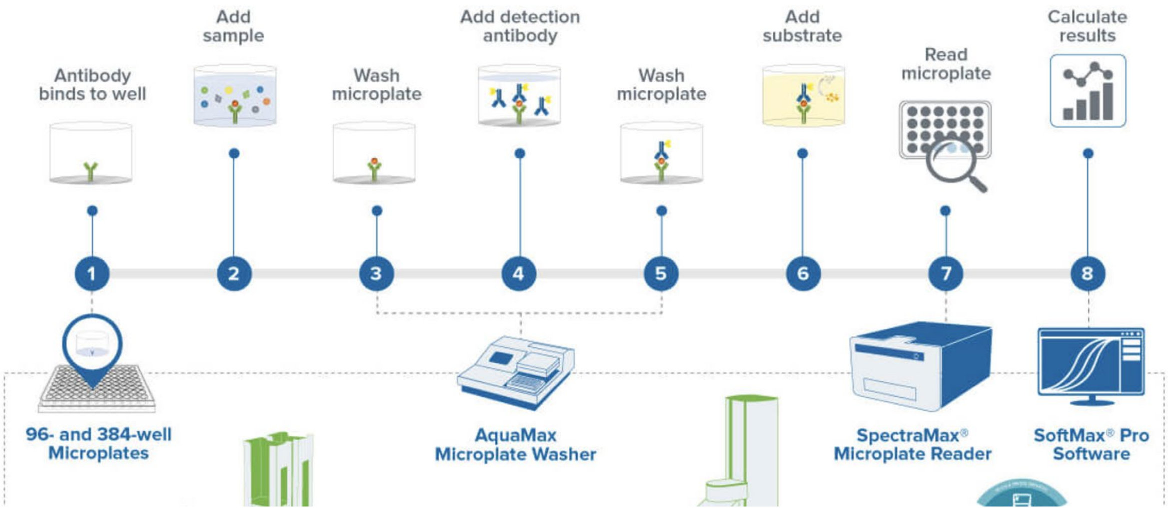


Figure 64 - ELISA overview. Source: MolecularDevices.

1. Sample collection [up to 3 minutes]
2. Capture antigen binds to ELISA plate wells [1 or 2 hours].
3. Add sample to well [10 to 20 minutes]. The antibody within the sample binds to the capture antigen.
4. Wash microplate [5 to 10 minutes]. Unbound material is washed away, leaving only the antibody of interest.
5. Add detection antigen [1 or 2 hours] . Enzyme-conjugated detection antigen binds to a second site on the antibody of interest.
6. Wash microplate [5 to 10 minutes. Unbound antigens are washed away, leaving only those specific for the target of interest.
7. Add substrate [5 to 10 minutes]. Substrate is converted by the enzyme on the detection antigen, producing a color change.
8. Read plate [5 to 10 minutes].. The microplate reader detects the colored reaction product and outputs optical density (OD) values.
9. Calculate results [5 to 10 minutes].. The amount of antibodies in each sample is calculated and analyzed.
10. Communication of results [up to 7 days].

Advantages:

- Kits for a variety of antigens are widely available (Horlock, n.d.).
- Multiple samples can be measured in a single experiment (Horlock, n.d.).
- Very sensitive, even very small quantities of antigens can be detected and therefore measured (Gan & Patel, 2013).

Disadvantages:

- Long assay time (Everitt et al., 2021).
- Hands-on intervention (Everitt et al., 2021).
- Long wash times (Everitt et al., 2021).
- Over a sufficiently long period of time, the color strength will inaccurately reflect the amount of primary antibody present, yielding false positive results (Gan & Patel, 2013).
- Not useable as standalone diagnostic to identify cases or for contact tracing purposes (WHO, 2020).

Rapid and near-patient antibody test kits are other types of immunoassays which are simpler and can be used at the point of care (rapid tests) (Camille, 2020). Their functioning is the same as the antigen immunoassay described before. Their advantages are also similar, meaning that they can deliver diagnostic results in 15 min from a few drops of finger-prick blood or other bodily fluids (Gao & Quan, 2020).

Defining the user

Desk research was able to provide interesting insights in regards to the wider Covid-19 and pandemic context. Moreover, it helped in shaping an outline of the background and technical process related to the different Covid-19 testing typologies. It did not, though, provide any kind of data related to the actual experiences that people have when living through them. Therefore, mapping the multiple experiences, capturing in detail the people's perceptions, their behaviours and feelings was the logical next activity.

Before proceeding to the actual mapping of the testing experiences, though, another - fundamental - step had to occur: the definition of the user.

Establishing priorities on both application and environment (as explained previously) naturally excluded some user categories (eg. developing countries medical personnel, people living in extreme poverty, sex workers, sexually active people). Still, with keeping into consideration Covid-19 as an application (saliva/nose/mouth detectable diseases) and airports (travel related diseases) as main environment, multiple potential scenarios would arise.

At this point the decision taken was to mainly focus on users connected to travel (therefore "travellers") as the solution which would be generated could then be implemented or slightly modified for other travel-related applications. Despite this, it was deemed important to start from a broader, "generalized" public, to gather extra insights that could be useful to shape future alternative versions of the booth. As the main function of the booth is "taking a PCR Covid-19 test" a person could, in fact, utilize it for reaching a goal not connected to travel at all, despite it being in an airport (eg. for example, also for a regular health check).

To gather insights on this point, two main activities of user research were carried out: surveys and interviews. User research is an important component of service design, as it helps to understand user needs and preferences, and ensure that services are designed with the user in mind. Surveys and interviews are two of the common methods used in user research, the first to gather quantitative data from a large number of users while the second are more in-depth and qualitative in nature, and are often used to gather rich, detailed information from individual users.

The survey had the goal of gathering an overview of demographics and motivations, behaviours and needs related to the three different Covid-19 testing typologies, as it could reach a wider audience, both in terms of number of people and their "nature". It was shared both in Italian and English and was able to provide 71 answers.

It first asked about generalities, to then bring the focus on Covid-19 testing. Subsequently the two main testing typologies were investigated, first the antigen and then the PCR, with the same questions.

The semi-structured interviews, instead, were limited to the "travellers" user category and involved an heterogeneous group of 9 users, from 18 to 66 years old, 4 female and 5 male.

The goals in this case were to go deeper into the relationship between travel and Covid tests and understand what worked and what did not.

It started with a brief introduction to the project. It then shifted to understanding the background and then focused on travel during the pandemic. Finally, the Covid-19 testing was approached with multiple questions, but the structure was not followed in a strict way, as based on the occurrence some concepts were expanded more than others.

MAPPING

The persona/archetypes

Generally, at this point a SD process would entail the creation of personas. Personas are fictional characters that represent different user types that may use a service. They are created based on user research and include information such as users' goals, needs, behaviors, preferences, and pain points. They are a widely adopted design tool and are often used in SD processes to inform design decisions (eg. define requirements) and ensure that user needs are at the center of the design process. They are a two-sided tool, as if correctly developed (starting from real data) are potentially very useful, but at the same time they can also have a limited scope (may not account for the diversity and complexity of real users) and be too rigid. Based on data from desk research, user survey and user interviews four personas were drafted:

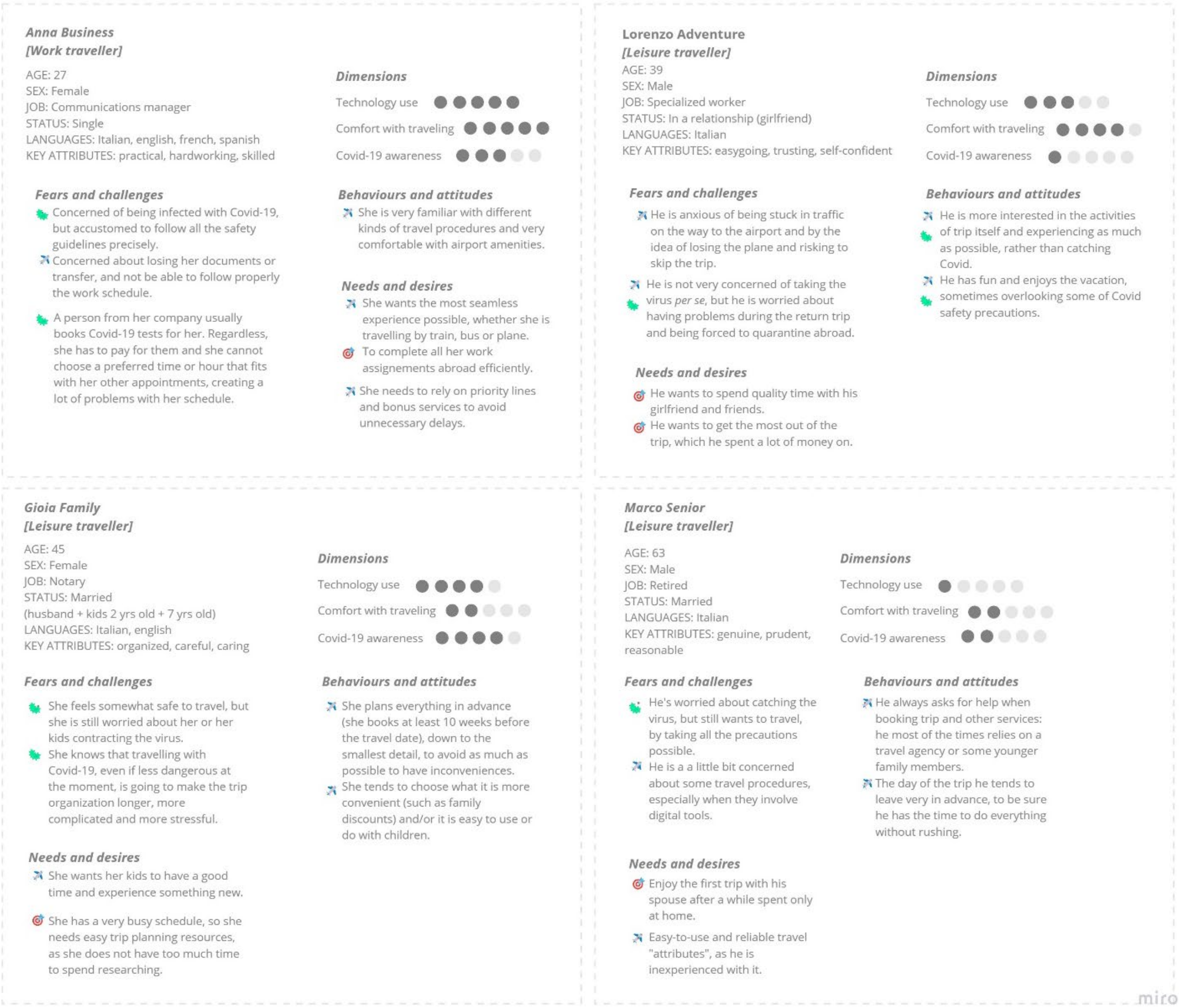


Figure 65 - The four personas that were identified.

The testing experiences

The experiences connected to Covid-19 testing (the "old object-behaviour-narrative") were then mapped, integrating details from the desk research, when addressing specific processes and technologies; insights from the surveys and user interviews when defining the scenarios, the artefact and the user/interaction story.

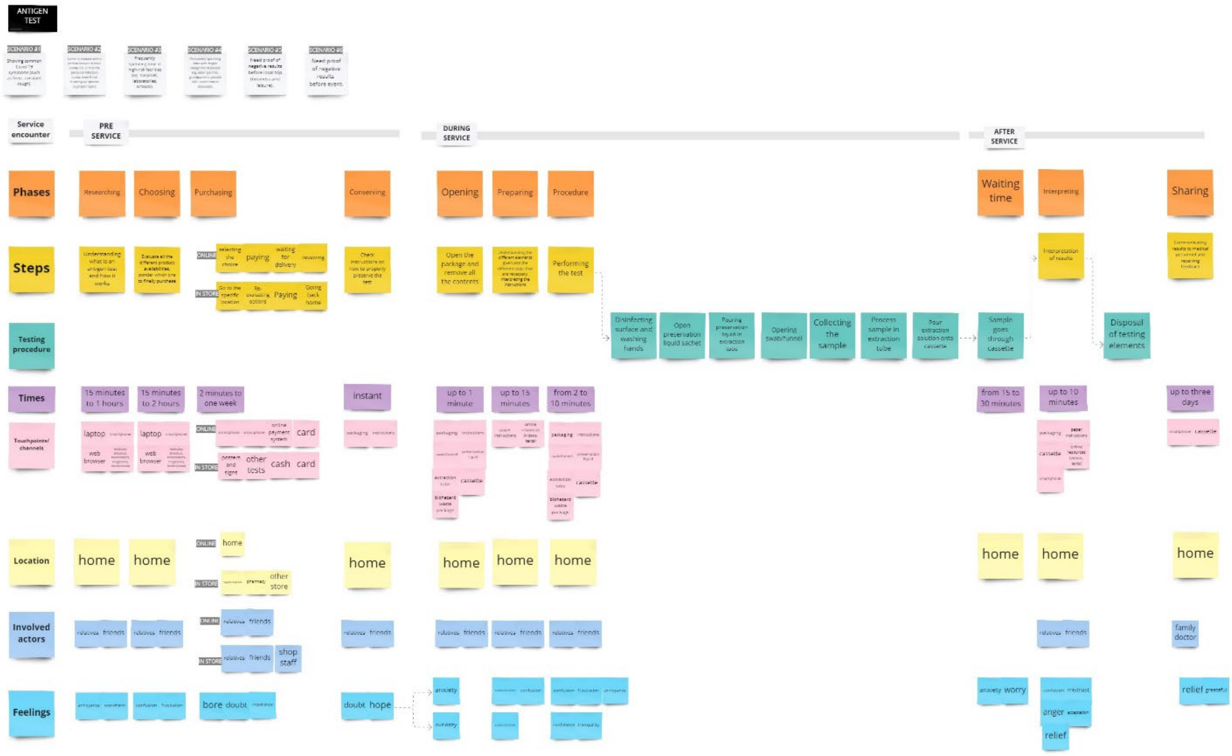


Figure 66 - Antigen test experience map.

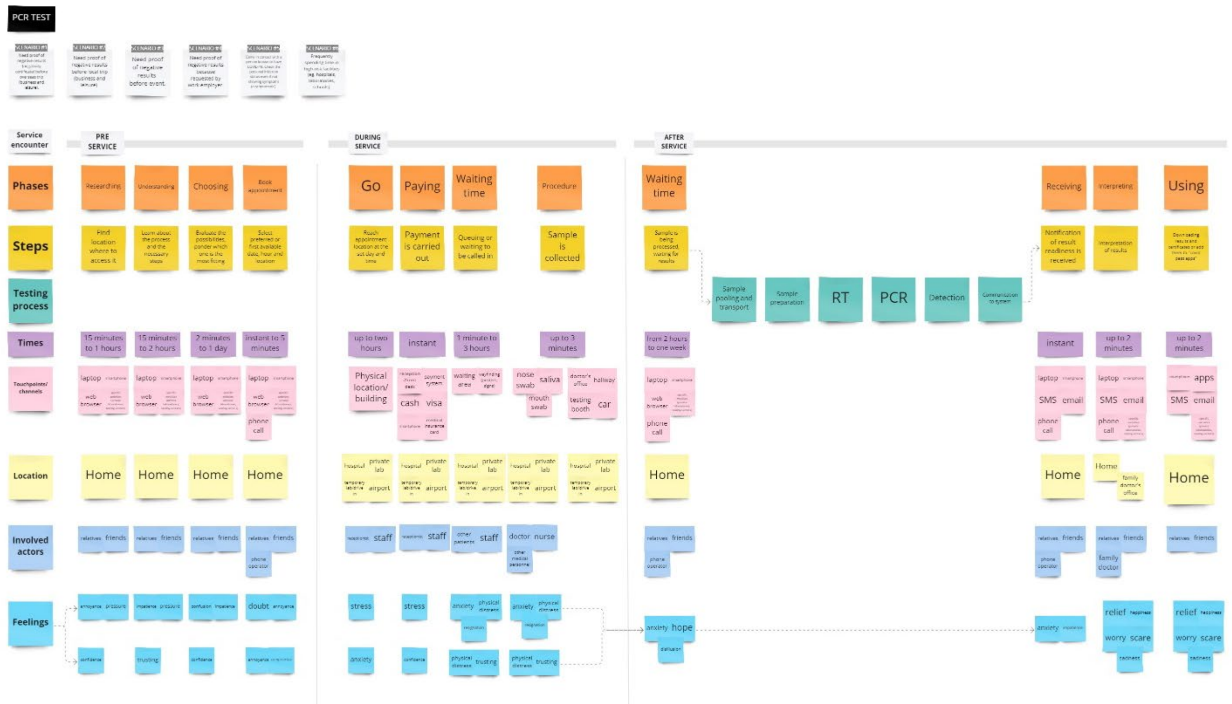


Figure 67 - PCR experience map.

EDUCING

A further layer of analysis was eventually added, which pointed out the pain and pleasure points, what worked and what did not work.

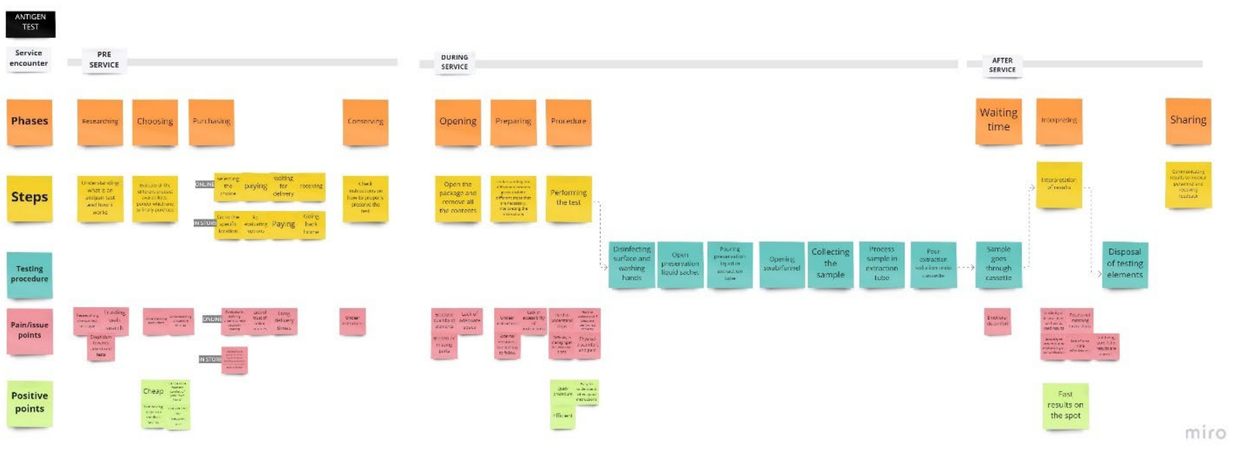


Figure 68 - Antigen test: educing.

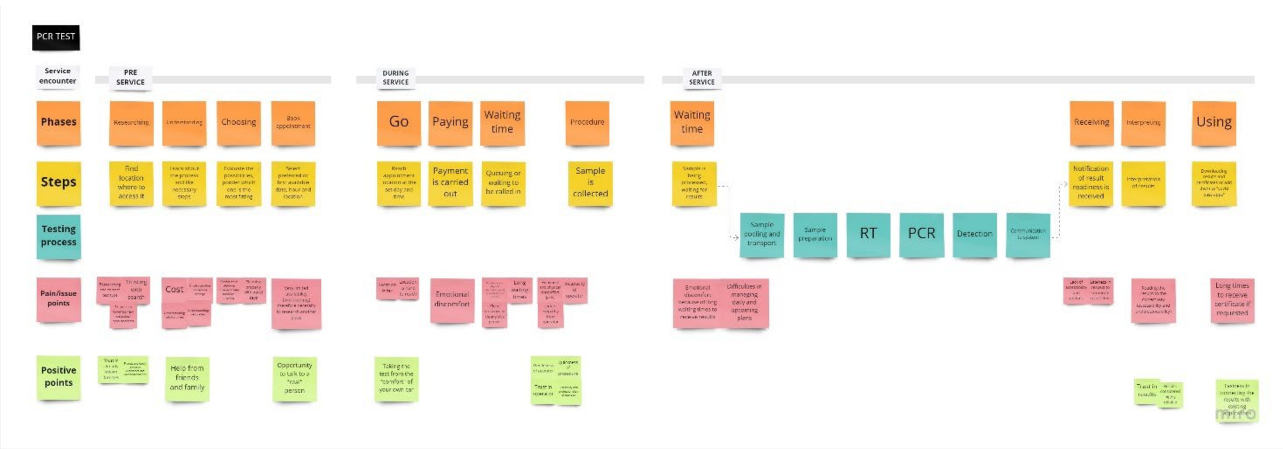


Figure 69 - PCR test: educing.

4.1.2 Layer #2: fasTest

DISCOVERING

Underlying technology and initial vision

The main objective of this project was to create a “testing station” that is fully automated and can perform an advanced molecular test (using PCR) by combining all the necessary steps including sample collection, preparation, and PCR testing. The testing machine would be designed to provide results to a layperson within 20-40 minutes from the time of sample collection, depending on the disease being tested and overcome the current logistical challenges connected to the PCR testing technique.

In order to reach this goal it was necessary for Diaxxo to automate the entire testing process, from sample collection to result, making PCR testing fast, scalable, and decentralized.

One of their products, the point-of-care PCR device (diaxxoPCR), was already capable of carrying out amplification of nucleic acids within 15-30 minutes.

The other aspects, instead, still needed to be fully developed:

- Preparation of the sample. Before performing a PCR test with diaxxoPCR, a "sample preparation procedure" is needed to remove impurities and purify the DNA or RNA. This purified DNA or RNA is then loaded onto test kits (cartridges pre-loaded with all the necessary reagents that can be stored at room temperature) so that the corresponding program can be initiated. This procedure, carried out with another Diaxxo device, diaxxoPrep, was though not compatible with the idea of a stand-along testing machine. In fact, despite relying on the same consumable of diaxxoPCR, it needed human intervention (laboratory staff) for pipetting. Therefore, an important point of the project was to automate also this process, while ensuring that the accuracy of the PCR remained high (sensitivity of over 90%) by adding more consumables capable of running the preparation. This would reduce the analysis time and eliminate the need for additional personnel.
- Sample collection. One of the main challenges in this regard was to achieve high throughput without creating a queue: the booth itself needed a high enough throughput to allow for fast sample deposition. This entailed to potentially have interfaces/booths to enable several samples to be deposited simultaneously, so that test subjects could spend the least amount of time possible at the station, reducing the risk of infection.

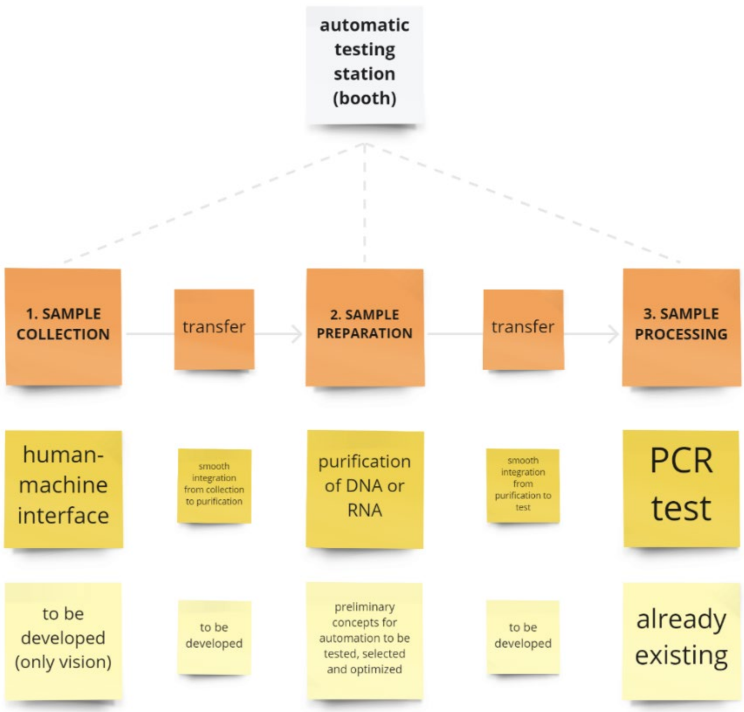


Figure 70 - Overview of project areas and level of development.

MAPPING

The fasTest "experience"

The envisioned booth testing proposed focused greatly on the company and technology perspective, with very little view over the experience of the user. Diaxxo's total priority was, in fact, to achieve a specific goal: the processing of 200 samples in two hours.

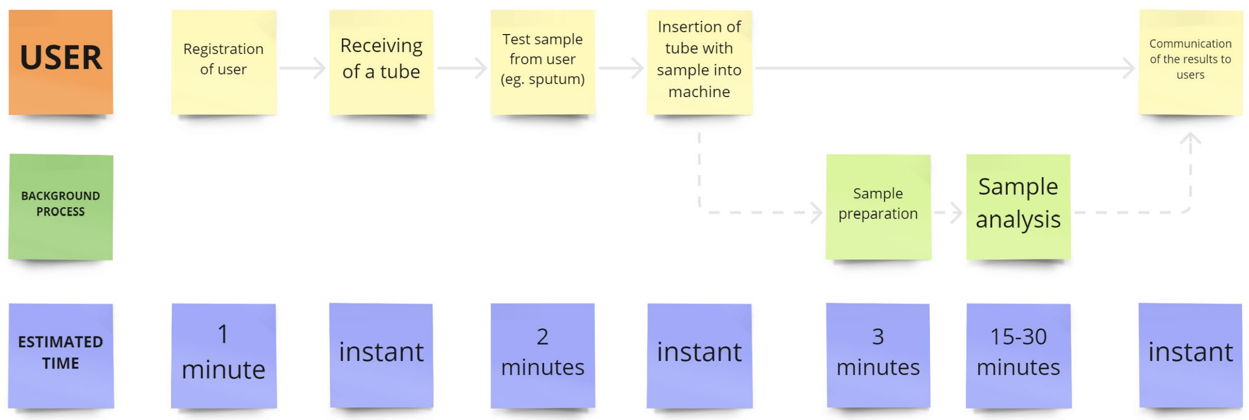


Figure 71 - Proposed steps for the automated testing station.

The company's vision foresaw users registering in one minute and producing the sample and submitting it in two minutes. Moreover, they underlined how the registration and sample production could be done simultaneously, if four "stations" were combined: while one person would register for the test, another one would be able to submit their probe. Then, depending on the testing position, the user would get a result after 41 to 53 minutes. They suggested that testing time could have been reduced even more. Through a more intuitive user interface with minimal user inputs registration and sample collection's time could be cut to approximately three instead of five minutes.

Finally, their vision implied the communication of results directly via smartphone, to both the user and if necessary – to the central authorities. The last step pictured, and core element of the value proposition, included issuing a certificate.

As for more business-related details, the cost-per-test imagined was very low - between 10 and 30 CHF. This includes the consumables (90% of the costs) and the operation of the testing machine (10% of the costs).

Regarding the structural side, their idea consisted of a square or hexagon based on interlocking panels, that would create the "nooks" where users would carry out the procedure.

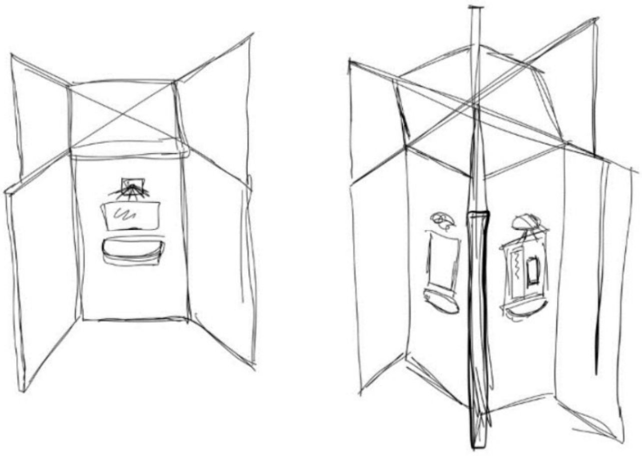


Figure 72 - Testing station with four (left) or six (right) user interfaces/booths to deposit tests.

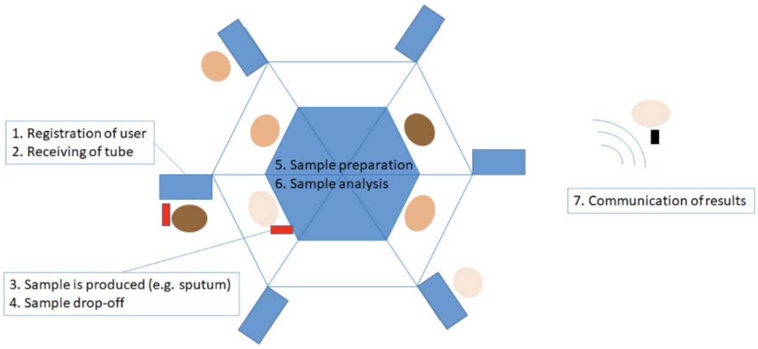


Figure 73 - Expanded concept with customer journey steps,

In Figure 4 a visualization of their vision is provided. It represents the top view on testing station with six user interfaces/booths. The design allows for six users to register and drop off sample simultaneously. The circles represent the users, that receive/drop off a tube/sample (red) or get results back on their smartphone (black). The blue hexagon indicated the testing station from the top view.

EDUCING

The emerging criticalities – service system (user experience)

The proposed "customer journey", despite being extremely superficial and generic posed as an interesting starting point. In fact, it was clear it was mostly constructed starting from the perspective of the company and the potentialities of the technologies and not on users and their actual behaviours and attitudes. This was especially visible from the time specifications: they were based only on assumptions and not on real data, therefore potentially overestimating the easiness with which to reach the ultimate technological goal. Moreover, some specific "service steps" were only broadly outlined, such as the registration procedure. Others were not even mentioned or taken into consideration (eg. waiting times, queues). One of the latter was the “identification” procedure, related to one of the core offerings: obtaining a certificate. In fact, to make sure that the right result is associated with the right person tested a comprehensive identity verification needs to happen all the times, either by a “real” worker or by means of specific softwares. In this regard it was necessary to understand how it could be implemented in the overall journey, considering also its implications with regulations, privacy and proper communication of data management.

Figure 74 - Overview of identification step issues to address.

An extended version of the possible “user experience” connected to the bare service was then drafted, adding the previously overlooked service encounters which are fundamental parts of the service itself. Issue points, positive points and opportunities of action were highlighted.

Figure 75 - The fasTest experience map revised: before service.

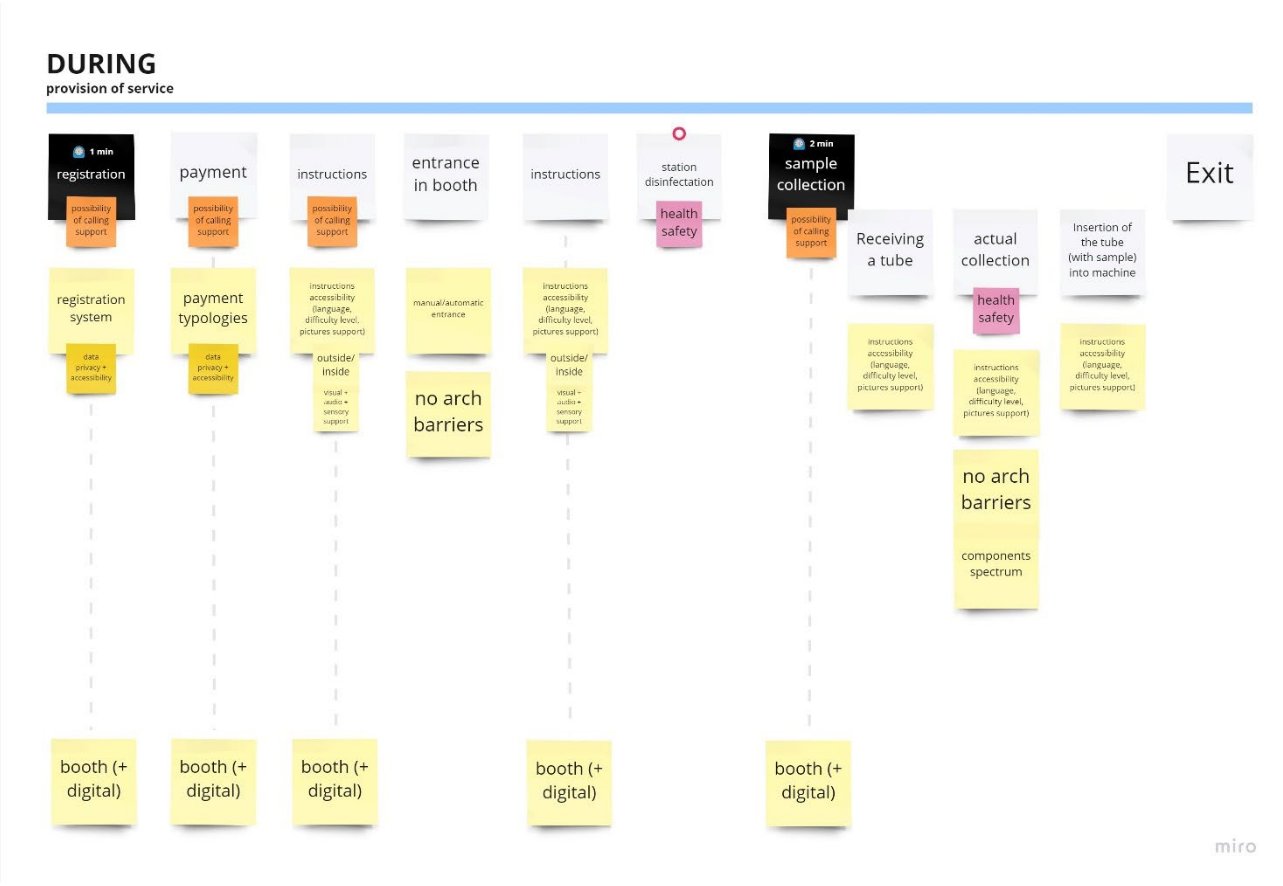


Figure 76 - The fasTest experience map revised: during service.

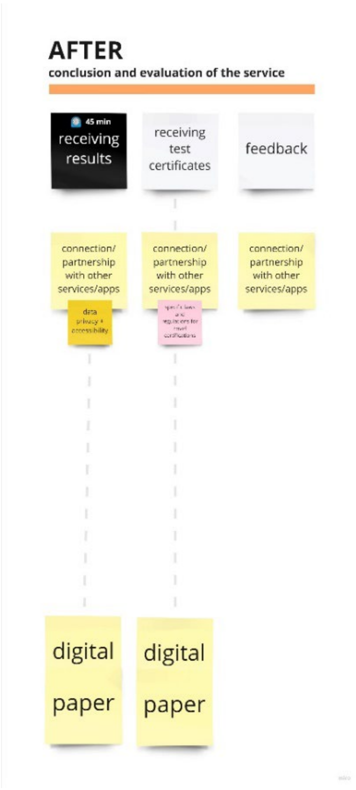


Figure 77 - The fasTest experience map revised: after service.

<u>The emerging criticalities – the product (structure)</u>

Also the physical structure presented some discussion points.

- Functionality: In principle, the structure is capable of accommodating multiple patients simultaneously, but its available spaces and surfaces are insufficient to properly contain all the necessary elements and artifacts involved in the sample collection procedure, severely limiting the potential layout. Furthermore, the structure does not take into account user flows, which can negatively impact both the functioning of the booth and user experience.

- Safety and Security: The shape and placement of the different sequences of steps compromise the safety and security of users. The close proximity of patients registering and taking samples hinders privacy for both parties, as they are separated by either very thin panels or cloth.

- Accessibility: The hexagonal shape of the structure with protruding sides does not meet basic accessibility requirements. For example, there may not be enough space for a wheelchair or adequate rotation space.

- Adaptability: The structure is only optimal for placement in a very wide and empty space, which may not always be available. To place it along a wall, it must be divided in half. It cannot be adapted for use in an angled space, and there are alignment complications when creating a sequence of full or half hexagons.

- Maintenance: The layout of the components does not offer a clear or straightforward path to access the interior that houses the machines and consumables. Ensuring that these sections are easily accessible should be a top priority in the design.

- Aesthetics: The structure lacks a distinct and recognizable shape and form, which may impact user interest in using the booth and building trust. Moreover, the construction itself did not aid in understanding the proper usage, for example it did not clearly indicate an entrance.

Despite defining these points a tentative to reformulate this hexagon proposal with slightly different configurations was made. The unsuccessful results brought to the confirmation that the structure had to be completely redesigned.

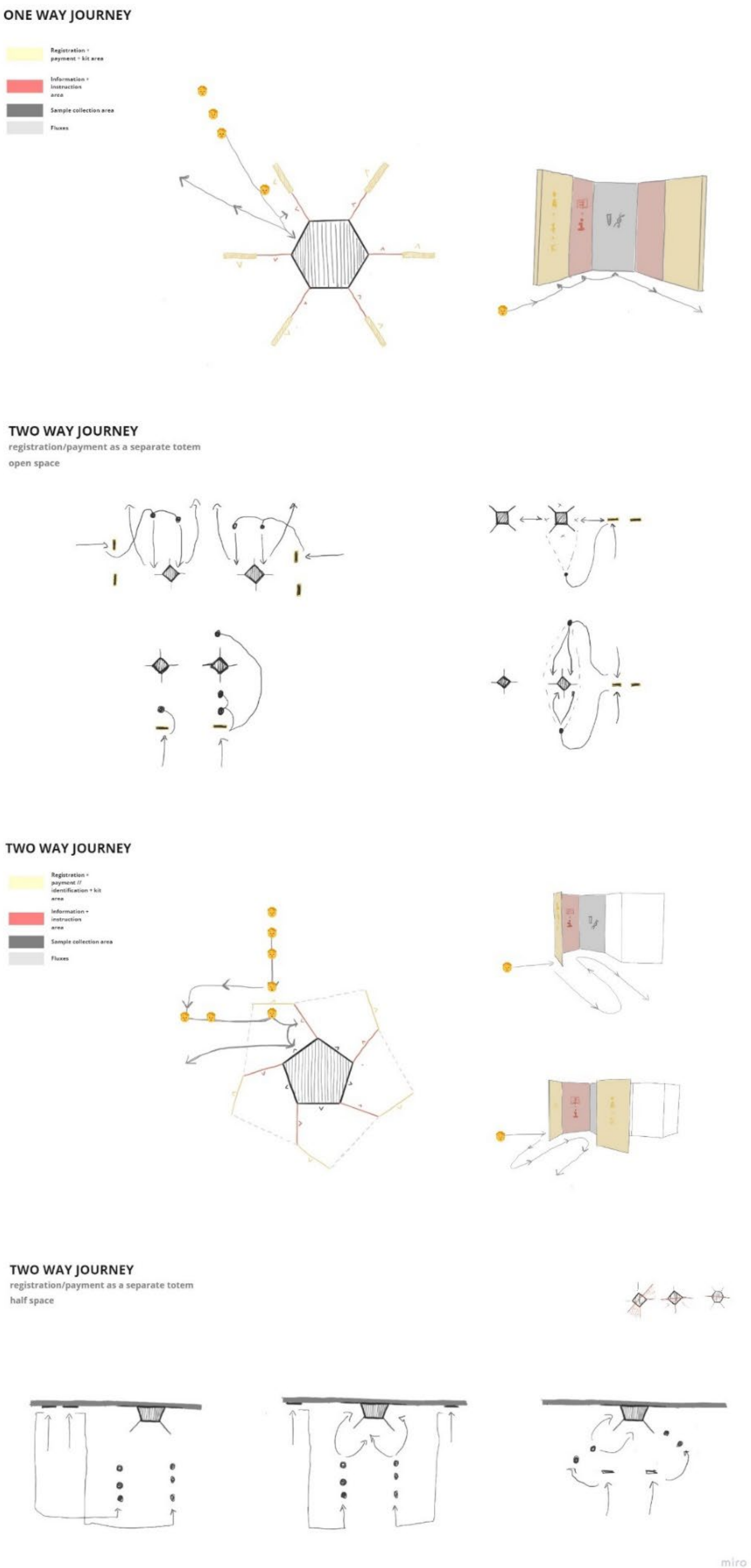


Figure 78 - Examples of some of the proposed configurations (one and two way journeys). As it is possible to gather also from the visualization, the positive functionality of having multiple patients at once depositing their sample is deeply hindered by the location and structure of the other steps that are constructed as “add ons” and not though as an overall,

holistic sequence. Moreover, the fluxes that ensue from these different options could be excessively complex, therefore creating confusion between the users and other people present in the space (eg. travellers that are just passing by).

4.1.3 Insights synthesis

The context

- Lack of preparation in case of outbreaks. By looking at the response to the past century's pandemics, including the ongoing COVID-19 pandemic, it is evident that we – as the world - are not adequately prepared to address the testing requirements of the next global outbreak. Fast, cost effective and accurate testing a missing key building block in combating pandemics today and in the future.

- State of the PCR testing. Insufficient automation and significant logistical challenges, such as sample transportation, pooling, transportation to medical labs, resolving pool issues (if needed), and communicating results, still characterize this testing technique even in wealthy nations and make it difficult to ensure prompt approach of diseases when emerging.

- PCR IN PoC. Although centralized laboratory tests have improved, the attempts to bring RT-PCR to a PoC (Point-of-Care) setting have been slow. While current approved systems have brought diagnostics closer to the patient, they still do not possess the low per-test cost or throughput required to provide large-scale testing, especially when considering an emergency context.

- State of LFIA testing. Currently, rapid antigen point-of-care (PoC) tests are the most practical way to test for an infectious disease such as Covid-19, as they are quick and affordable. However, they present significant limitations, such as low accuracy compared to PCRs, which have a specificity of 80-100%. Additionally, if a new mutated version of viruses (such as variants of Covid-19) emerges or a new pandemic with a different pathogen arises, a new rapid test must be created because the current rapid tests may not be able to detect it.

The covid-19 test experiences

- A significant number of people expressed anxiety and discomfort related to taking Covid-19 tests. Rapid antigen tests especially. The discomfort was related to the nasopharyingeal swabbing process, which can be uncomfortable or painful. This lowered drastically the quality of the experience.

- Quality of the experience of PCR tests was overall higher and mainly dependent from the operators (gentleness, empathy) and time to wait for results.

- Despite the discomfort and inconvenience, many people have reported feeling a sense of relief or peace of mind after taking a PCR test, particularly if the result is negative, due to its reliability and precision.

- People expressed the need for clear and concise instructions on how to take rapid antigen tests. This would help to reduce anxiety and increase confidence in the accuracy of the test. Moreover, too many sources of information were regarded as distracting and annoying.

- People appreciated the speed and convenience of the rapid antigen test, which allows for quick results and less waiting time, though rarely trusted the devices.

- Participants expressed the need for clear communication about the results of the test and what actions should be taken based on the result. This is particularly important for people who receive positive results and need to take additional steps such as self-isolation and emerged from both the experiences (PCR and rapid).

- Participants also expressed the need for a clean and hygienic environment for taking the test, which was hard to achieve at home. This includes the cleanliness of the testing area, the use of protective equipment by other present people and the availability of hand sanitizer and other cleaning supplies.

- For both the tests types critical is the support, help and presence of family and friends, especially when users are older adults that lack in digital skills. Also previous experience from either known people or strangers (eg. reviews) were an important point.

4.3 Phase two: ideation and design

4.2.1 Introduction to the process

The start of phase two began a few weeks later after my arrival in Zürich. On June 6th, in fact, I moved to the site and began working immediately. The first day I was provided with an explanation that covered everything relevant in and I was finally able to meet the entire team, gaining an overview of their roles and basic background. Furthermore, I was given a more detailed rundown of what the company actually does, which included a tour of the available spaces and laboratories in their offices in the ETH Hönggenberg Campus, as well as an introduction to the different machines I could use for the project.

During this process there was also a rundown of every product developed by the startup, including their advancement state and details regarding their functionalities. I was able to learn about each product and its purpose, including what they were planned to do in the future. This comprehensive overview provided me with a solid foundation for my work and helped me to understand the company's goals and how my project fit into them.

In the first weeks of being in the Diaxxo Headquarters, my primary focus was on familiarizing myself with the startup's methodologies and mindset and start developing the project alongside their team. This, at the beginning, was challenging: not only the topics and areas tackled were extremely unfamiliar and unknown to me, but also the procedures and protocols that they utilized were almost the opposite of the traditional design thinking approach. Regardless, I was able to develop and distribute the user survey, as described in the previous chapter (paragraph 4.1.2). Concurrently, I attended weekly meetings with the team responsible for the technical aspects of the project, specifically the sample processing and DNA extraction mechanics, which were in need of an automation procedure.

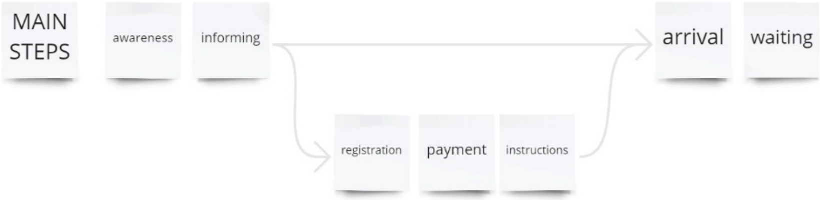
4.2.2 Preliminary concept

THE SERVICE SYSTEM

The preliminary concept for the new service system was drafted by building on the findings and insights of “layer #1” and merging them with the service outline proposed in “layer #2”. It was visualized in an extended service journey and presented to the stakeholders. The goal was to explain the evolution of “fasTest” by offering an holistic overview of the new possible service encounters. In this case, I adapted the service journey’s structure to match with the audience, their mindset and objectives. For the moment it focused much on the operational and functional side: service touchpoints, possible interactions and different layers of information that would be connected to the product-service system took the precedence over users feelings and thoughts, which were omitted. Most of the changes were positively accepted and discussed, but what emerged as critical and still in need of advancements was the disinfection and sample collection procedure. One of the main challenges related to this point was the technology that allowed it: it was, in fact, still in early development stages and it did not offer a solid starting base to draft a possible solution on. Elements to be used as touchpoints and interactions artefacts where still “undesignable” from a practical perspective, as they would be highly influenced and dependable of the exact steps and automation level that would be reached.

BEFORE

[how to get in touch with the service]



1 - PRODUCT-SERVICE AWARENESS + GETTING INFORMATION

Channels?

ONLINE/DIGITAL
- dedicated website
- institutional websites
- general website search
- socials

OFFLINE/PHYSICAL
- desk/infopoint in concernin location
- leaflet

Type of information?

- benefits
- type of testing
- how much it costs
- how it works
- locations
- hours
- what can they do next

Format?

- multiple languages
- images + text
- video

With which existing systems is it possible to partner/integrate with?
- concerning location
- workplaces
- institutions
- insurance companies?
- general doc?

2 - REGISTRATION + PAYMENT (1)

When/where?

- before going to the booth

(ex. from laptop at home)

Channels?

- dedicated website

Type of information requested?

- name
- last name
- DOB
- address
- ID for verification (take picture and upload)
- type of test
- acceptance privacy policy / terms and conditions

- child/caretaker?

Type of information given?

- personal reference code
- location information
- instructions

3 - ARRIVAL

Location
- best environment?
- best location in environment?

Reaching
- floor signage
- integration with existing signage
- app/website

Queue

BOOKING
- probably less queue
- more organization (for customer and operators)
- walk-ins are rejected
- possibility of not having full booking (lost revenue)
- systems to "call" numbers

WALK-IN
- probably more queue (unpredictability)
- no access limitations
- no lost revenue

Waiting
- standing + sitting
- floor signage (text + icons)
- posters

miro

DURING

[provision of service]

registration | payment | instructions | waiting | entrance in booth | instructions | Receiving the kit | station disinfectation | sample collection | actual collection | Insertion of the tube (with sample) into machine

1 - REGISTRATION + PAYMENT // IDENTIFICATION + KIT

Journey?

Registration + payment // identification + kit withdraw

- together
- separate

Channels?

- touch screen (registration)
- money (coins, paper)
- card (reader + wireless)
- cameras (ID + identification)
- pickup box

Type of information requested?

- name + last name
- DOB
- address
- ID for verification
- type of test
- acceptance privacy policy / terms and conditions

- child?

Type of information given?

- cost (variable?)
- personal reference code
- instructions

2 - INFORMATION/INSTRUCTIONS

Where?

- booth wall

Type of information given?

- how to clean the station
- how to correctly take the swab
- how to place it into the machine
- other actions?

swab / spit } first tube | open a door | put the whole thing inside the slot | remove plastic | close the door

Format?

- multiple languages?
- images + text
- braille/audio

3 - DISINFECTATION+SAMPLE COLLECTION

What?

- booth parts

Additional instruments given?

-

Steps?

-

Help?

- button?

miro

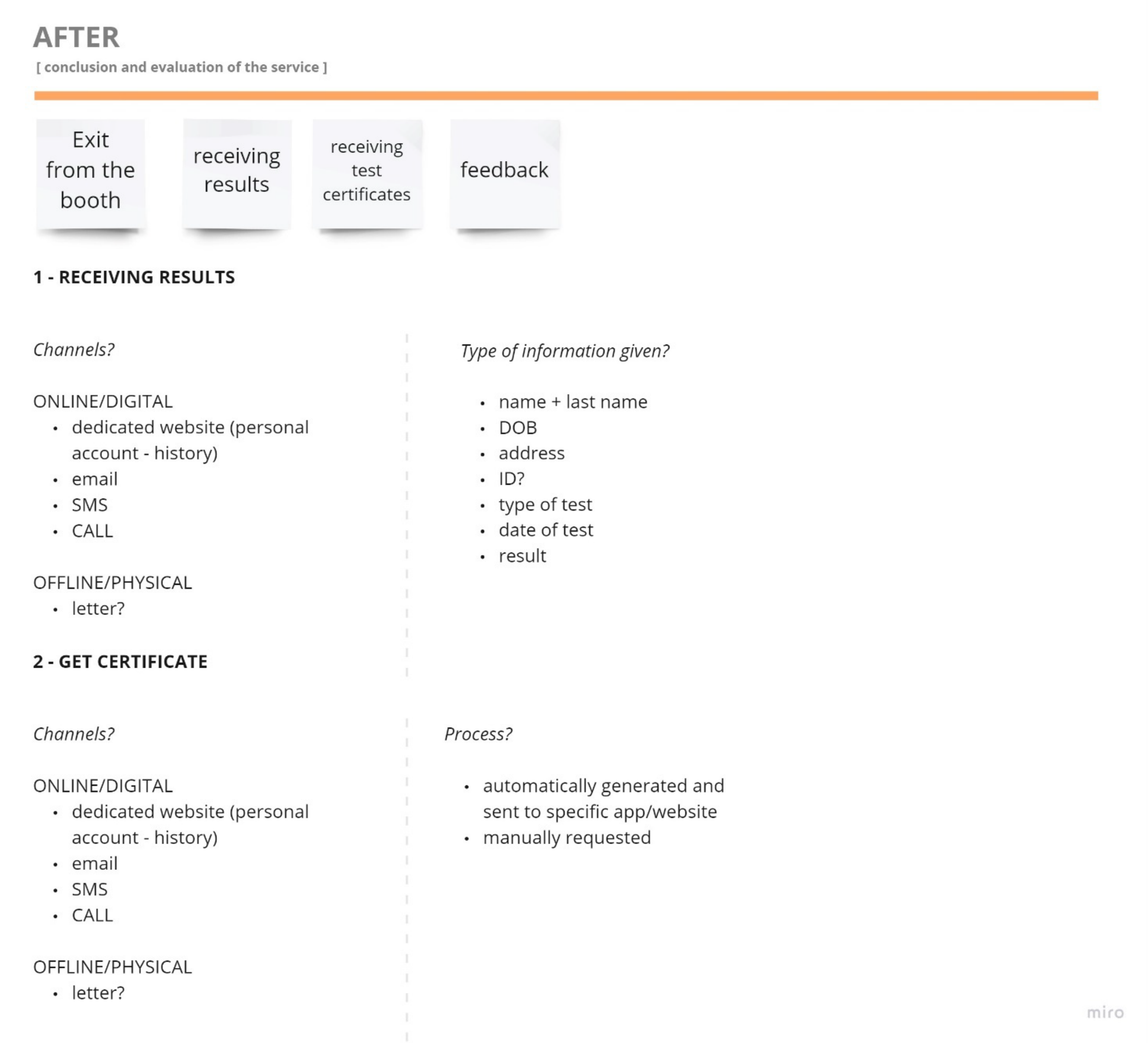


Figure 79 - Preliminary concept of the new "object-behaviour-narrative" or service system where it is possible to point out the missing detailing of the disinfection/sample collection segment of the journey..

Figure 80 - Potential aspects in need of definition regarding the disinfection/sample collection steps, analyzed and mapped using the dimensions of engagement (from MEDGI) approach.

THE PRODUCT

The preliminary concept for the product itself (the booth) was generated after a whole process of re-design. In particular, by taking into consideration insights from the context, it was deemed necessary to probe additional topics pertaining to the structural aspects and specific requirements of point-of-care testing (POCT). To frame this, three primary sets of guidelines were analyzed, all of which were related to POC, diagnostics, and disease testing.

<u>*ASSURED*</u>

The ASSURED criteria are a set of guidelines developed by the World Health Organization (WHO) to help determine the suitability of diagnostic tests for use in resource-limited settings. The criteria stand for the following:

A – Affordable. The diagnostic test should be affordable and cost-effective, particularly for use in resource-limited settings. Cost of the test should be low enough to be accessible to the people who need it.

S – Sensitive. The test should be able to detect the target condition with a high level of sensitivity, meaning that it should accurately identify individuals who have the condition. This is particularly important in areas where the disease burden is high.

S – Specific. The test should also be specific, meaning that it can accurately identify individuals who do not have the condition. This is important to avoid misdiagnosis and unnecessary treatment.

U - User-friendly. The test should be easy to use, even for people with minimal training or education. The test should not require specialized equipment or extensive technical expertise to operate.

R - Rapid and robust. The test should provide results quickly, ideally within a few minutes or hours. This is important in areas where access to healthcare is limited and patients may not be able to return for follow-up visits. The test should also be robust, meaning that it can withstand harsh conditions, such as high temperatures or humidity.

E - Equipment-free. The test should not require specialized equipment or laboratory facilities, as these may not be available in resource-limited settings. Ideally, the test should be able to be performed at the point of care, such as in a clinic or community setting.

D – Delivered. The test should be able to be delivered to the people who need it, regardless of where they live or how remote their location. This may involve innovative delivery methods, such as using drones or mobile clinics, to reach patients in difficult-to-access areas.

In order to be considered suitable for use in resource-limited settings, a diagnostic test must meet all of the ASSURED criteria.

CLIA

The FDA CLIA-waiver criteria are a set of guidelines established by the U.S. Food and Drug Administration (FDA) that allow certain clinical laboratory tests to be performed outside of traditional clinical laboratory settings, such as in physician offices, clinics, and other non-traditional laboratory sites. In order to be granted a CLIA waiver by the FDA, a laboratory test must meet the following criteria:

1. The test must be simple to perform, with minimal opportunity for error.

2. The test must be easy to interpret, with results that are unambiguous.

3. The test must pose minimal risk to the patient if performed incorrectly.

4. The test must have a low risk of producing erroneous results that could cause harm to the patient.

5. The test must be used in a setting where the patient can be directly informed of the results and receive appropriate follow-up care.

If a laboratory test meets these criteria, the FDA may grant a CLIA waiver, which allows the test to be performed by non-laboratory personnel in non-traditional laboratory settings without requiring the same level of regulatory oversight and quality control as traditional clinical laboratories.

The purpose of the CLIA waiver program is to expand access to diagnostic testing, particularly in underserved areas or in situations where rapid test results are needed.

STARLITE

STARLITE is an acronym for specific Point-of-Care (POC) diagnostic test recommendations to address the massive testing needs during a pandemic. It was proposed by a group of researchers in the scientific paper "A critical review of point-of-care diagnostic technologies to combat viral pandemics" (Everitt et al., 2020).

The STARLITE criteria are:

S - Sample-to-answer: the test should be able to provide results without the need for complex sample preparation or additional equipment.

T - Rapid: the test should provide results quickly, ideally within minutes.

A - Affordable: the test should be inexpensive and cost-effective for widespread use.

R - Reliable: the test should be highly accurate and have low rates of false positives and false negatives.

L - Local: the test should be available at the point-of-care, such as in clinics or hospitals, rather than requiring samples to be sent to centralized laboratories.

I - Instrument-free: the test should not require specialized instruments or equipment for analysis.

T - Traceable: the test should be able to provide documentation of test results to enable tracking and monitoring of disease outbreaks.

E - Easy-to-use: the test should be simple and user-friendly, with minimal training required.

The STARLITE criteria were proposed in response to the ongoing COVID-19 pandemic, which highlighted the need for reliable, affordable, and widely available POC diagnostic tests for rapid and accurate detection of infectious diseases.

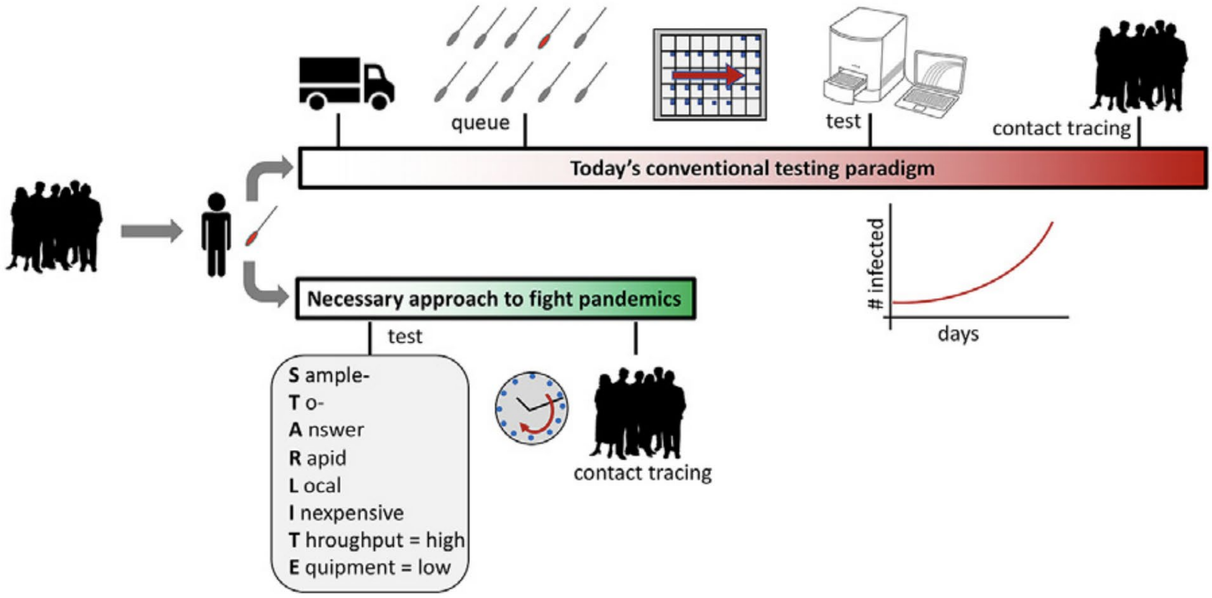


Figure 81 - STARLITE overview. Source: Everitt et al. (2020).

From the analysis of this frameworks, some key recommendations were deemed as applicable and relevant to take into consideration for the project, because that could apply to the specific situation of the booth. Some of the aspects, instead, were not considerable as my direct competence and it was not necessary to include them in my synthesis. Eventually, it emerged that some of the topics approached could also refer to the service-system itself. I therefore considered them as a basis and expanded on them with more considerations.

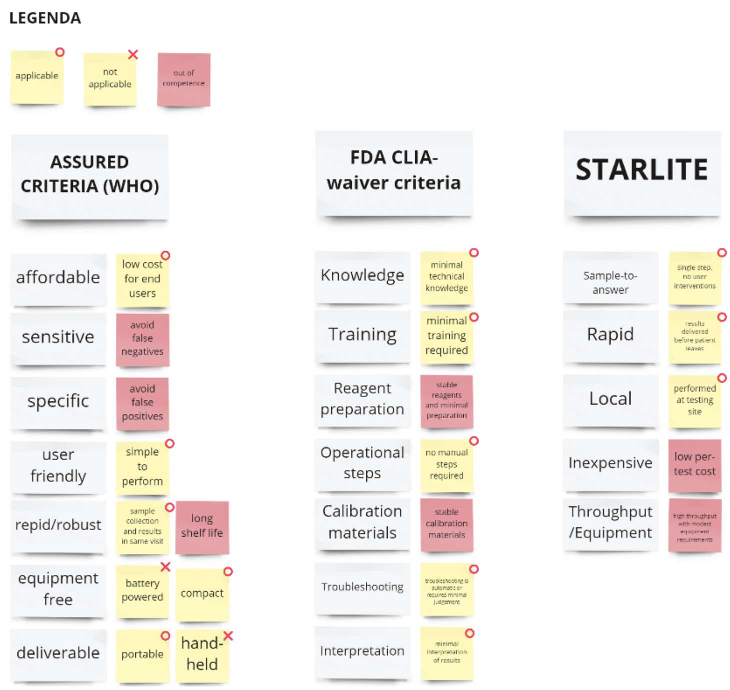


Figure 82 - Frameworks criteria and application on the project.

Figure 83 - Extra set of recommendations developed in conjunction with the engineering team.

Two possible and distinct views were defined at first:

PATH #1: the original concept of the "vision" chapter and the photo booth design-like is embodied in this path. It features geometrical and blocky features, and takes the cubicle as its reference shape. The cubicle is characterized by its solidity and essentiality, both of which would be key elements of the design.

PATH #2: this design direction is inspired by the new products developed recently by the company, including diaxxoPrep, diaxxoPod, diaxxoPCR, and diaxxoCare. The design has a more organic feel compared to the original concept in Path 1. The shape that serves as a reference for this design direction is a spiral, which embodies sinuosity, progression, and dynamicity.

Additionally, pros and cons for each were defined:

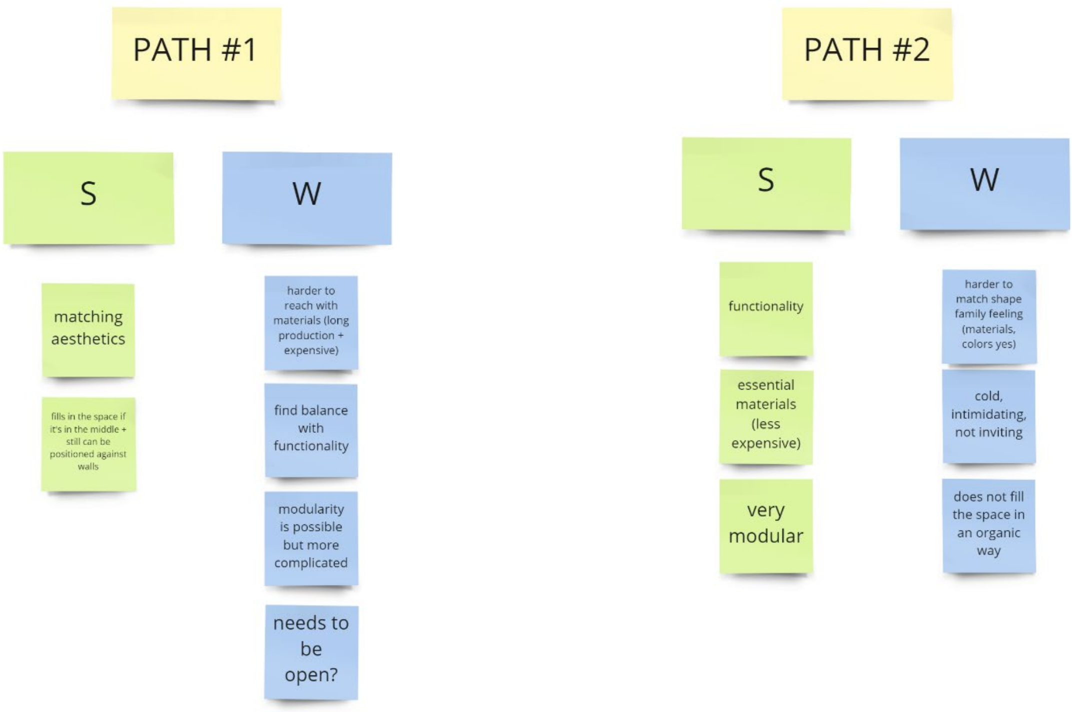


Figure 84 - Strengths and weaknesses of possible conceptual paths.

A third path, the actual preliminary concept was then defined, as a "mid-way", a compromise between these two. This third view entailed a concept based on the idea of "alcove", a space where both more organic elements could be combined with a more traditional structure. Moreover, additional feature and variables were taken into consideration.

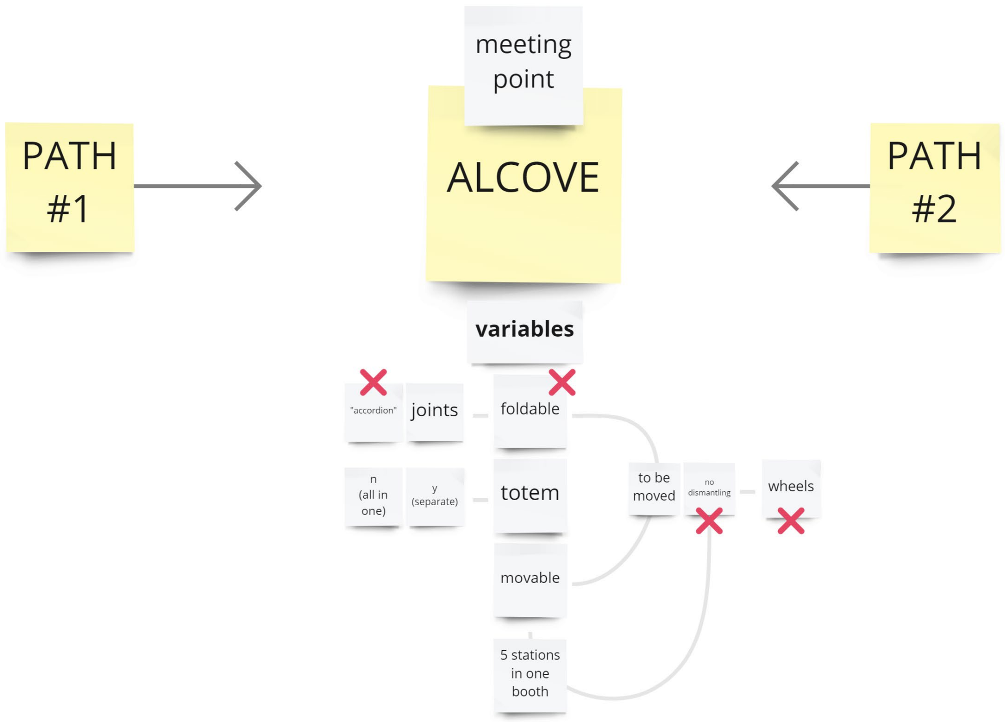


Figure 85 - Overview of possible third conceptual path.

These preliminary designs were presented to a small team, made by the CEO and the design engineer.

The presentation aimed to gather feedback and ensure that the direction taken was aligned with Diaxxo's and pd|z plans for the project. While the first option ("path #1) was considered interesting and innovative in terms of product continuity, it was deemed insufficiently functional for the ultimate goal of the structure. On the other hand, the alcove solution received positive feedback and was regarded as highly promising, especially pertaining the backstage automation. As a result, it was chosen as the basis for the next steps in the process.

Up until now, the concept development had been mostly based on the original "vision" of fasTest which was, in turn, born mostly from a technological innovation and some market scoping, other than brief desk research. Moreover, the preliminary proposals had also been highly focused on meeting very specific technological goals. However, there were still many open possibilities for development, related to the end users, their needs, behaviors, and perceptions.

These open possibilities extended beyond just specific interactions or touchpoints, and also included the wider Service-System. Overall, the concept was still in its early stages of development and there was plenty of room for improvement. Particularly user input could provide invaluable information regarding the most critical steps, which were still barely drafted: the registration procedure and the sample collection procedure. Nevertheless, the focus on meeting specific requirements was deemed necessary in this case to ensure compliance with guidelines.

During one of our weekly team meetings, I brought forward the need for user involvement in the co-development of our product service system. I explained how it was crucial at this stage of the process, as there were still unresolved possibilities that needed to be addressed. “As engineers and designers”, I said, “we cannot assume that we know what is best for the users, as we are biased by our own disciplines and background, and we do not have a deep understanding of the real user’s needs”. Therefore, I proposed how we must allow the users, “experts of their own experiences” by quoting Manzini (2015), to give inputs and ideas on the booth and its system, which can prove to be extremely valuable to gather insights to proceed with the concept.

I presented a brief outline of my proposal with an explanation of a possible co-design session actual aim and process, which was met with interest from the stakeholders who were supportive. I was even encouraged to “experiment” and propose unconventional solutions, regardless of the many technical limitations. However, while this was an exciting prospect, my main concern was to establish realistic boundaries and determine what was feasible in practice.

4.2.3 Co-design sessions

The codesign workshops held in the phase 2 was structured by following the Collaborative Design Framework presented in chapter 3, that provided a strong basis.

Defining the position of the activities into the framework itself was the first step to start the process of workshop definition: the overarching goals of the codesign sessions themselves acted as a guide.

FRAMING

The goal

Between the four available quadrants two were the targets:

1. EXPANDING AND CONSOLIDATING OPTIONS → expanding or assessing given options, adding elements of interest, feasibility and concreteness (Meroni et al., 2018).
2. CREATING, ENVISIONING, DEVELOPING OPTIONS → generating new options or elaborating existing ones, through a creative and though-provoking process (that might also bring to question some principles) (Meroni et al., 2018).

Normally the co-design session would “fit” into one specific quadrant. In this case, though, it actually covered two. Then the question was: why both? The top right quadrant, focused on refining and improving the existing options, making them more effective and valuable for the end-users was connected the Product-Service System level of the project. The bottom right quadrant, instead, by involving new possibilities and finding innovative solutions was deemed more coherent to face to the "physical" challenges of the project, meaning the booth structure itself and the sample collection procedure.

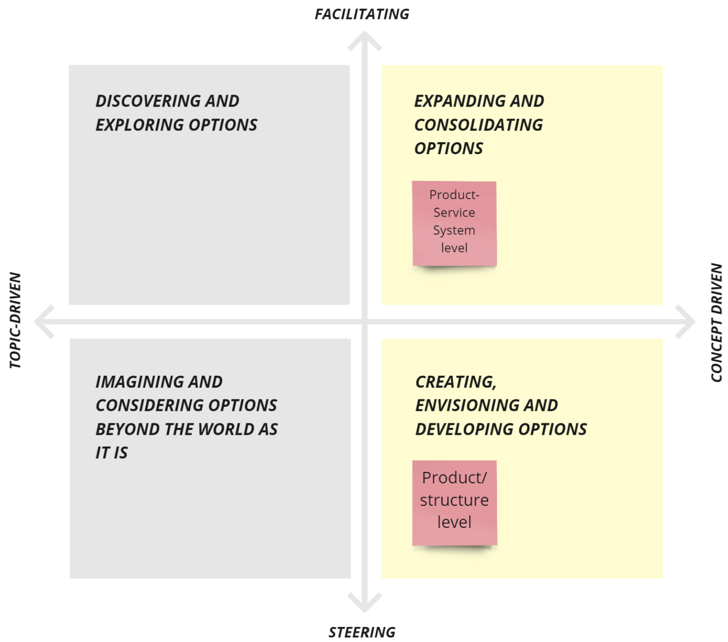


Figure 86 - Framing of project inside the Collaborative Design Framework.

In practice, two main aims were outlined:

- Expand on the service system "bare bones", generated through the combination of the insights gathered in the two "exploring" layers in phase 1.
- Start a generative and constructive discussion around the different facets of the structure (booth) itself, such as the look and feel, the spaces, the interactions with the machines inside, in order to draft a possible initial concept.

Style of guidance

In this case, the style of guidance I had to adopt was flexible and adaptable, depending on the specific step of the session and its ultimate aim. At times, I had to be "steering", while at other times I had to be "facilitating".

When facilitating, I had to perform actions such as explaining concepts, clarifying points, and supporting participants in active confrontation, but eventually all of these actions maintained a steering quality to it. Besides supervising the activities, I consistently asked thought-provoking questions, provided comments, and shared opinions that could drive the conversation forward and create new connections.

Design subject matter

The subject matter of the sessions was clearly “concept” driven. The two main starting points were: the draft steps of the Product-Service System’s journey and the booth structure preliminary version. Both rendered in a “concrete” way ideas about how the product and the service should be like, with the second element being very broad, with multiple “open-ends”.

Stage

As this project did not follow a traditional Double Diamond process it is not possible to refer to a specific stage of it. Typically more “concept” driven sessions are carried out during later stages of the process (approximately in the “develop” and “deliver” areas. In this particular case it is possible to say that the step in which co-designs were carried out was still fairly early in the overall process, closer to exploration phase and just “at the cusp” of a ideation/design phase.

The expected challenges

Designing a product or service can be complicated, particularly when dealing with a diverse group of users with varying needs and preferences. This is particularly relevant in the context of CHECKD., which aims to provide a solution for a broad range of users, from individuals who are more comfortable in carrying out specific operations in autonomy to people who have very specific requirements and/or limitations in the matter. The challenge lies in designing the activities themselves. Due to differences between users, the co-design session must either be designed to be clear, accessible, and inspiring for everyone, or each cluster of users must have their own tailored tools and activities.

Another key challenges in designing CHECKD. is the need to address the diverse needs of its users while also considering technical constraints. While there are many different typologies of users who may benefit from CHECKD., each with their unique needs and requirements, it is not always possible to design a single solution that can meet the needs of everyone. This is particularly relevant when it comes to designing the physical aspects of CHECKD., such as the sample collection procedure, which may require different approaches for different users. In this case the difficulty stood in both the design and the activities themselves. For the first point it involves being innovative with the design of the tools and/or prototypes for people to engage with, so that this “technical” boundaries are clear. The second point includes the challenge of properly directing people, for them to respect these boundaries, but at the same time avoid too much limitation which could hinder the development of new solutions.

DESIGNING

The phases

Codesign session, despite being highly specific to their context and situation, can be built around one main structure: warmup, core, closure. Therefore, my process to develop the sessions was to sketch what it was "necessary" to gather/know from each phase, by responding to the question "W*hat do I want to understand from this?".*

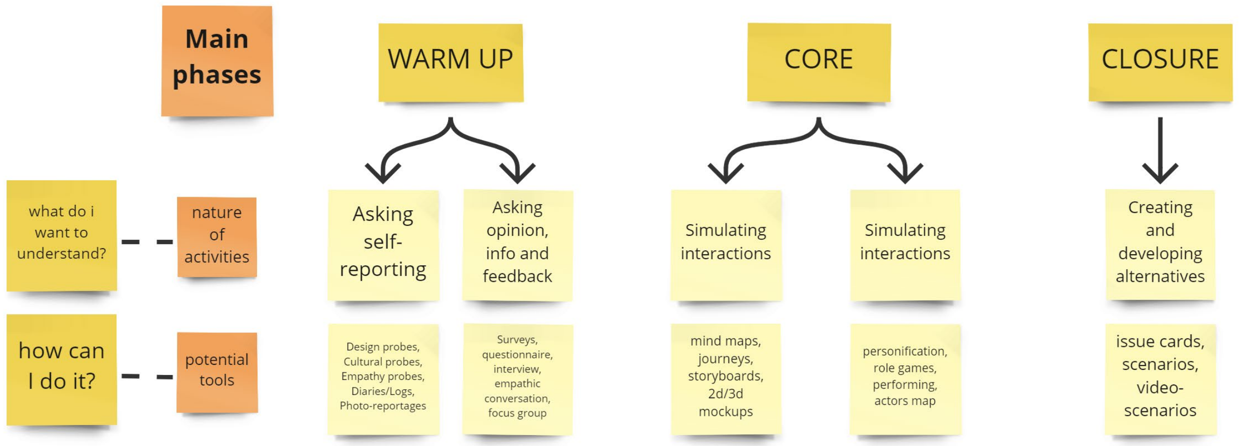


Figure 87 - Preliminary framing of co-design sessions' phases, based on Meroni et Al. (2021)

1. Warmup. This first step was to be leveraged to confirm some of the information previously gathered during the user research and topic exploration, since it must be a lighter activity, to open up the practice to people. Moreover, it has to be short, not too detailed.

Possible questions that needed to be answered covered different topics:

How is the person when travelling (with Covid-19)?

- emotions (how do they feel before travel? during preparations and right before)
- needs (what are their primary concerns?)
- behaviors (what do they do, bring and how they act and where they go and how? why?)

How is their relationship with Covid-19 tests?

- emotions (how do they feel before travel? during preparations and right before)
- needs (what are their primary concerns?)
- behaviors (what do they do, bring and how they act and where they go and how? why?)

How do they act inside a specific scenario?

- airport
- station

- other transportation hub

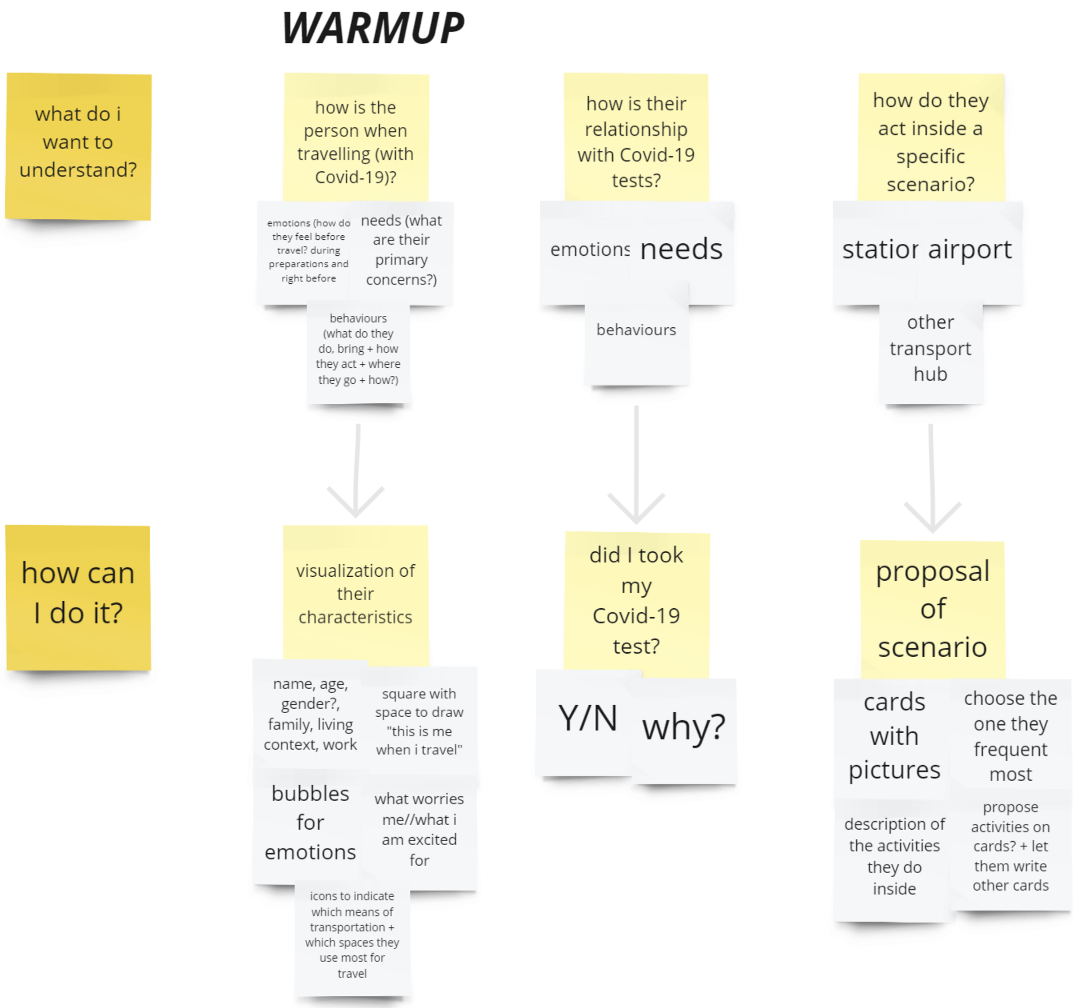


Figure 88 - Breakdown of warmup design.

2. Intermezzo. Usually this kind of activities that are in the middle of phases have as a goal the one to "summarize" what done previously. In this case the idea was to set a basis for future comparison, due to the different elements that had to be taken into consideration and the fact that a concept basis already existed.

Possible questions that needed to be answered were:

How do they picture an automatic booth for disease testing?

- physical/material level

- visual level

- emotional level = feelings, memories

- social level

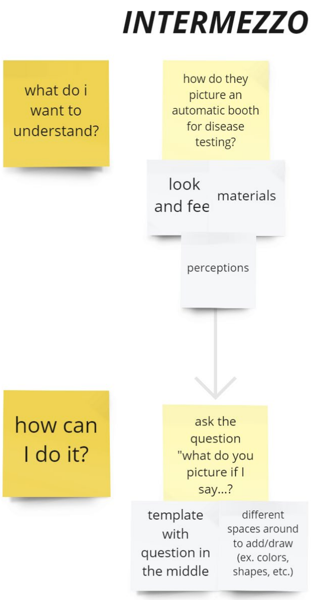


Figure 89 - Breakdown of intermezzo design.

3. Core. It is the main part and usually the most complex and time consuming. The idea was to address the actual Product-Service system level of the booth, by giving a full overview, but at the same time go into some level of detail. All without creating confusion or misunderstandings.

Possible questions that needed to be answered were:

- *which channels would they use to come into contact with the service?*
- *which information would they need before using the service?*
- *how would they need this information?*
- *how would they approach the registration?*
- *relationship with space - how would they reach the spot and understand what to do?*
- *which nature of the service makes more sense for them? (book or queue)*
- *which kind of interactions would they want to have with the booth?*
- *which way is the best to convey instructions on how to use the machine?*
- *how to make the most easy to use and comfortable sample collection experience?*
- *which type of kit (shape and ergonomics), how many elements, how to follow instructions, how to give feedback?*
- *which ways will cause less probability of sample contamination?*

- *how to keep the whole thing igenic and safe for them?*

- *which ways for them to receive results?*

- *how easy it is for them to understand the contents of the results?*

- *would they integrate this service with other existing touchpoints in their daily life? how would they integrate this service with other existing touchpoints in their daily life?*

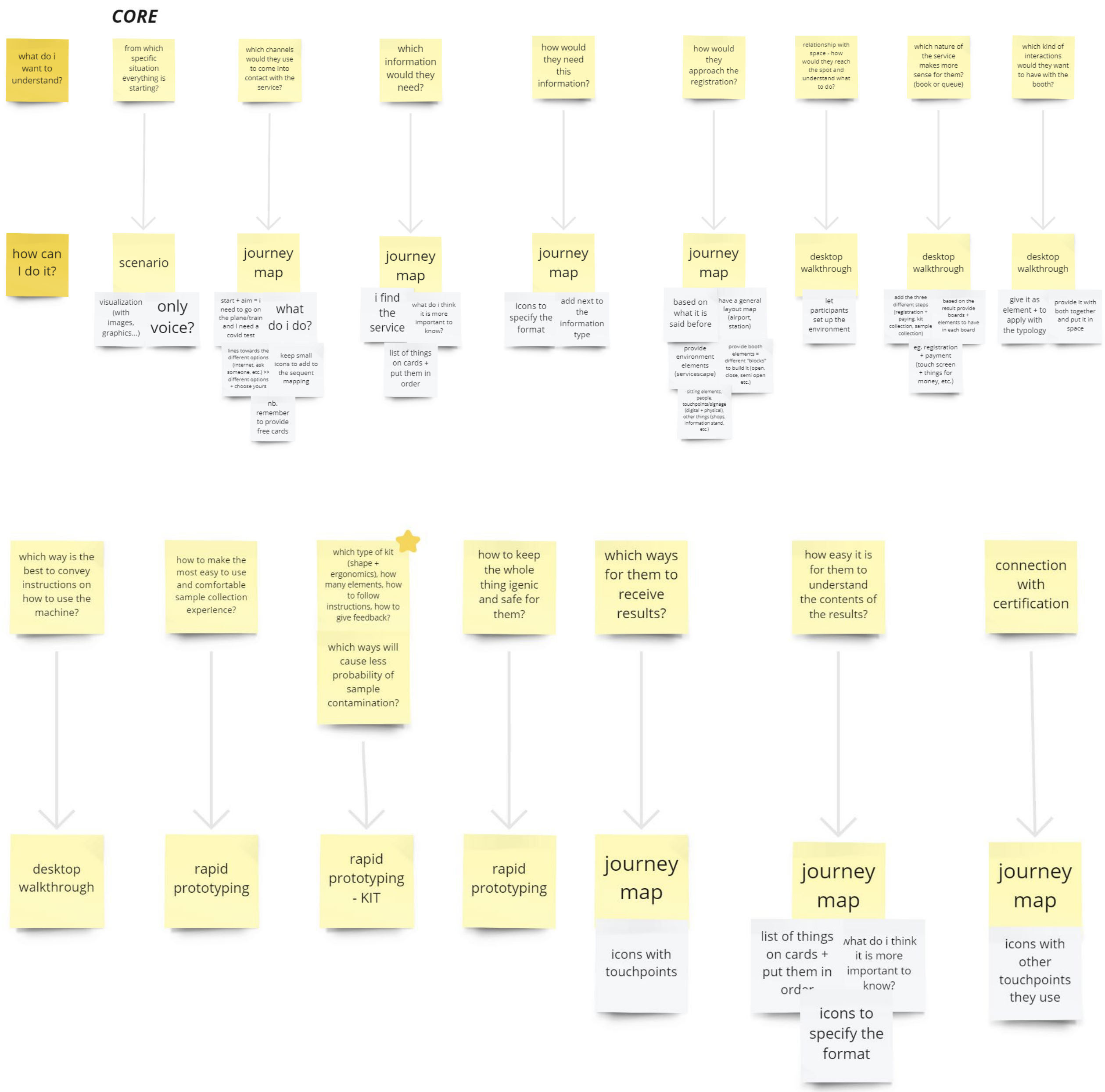


Figure 90 - Breakdown of core design.

4. Intermezzo #2. This phase would follow the same reasoning as the intermezzo presented before. In this case the goal was to get something comparable with the first one.

Possible questions that needed to be answered were:

How do they picture an automatic booth for disease testing?

- physical/material level
- visual level
- emotional level = feelings, memories
- social level

5. Closure. This phase is conceptually similar to the warm-up. It should include a simple and light activity, that mostly entails doing a synthesis or evaluation of the topics/solutions discussed in order to gather some form of direct insight. For the specific case of this co-design session the plan envisioned a first “wrap-up” of the concept, and a more specific and “directed” feedback collection moment on the activities carried out.

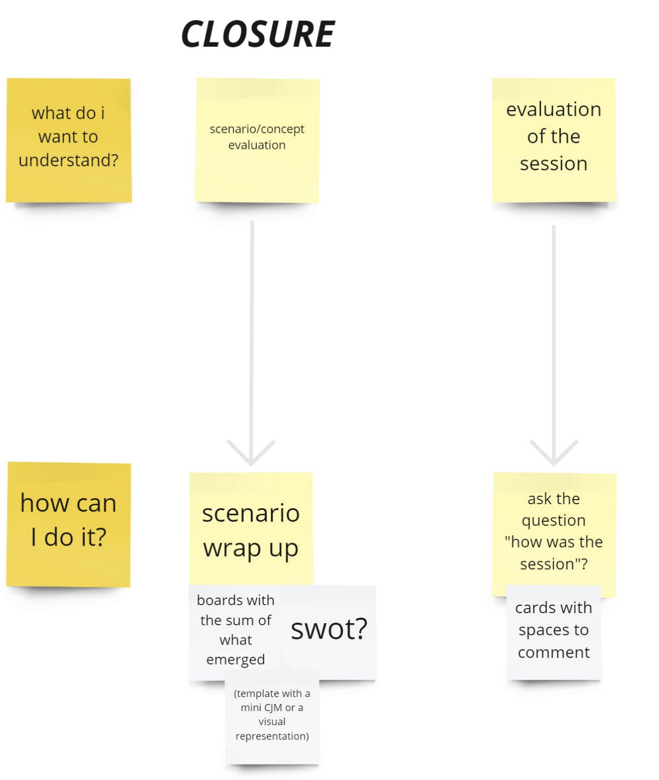


Figure 91 - Breakdown of closure.

<u>*The boundary objects*</u>

As explained previously in the disciplinary background, for each phase and/or activity of the co-design sessions, boundary objects (made of tools and prototypes) need to be defined and developed, in order to be used as main triggers and activators of discussions and creation:

- First part of the sessions. This part was the one related to the Product-Service System in the "Concept-Driven / Facilitating quadrant". Here the boundary objects created are mostly a mix between tools and prototypes. These objects offer participants a range of options for freely expressing their ideas about one or more concepts. They also aid participants in deciding on certain topics and integrating their knowledge into proposals by provide multiple levels of explanation, while using a correct language (Meroni et al., 2018).
- Second part of the session. This part was the one related to the actual booth structure and its facets, in the "Concept-Driven / steering quadrant". Also in this case the boundary objects created are mostly a mix between tools and prototypes. Both must have modularity, scalability, and transformability to ensure that participants' creativity is not hindered, while also supporting their perspective and consider other worldviews (Meroni et al., 2018).

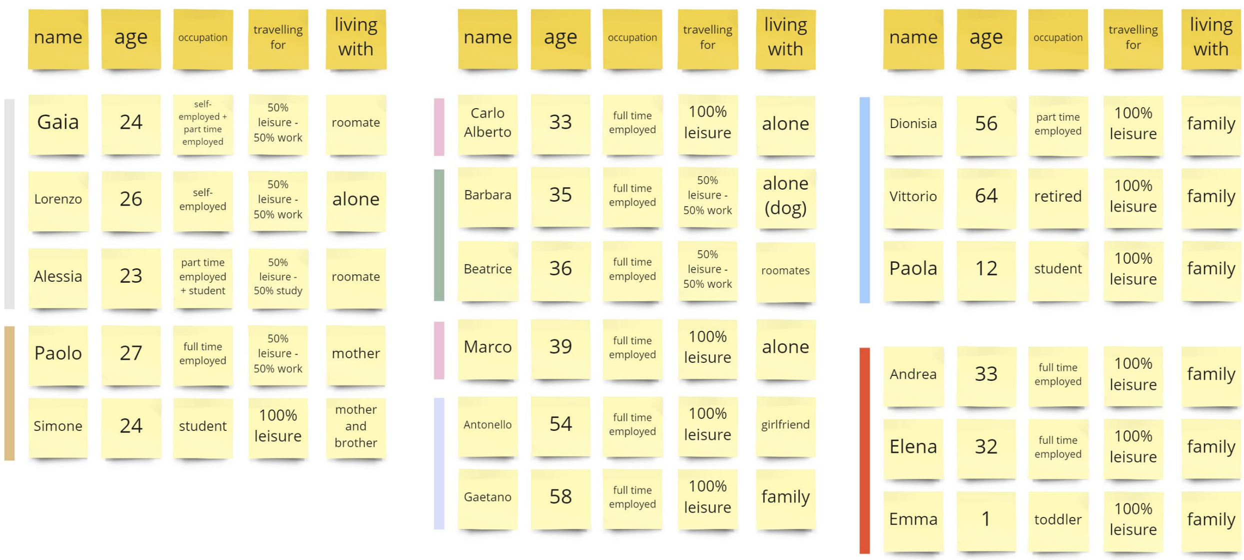
For this co-design sessions I decided to utilize the same structure and boundary objects for all the different clusters of participants. This brought about one main implication: the boundary objects had to be flexible enough to suit all of their “co-creation” needs and to eventually be modified during each session, based on the situation at hand.

In order to define and design them “ad hoc”, I went through all the phases and the list of related “questions that needed to be answered”. For each “what”, then I then addressed the question of "how can I understand it?"

SESSIONS DETAILS

Participants

A total of 16 participants were involved, selecting them from the main user categories defined in the previous stages of the project. The sessions counted with different numbers of people each time, with either two or three participants at a time, all from the same user cluster. They were heterogeneous, then, only in the overall view of the sessions.



name	age	occupation	travelling for	living with
Gaia	24	self-employed + part time employed	50% leisure - 50% work	roomate
Lorenzo	26	self-employed	50% leisure - 50% work	alone
Alessia	23	part time employed + student	50% leisure - 50% study	roomate
Paolo	27	full time employed	50% leisure - 50% work	mother
Simone	24	student	100% leisure	mother and brother

name	age	occupation	travelling for	living with
Carlo Alberto	33	full time employed	100% leisure	alone
Barbara	35	full time employed	50% leisure - 50% work	alone (dog)
Beatrice	36	full time employed	50% leisure - 50% work	roomates
Marco	39	full time employed	100% leisure	alone
Antonello	54	full time employed	100% leisure	girlfriend
Gaetano	58	full time employed	100% leisure	family

name	age	occupation	travelling for	living with
Dionisia	56	part time employed	100% leisure	family
Vittorio	64	retired	100% leisure	family
Paola	12	student	100% leisure	family
Andrea	33	full time employed	100% leisure	family
Elena	32	full time employed	100% leisure	family
Emma	1	toddler	100% leisure	family

Where (environmental set up) and when

The sessions were carried out during one week, in the beginning of July 2022, in Italy. Most of them were carried out in the participants home, to simplify the procedures. Only in one case the participants were welcomed in my house, where a space was set up.

Duration

Each session had a different length in time, mostly depending on the quantity of people participating. The shortest had a duration of 57 minutes, the longest was over 4 hours.

DESCRIPTION OF ACTIVITIES

STEP 1 - the Warm-up

After introducing the project and the setting, a simple travel scenario was presented to the participants. They were then invited to independently complete a basic template to describe themselves and their behaviors while traveling. Eventually, the participants presented their work to each other, and were able to share or disagree with some of the statements.

STEP 2 - the intermezzo

The participants were given another sheet to fill out, which prompted them with the simple question, "When I say 'automatic booth for disease testing', what do you picture?" Through this activity, they communicated their first impressions about the product-service facets without any prior knowledge. They explored areas such as the structure and interiors (through drawing), colors, materials, and feelings and emotions. This was an individual activity.

Figure 92 - : Users and tools.

<u>*STEP 3 - the core*</u>

Part 1

As a starting point for this step, a detailed and complex scenario was presented to the participants. Multiple boards featuring schematic and visual representations of the "minimal" service moments served as a foundation for discussing the project's service level. Potential users were prompted by different questions to expand on the contents of the boards, completing all the steps and filling out any blank spots with the help of provided cards depicting various elements of the service, such as touchpoints, actors, actions, and places.

Part 2

Instead of discussing the more physical aspects of the project in detail, a fast prototyping tool was used. A small and anonymous model of the booth was presented, and conversations around the same aspects introduced in step 2 were discussed in greater detail. Simple materials, such as paper, cardboard, and post-its, were provided as a support for experimenting with new possible solutions. The goal of this fast prototyping was to explore and expand on new possible options regarding the booth structure, wayfinding, procedure, and human-machine interface.

Participants engaged actively with all available support to explain their ideas, using hand sketches mostly when discussing the wayfinding and occasionally when discussing the structure and human-machine interface. In multiple occasions, participants role-played actions and service moments with each other without direct prompt, using physical objects such as pens and pencils to represent swabs and paper to simulate walls and surfaces.

Regarding the structure, no major actions were taken on the actual model; instead, participants focused on adding post-its with indications on them. These activities were carried out collaboratively, allowing participants to discuss among themselves and propose different points of view.

STEP 4 - the second intermezzo

As a final activity, the same template from step 2 was proposed to the users. The aim was to capture their renewed impression of the automatic booth for disease testing after they acquired a more detailed understanding of the service-system linked to it. They could then compare it to the first version and note the differences and possible hints about details such as colors, materials, and more. Again, this was an individual activity.

STEP 5 - the closure

The ending was the part that “failed” the most. There was an initial idea to do a scenario wrap-up, but unfortunately, too much time was spent on the other parts, and it was not possible to carry it out. Similarly, the evaluation itself turned out to be more of a general feedback session that resembled a casual chat, rather than a structured discussion. Though questions were still asked, the tone was relaxed and informal.

Outputs

The “warm-up” and the two “intermezzos” produced complete and filled out tools, with drawings and writings.

Two were the main outputs generated by the “core” session, both of a “concept” nature:

1. Enriched Product-Service system journeys, with some specific aspects newly ranked and prioritized in the form of sheet of paper with over imposed artefacts (cards, post-its).
2. More defined draft of the booth structure, in the form of drawings and other less visual artefacts.

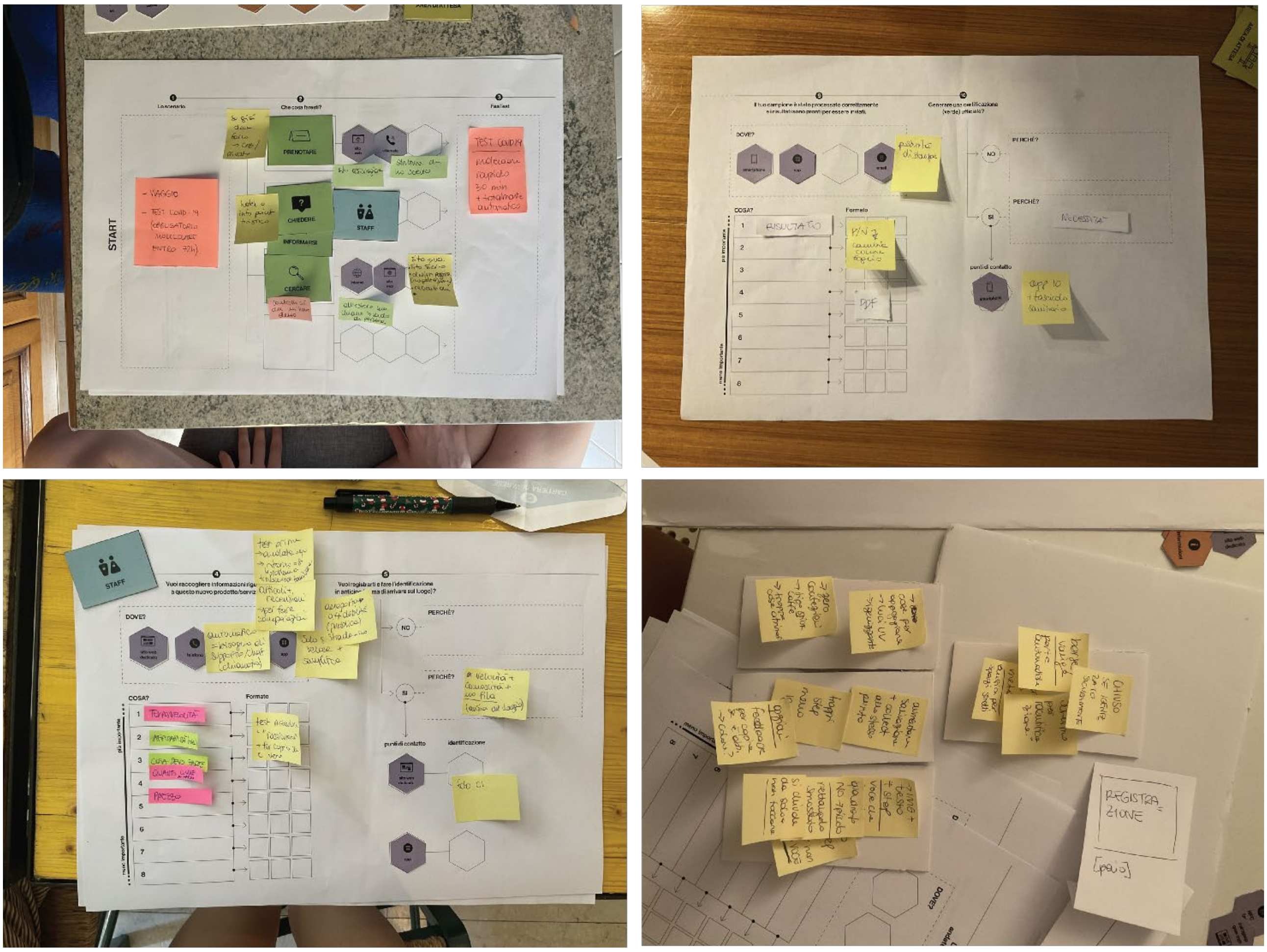


Figure 93 - Some outputs of the core phase of the co design session. Users built on the "mainframe" of the service journey working with the given cards and elements and voicing comments and ideas.

POST-SESSION

Co-design evaluation

As all co-design sessions, many were the failure and success points. Some aspects are related to limitations and obstacles, others to what did/did not work.

Regarding the session itself and the process:

- Time management. This point is always critical for co-design sessions, since they involve "generating" activities, despite careful planning and scheduling it is always fairly complex to keep such timings in real life. Especially, some initial "warm-up" moments took longer than expected, as participants spent minutes reflecting on their work. I expected participants to be way faster and concise with their representations, instead they asked for extra time when I tried to close the activity itself.
- Ending. Partly as a consequence to poor time management, the closing was the part which "failed" the most: the planned activities were not undertaken and instead a lighter, more organic discussion was carried out. Under a perspective, this could be intented as a positive point, as it provided more honest and real feebacks and opinions, on both the sessions themselves and the content of the design. At the same time a more structured "synthesis" of aspects would have been more complete.
- Participants attention. The participants were always highly engaged and active during the sessions themselves and, especially in some cases, rarely needed prompt to keep the flow of the discussion going. Regardless, mostly in the sessions that lasted more than 3 hours, close to the end participants started to lose focus and it was challenging to keep their attention on the topics.
- Balance between style of guidance. At times is was challenging to keep a proper balance between the guidance styles – steering and facilitating – as some of the participants were strong willed and very inclined in being active and keep the engagement of others very high. At the same time, often the discussions started lost the original focus quickly, so it was necessary to intervene without creating confusion or "dimming" the interactions.

More specifically regarding the boundary objects:

- Mechanics. The mechanics of some boundary objects could be improved: sometimes it was difficult for the participants to find the information they wanted through all the set of cards.
- Flexibility vs inputs gathering. To maintain modularity and flexibility of the objects, nothing "permanent" was applied. This made it difficult to efficiently record insights and results, and often required interruptions of the activities themselves, in order not to lose the insights.
- Tool details. The naming of some set of cards was not so clear and explicit, so it was necessary to give extra support in understanding and contextualizing them.
- Level of interpretive flexibility. In the second phase of the core as presented before a very bare model of the booth was used to spark conversations around it. The idea I followed when creating it was an "open" artifact. with space for improvisation, as the draft of the structure was a critical and very interesting point to discuss. While in some sessions this boundary object was successful, in others, initiating and maintaining focused discussions was challenging. In fact, the co-creation process was hindered because, when participant were

given too much freedom to fill in blank areas or generate new ideas, they found themselves either lost (no ideas) or would get enthusiastic and wander off (too many ideas). From my side it took some time to develop effective management strategies, and this impacted the results of the sessions.

- Expected results. For point 1 of the outputs, they reflected what was expected during the planning activities, both in the nature and the content level. Regarding point 2, the outputs were slightly less aligned with the original assumptions, both in contents and outputs.

Reflections on the process

One relevant limitation of the co-design process employed in this thesis is that not all the (real) user categories were involved, which means that parts of the service might be missing and certain details might not have been discussed and explored enough. This gap in participation could lead to an incomplete understanding of the user needs and preferences, and result in a service that does not fully meet the requirements of all potential users. Additionally, the fact that I, the researcher, was alone in the process presented another major challenge. While I attempted at recording everything, it is possible that some important details, especially visual cues and other nonverbal communication, were missed. This highlights the importance of having a team of researchers involved in the co-design process to ensure that all relevant information is captured and considered. Moreover, the lack of a collaborative team could potentially affect the quality of the service provided. Therefore, it is always recommended to have a diverse group of participants and a collaborative team of researchers to ensure a comprehensive and effective co-design process.

4.2.4 Insights synthesis

The output of the co-design sessions underwent a review and analysis process, culminating in the development of a representation that effectively visualized the salient features of the new and enhanced Product-Service System. This step was critical, given that the insights generated were not meant for my personal use and guide as the sole designer and researcher, but instead had to be presented to a group of stakeholders with varying levels of familiarity with the topic. In this context, creating a clear and easily interpretable visualization was crucial, as it was necessary to communicate an unfamiliar perspective to the audience. Additionally, it was important to demonstrate the value of the codesign session itself, which proved to be a challenging task, particularly given the lack of prior consideration of user needs or inputs among the group. The stakeholders were, in fact, holding the final decision-making power.

What I presented was an exemplary version of an experience map or customer journey map that was based on the Service-System-related insights generated during the co-design sessions. Additionally, a different schematic visualization included key aspects that emerged regarding the physical "product" (booth), which were later defined as "requirements", retracing a more engineering-bent wording

SERVICE SYSTEM INSIGHTS

Pre service

- General lack of understanding and a high level of confusion regarding the difference between antigen and molecular tests. This lack of understanding is consistent with previous user research findings and refers to all user categories.

- Reliability when referring to Covid-19 tests or in general medical procedures are high priorities for the users: they tend to refer initially to already existing services if they offer a viable possibility but are open to try new ones, as the outcome of the activities can have a big impact on their lives (eg. not allow travel).

- Skepticism remains high when coming in contact with new services online, especially for younger users and families. Before trusting a new service related to Covid-19 testing they are would research thoroughly (eg. check if was cited in some articles,would compare it with similar services, would check if it had reviews not only on the dedicated website).

- Information regarding the service displayed in the different channels have to be very precise and detailed (eg. procedure times and process, certificate validity, what to do in specific emergency cases, how to be reimboursed, …) according to all user categories. Leisure travellers between 30 to 55 were the only category who is more prone to only superficially look at the information and understand more directly on the spot. Moreover, it needed to show explicitly the added value in respect to other options on the market (eg. simple procedure, fast results, system of booths).

- Between the most cited “incentives” to trust a website there were the endorsement and sponsorship of well-established institutions, governments and other official services (eg. airport).

- Touchpoints were mostly varied by user categories. Business travellers and families tend to gravitate towards laptops and website. Leisure travellers would rely on app and information directly on location. Older users (leisure travellers), instead, always search first for “physical” touchpoints (eg. leaflets). All the user categories, though, considered fundamental to always have the possibility of contacting by telephone call a “human” operator and not only rely on digital/static information.

- All the user categories had a shared perspective for registration and booking: they all remarked the usefulness of having the possibility of doing both the actions in advance. Leisure travellers between 30 and 55 were the more prone to use a “walk-in” version of the service along with the “booking” version. The other user categories, instead, highlighted the need for security and “peace of mind”.

- Touchpoints for these two activities were opposite. Business travellers, families and younger leisure travellers would perform everything with the laptop and an official website, only considering of downloading a dedicated app if their first use was successful or if it would simplify or streamline the process greatly. Leisure travellers between 30 and 55 would, instead, only perform the journey through the app.

- Almost all users categories would pay right away, as it is considered faster and convenient. The only exceptions were older leisure travellers (55+) that do not trust online payment systems or lack the knowledge to perform such actions. Therefore, they expressed the need for a way to pay on site.

- Arrival on site and finding the actual booth was related to pessimistic affirmations, as all the users involuntary created connections with previous experiences in airports and similar facilities. They all expressed the need for precise information on the location of both the main building and the CHECKD. structure inside this building. Touchpoints for these varied between the users, with digital touchpoints (eg. app, .pdf on phone) for everyone but older leisure travellers (55+) who preferred a physical copy of the "map".

- Waiting time is expected by all user categories to be kept at a minimum (max 5-10min) and in a comfortable space, where it is clear how to behave and queue.

<u>During</u>

- Safety and security inside the booth was a common point between all users: all agreed on the necessity of identification prior to entrance. Mostly all users agreed on carrying it out with only digital tools (eg. Screens, qr codes) and no humans. Also older leisure travellers felt knowledgeable enough to perform such actions. Finally, a key point was emergency: participants all mentioned the need for a "help" button that would allow them to leave the booth if in a critical situation.

- All the participants, but especially older leisure travellers, expressed the need for clear instructions and directions both inside and outside the structure, as the anxiety of carrying out the test would deeply impact their capacity of staying focused and properly understanding everything. Instructions with illustrations, brief videos and audios were the most cited. Moreover, they conveyed on having an "assisted" logic, where they would be guided "step-by-step" by the booth itself.

- Inside the booth disinfection and hygenization were high on the priority list, especially in families of leisure travellers. They tended towards a system of artifacts that avoided touching too many elements or staying inside the closed space for too long.

- All the participants agreed that the sample collection procedure had to be straightforward and simple. Passages/steps and elements involved need to be kept to a minimum, to "reassure" the emotional discomfort, which was remarked as a "certainly present" element during the procedure. Longer and more complex steps were regarded as a failed procedure, as they would imply the possibility of committing more errors. Moreover, constant and clear feedback from the booth itself was mentioned as fundamental.

- A painless procedure was also another point supported by all the users. Saliva is seen as the most “disgusting” and least “hygienic” method of taking a sample, while the nasopharyngeal swab is considered too painful and uncomfortable.

After

- Clarity in depicting the results on the certificate and accessibility in managing them was a shared point between all the users. They all expressed the need for them to be incorporated in pre-existing digital services (eg. Certificates apps).

- Accessibility of results from multiple sources was deemed important, especially for younger leisure travellers and business travellers. In fact, they gravited towards “worst-case scenarios” in which their travel plans had to be rescheduled because of missing or unreachable results (eg. Lost phone, internet problems). Some options were mentioned more frequently: results on app, via SMS, via email and offering the possibility of printing them from a “physical” totem on location.

PRODUCT/STRUCTURE INSIGHTS

Materials and characteristics

Users, before carrying out the co-design session presented two main strands of understanding regarding the booth.

1. People formed connections with pre-existing products or spaces they had personally experienced, such as photobooths, phone booths, hospitals, and COVID-19 drive-through testing sites. Negative emotions were associated with these connections, particularly those related to COVID-19, and characteristics attached to these products reflected skepticism and a lack of trust. In this case use of metal, darker colors and rigid structures were proposed, along with heavy and bulky presence. In general cold and aseptic were used to define this kind of vision.

2. People imagined something futuristic and utopian that uses advanced technology to detect various diseases, participants felt more positive emotions such as security and precision. Characteristics associated with these futuristic products included lighter colors (white, grey, red, green) and materials (soft, relaxing), in line with the positive emotions expressed.

After the co-design sessions the participants' visions largely aligned towards a similar idea, although some differences remained. The emotions expressed veered more towards the positive side, although there was still some negativity associated with the idea of taking a test, especially in a travel situation, which was viewed as particularly stressful. Nonetheless, security and reliability remained important factors. Certain characteristics related to materials and colors remained consistent across the various visions (metallic materials, usage of gray). Participants' perspectives on the cleanliness of the machine and its efficiency in actually working were changed.

Overall, the aesthetics qualities tended towards a structure that would reflect its being new and innovative, without either being intimidating or boring.

Signage

- Clear information and signage are important for queue management. Users suggested having clear signage on the floor to indicate where to queue, and to have barriers to define queue spaces. It is also important to distinguish between those who have booked and those who have not.

- Providing additional information in the form of posters or signs can be helpful. Users suggested having posters that allow them to download the app, as well as providing vertical and horizontal signage. However, it is important that this information is presented in an organized and clear manner, to avoid confusion.

- Floor signage can be used for both queue management and directing people to the correct booth. Participants suggested using floor signage to direct people to the correct booth, as well as to maintain distance in queues.

General structure

- All users expressed a desire for privacy, but at the same time they did not advocate for a small, closed spaces as it may create anxiety. They suggested that booths should have a semi-open or open top, and should not feel cramped or suffocating.

- A point was made on the structure being fully “automatic” and was often connected with the previously mentioned need for high level of hygiene and health safety. Participants expressed how they expect the structure to be “smart” and adaptable to their actions, first of all providing automatic doors at the entrance and other movement or sensor enabled interactions.

- All participants highlighted the necessity of considering wheelchair accessibility when designing the booths. It is important to ensure that the booths are large enough to accommodate wheelchair users and that they have appropriate features for accessibility.

- Participants, particularly leisure family travellers, suggested that the booths should be large enough to fit two adults or one parent with two children. They also suggested that there should be enough space to leave a luggage and maybe even an antechamber for this purpose.

- User mentioned the need for enough light inside the booths, especially younger users. Additionally, they suggested that there should not be fixed seating inside the booths, except if necessary for older people. This would allow more flexibility for different needs.

Staff

- Users proposed the presence of staff presence to managing queues and ensure that people are organized and moving in the right direction. They also suggested of having staff members specifically designated to help those who have not registered to ensure that they do not disrupt the flow of the queue.

- Users deemed important staff members, especially because they can help in emergencies and answer questions and hypothetically also check check their luggage.

4.2.5 Concept definition and proposal

From the final developed insights, It was possible to advance both the Service-System and the preliminary concept of the structure. In-between the concepts developments and the actual concept presentation another survey was carried out, in regard to the “openness” of the structure. After presenting a brief scenario (Covid-19 self test in a public setting - eg. airport) it proposed the two options: booth with four sides closed or booth with one side open and two closed and why. Despite the numerous answers the results did not provide a definitive answer, as they were 50/50.

For this reason, it was decided to keep both the options. Three way more defined concepts were drafted, along with the ideal sample collection procedure and its steps, that could be adapted to both a “booth with booking” and a “booth walk-in”.

Concept #1

The concept is inspired by the original aesthetic of Diaxxo PCR, which features a pyramid shape and a base color of metal gray. In terms of accessibility, the structure is designed to accommodate wheelchair users with one other adult person, or one adult and two kids or two adults. All four sides of the structure are fully closed. Additionally, the doors or panels can be made of a dark transparent material, such as glass, with a "window-like opening" at the top for ventilation and natural light. Overall, this concept offers a distinctive look while prioritizing accessibility and functionality and assuring complete privacy during the procedure. Criticalities can be connected to the fact that, in being fully closed, might not appeal to claustrophobic people or in general create a sense of discomfort.

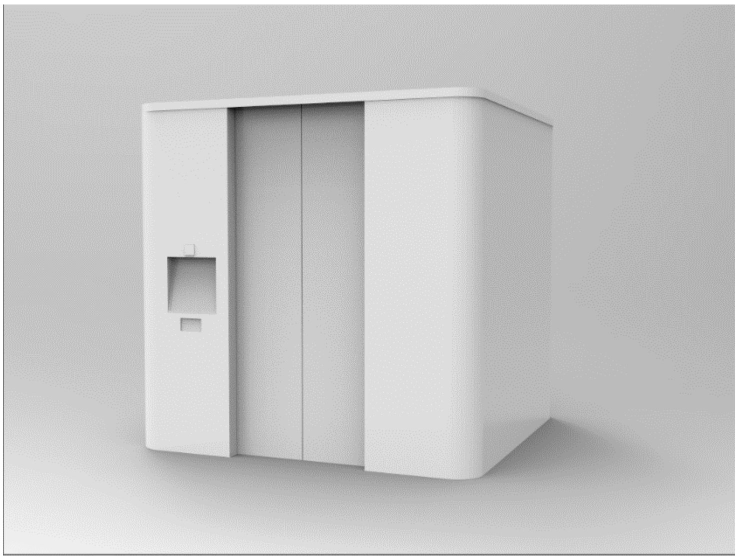


Figure 94 - Render of concept #1

<u>*Concept #2*</u>

The concept is inspired by the new aesthetic of Diaxxo products and features a base color of white, as well as a more organic form. In terms of accessibility, the structure is designed to accommodate wheelchair users wheelchair users with one other adult person, or one adult and two kids or two adults. All four sides of the structure are fully closed. Additionally, there is an opening on the top, which can provide ventilation and natural light. Overall, this concept offers a unique and visually appealing design while prioritizing accessibility and other practical considerations. Also in this case privacy is fully assured, as the doors, despite being made of a dark glass are opaque, then impeding outside people to see inside. Similarly to concept #1 this booth might not appeal to claustrophobic people or in general create a sense of discomfort.

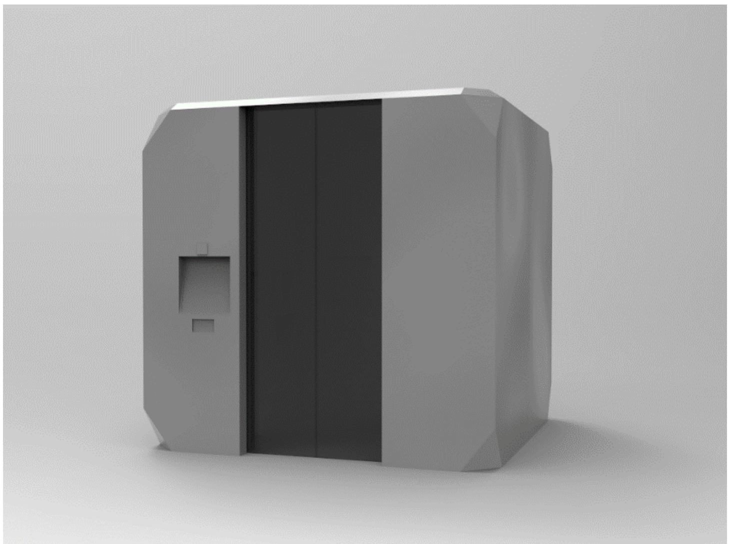


Figure 95 - Render of concept #2.

Concept #3

The concept is inspired by the new aesthetic of Diaxxo products and features a base color of white, as well as a more organic form. This variant is different from the previous concept in that it is designed to accommodate only onw wheelchair user without another adult, and with space for either one adult or one adult and one child. The top is completely open, which provides ample ventilation and natural light. The fourth side features sliding panels made of a light transparent material. Overall, this variant is very similar to the concept #2, but it brings the dimensions down to the limit, as a possible option to take into consideration. Moreover, in this case privacy is still somewhat assured (the transparent panels are opaque), but the small crease still allows people to see through. Criticalities can be connected to the fact that, in being fully opened there is not a complete "detachment" from the outside space, which might hinder the correct procedure (eg. sounds and other distractions, worry about being seen, …).

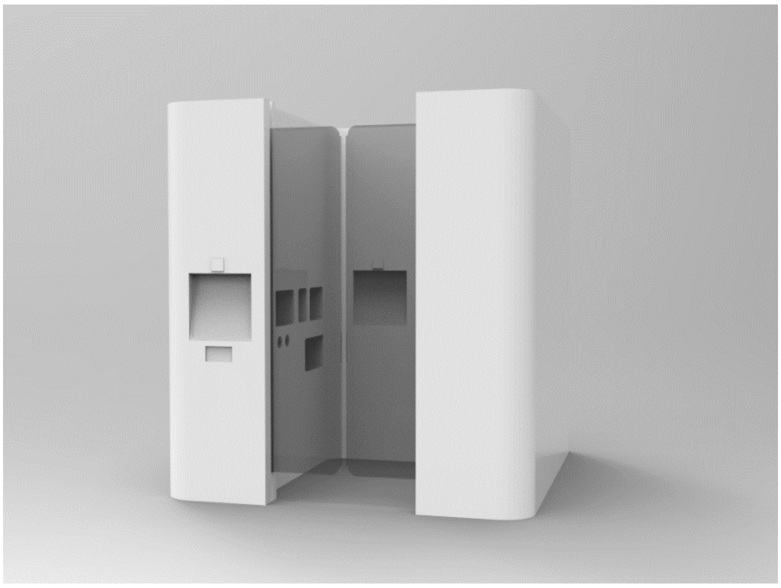


Figure 96 - Render of concept #3.

Regarding the service and interaction steps (exterior steps and interior) only one version was developed as it could be replicated in the same way in all the three structures.

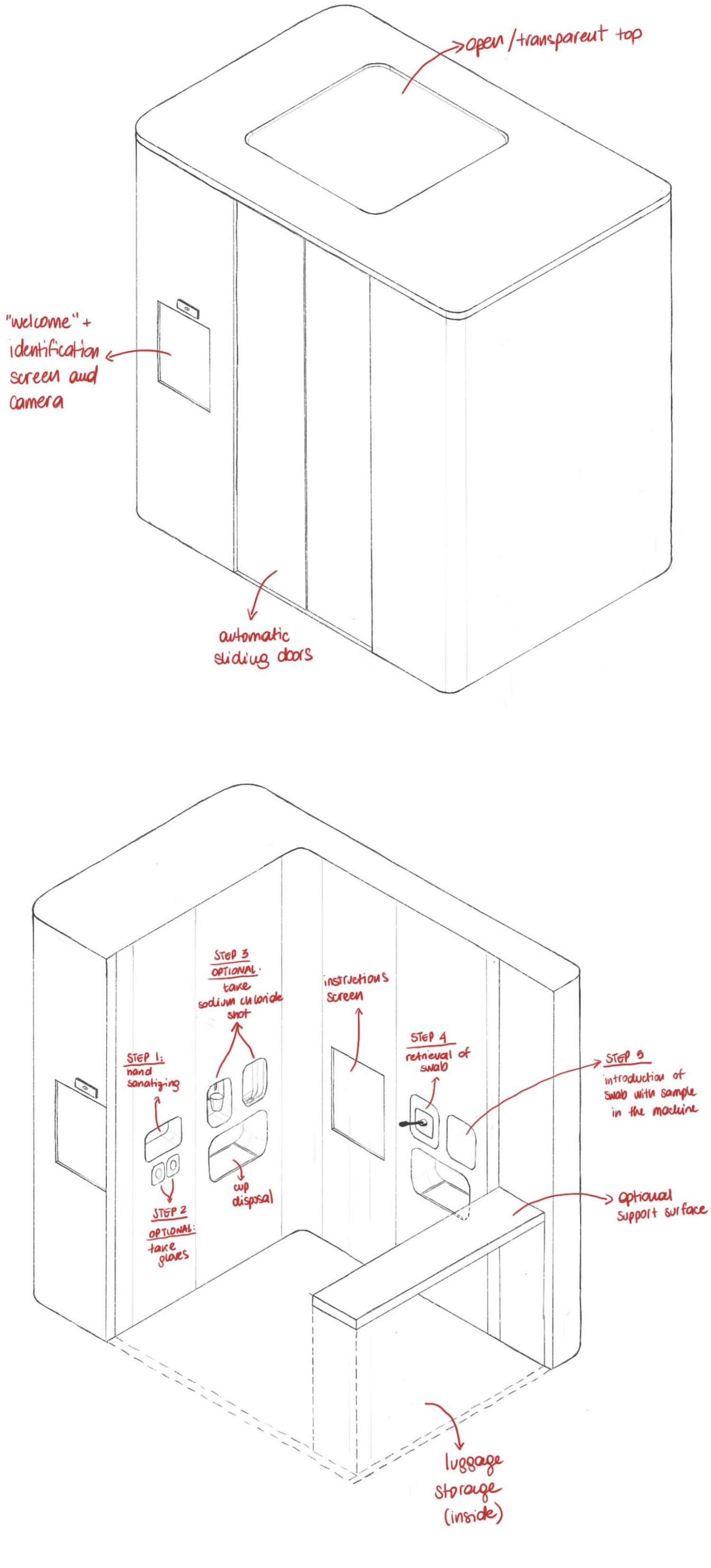


Figure 97 - Axonometric view of possible product-service system interaction moments.

These three outlooks were presented again to the full panel of stakeholders. A discussion was held, where each person was able to give their own opinion and feedback. The aim of this meeting was to make a final selection. Decisional criteria were set to choose which structure to proceed with:

- Structure complexity. Level of unconventionality of forms, construction techniques possible, ad hoc design or already manufactured parts while maintaining the structure safe, functional, and meet the requirements of their intended use.

- Forecasted cost. For structure materials, productions (if specific customized parts), construction (out sourced, in house). Also a forecasted cost for a possible prototype was taken into consideration.

- Accessibility. Level of usability by all people, regardless of their age, ability, or disability

- Aesthetics. Visual and sensory qualities of architecture, such as form, shape, proportion, scale, color, texture, materials, and spatial relationships.

	CONCEPT #1	CONCEPT #2	CONCEPT #3
Structure complexity	Medium	High	Medium-low
Forecasted cost	High	High	Medium
Accessibility	Fully accessible	Fully accessible	Only partially accessible
Aesthetics	Organic, clean, professional, hygienic	Squared, cold, functional, professional	Organic, simple, open

The results of the discussion held in a democratic way with allowed to pin point as the preferred solution the third concept, but with structural dimensions of the first concept, as general structure complexity and forecasted cost were deemed lower. At the same time, maintaining full accessibility was important.

Each concept was presented with a different wayfinding/signage system on the outside of the booth. The latter was not necessarily connected or had a particular reason to be related to the specific architecture. The opposite, it could be totally interchangeable, as the main elements to be visualized were always the same: booth number, booth type (booking/no booking), occupation status, interal specifications (disinfection, space for luggage, accessibility).

As a result, a decision was made to postpone selecting a specific wayfinding option until the prototyping phase, where its effectiveness could be tested in a real environment. This step was deemed crucial in defining a viable solution.

Finally, alongside these concepts I made a proposal regarding the brand identity, which was comprised in my deliverables. I presented four different concepts that were also discussed and reduced to a final decision.

4.4 Phase three: prototyping

4.4.1 Introduction to the process

As previously mentioned in the background chapters of this thesis, prototyping is an integral and fundamental component of the Service Design process because it enables designers to test, refine, and communicate their ideas in a low-risk, iterative manner that leads to better-designed services. After building a stronger and more defined concept on the co-design results (comprised of both the product and the service) it was now time to create a tangible representation of it, gather feedback from users and make improvements before investing time and resources in a full-scale implementation. Most importantly, these sessions would be essential to establish specific metrics which were absolutely necessary to inform engineering-related designs, that, in turn, would help achieve operational project goals.

The first key step in order to develop a prototyping plan was to decide the scope and scale of the activities. In parallel decision with Diaxxo, I decided to tackle the service with a ‘zoom-out’ approach, focusing first on singular service moments, to then observe the holistic service experience.

More precisely, I started by reviewing the overall service journey and its different elements and their level of potential immediate implementation. One particular service moment that stood out was the sample collection procedure, which had several points of uncertainty and criticality. Specifically, the challenge was to reconcile user needs and vision with the actual feasible options available. To address this, a lengthy discussion was held with the engineering team.

The co-design sessions produced certain results in regard to the sample collection procedure. The “ideal situation” drafted by user input, would entail a very simple sequence of steps with limited possibility of action.

In brief: the swab comes out of the machine, the user easily collects the sample, and they re-insert it again in the machine. However, this procedure would require a highly complex automation system in the back-end that could:

1.Provide a single-use and sterile swab (therefore manage a whole array of them).

2.Retake the swab in a way that avoids contamination, and it is properly “located” to support next steps.

3.Prepare the sample for processing, meaning carry out an nucleic acids extractions procedure.

4.Process the sample with a PCR technique.

5.Correctly dispose of and store biological waste.

The state of the technology (as of November 2022) was deemed definitely not capable of carrying out these actions. Main obstacles were:

- Automation systems for point 1, 2 and 5 were not existent yet, and the proper development of a system would require many months still.
- Point 3 and 4, mostly carried out by the DiaxxoCare product, were still under heavy improvement, always under the automation perspective: many steps still required human intervention (eg. change cartridge, load samples), which is not possible to have the case of the booth.
- The utilization of *ad hoc* designed swab (the so-called "lollipop", that would allow the user to perform a very straightforward sequence of steps) would also be necessary. The process of designing, testing, producing and obtaining an official IVD certification, though, would be extremely long and expensive.

A possible solution discussed was to simplify this "behind the scenes" system, by shifting the complexity onto the user. However, as the number and difficulty of tasks a user must perform increases, the time required to complete the procedure also increases, leading to a new set of challenges related to time management. Finding a new trade-off between the user and the machine, then, was absolutely necessary.

Multiple options and scenarios were discussed. Two new procedure steps were finally proposed, both compatible with the current version of diaxxoCare and its automation level. Those two, along with the original concept born from user input, were the focus of the first round of prototyping. Despite being aware and have acknowledged the limitations of the current level of development of the products, it was still deemed necessary to include the co-design generate concept. The latter, in fact, would act as main long-term guideline and "ideal state to achieve" with the future developments of the booth.

4.4.2 Prototyping #1: the sample collection procedure

POSITION IN PROCESS AND PURPOSE

At this moment of the process, we proposed a prototyping activity with the aim to define which option to implement between the two new solutions and the ideal one emerged in the co-design workshops.

1 - "Version 1: the Automatic Lolliswab"

AUTOMATION COMPLEXITY: HIGH

DEVELOPMENT TIME: 1 TO 2 YEARS

COST: HIGH

The Automatic Lolliswab, or "the ideal procedure", is a proposed design that aligns with the insights gained from co-design sessions. These insights highlighted the importance of developing a product that eliminates the need for spit and nose contact and reduces the number and complexity of steps required (eg. unwrapping of packages).

The proposed steps for using this lollipop are straightforward: first, the user detaches the lollipop from its cap/cover, ensuring that it remains clean. Next, the user inserts the lollipop into their mouth for a few seconds. Finally, the user sticks the swab back on the cap/cover.

Overall, this design seeks to provide a more user-friendly and hygienic swabbing experience, with minimal steps and maximum convenience.

2 - "Version 2: the manual saliva"

AUTOMATION COMPLEXITY: LOW

DEVELOPMENT TIME: < 1 YEAR

COST: MEDIUM

In this procedure the booth dispenses two packages to the user. The first package contains a spit funnel and a tube, while the second package includes a tube with preservation liquid. To begin, the user opens the first package and spits into the tube while keeping it upright. Next, the user opens the second package and mixes the contents of tube 1 with the substances in tube 2 before sealing the tube with a cap. The tube, now containing the mixed substances, is then inserted into the machine without the cap. Lastly, any unused materials are disposed of.

This design does not align perfectly with the insights generated from the co-design sessions, but it provides a viable option for those who are comfortable with using their spit in the process.

3 - "Version 3: the manual lolliswab"

AUTOMATION COMPLEXITY: MEDIUM

DEVELOPMENT TIME: 1/2 YEARS

COST: MEDIUM

This procedure follows five steps. Firstly, the user takes a package from the machine and opens it. Next, the user places the swab under their tongue for a duration of 20 seconds. After this, the user unlocks the cap using the swab and turns it upside down. The swab is then placed into the tube, and the contents are stirred a few times. Lastly, the tube without the cap is inserted into the machine.

With this option the attempt is to balance the co-design insights with technical requirements and limitations. The actions are kept straightforward for the user, but at the same time it is also practical for the collection system of biological samples.

We planned to test each single procedure to validate or disprove assumptions and gather feedback to guide subsequent improvements.

The assumptions touched upon these aspects: total time of completion, steps (number, complexity), instructions (length, complexity).

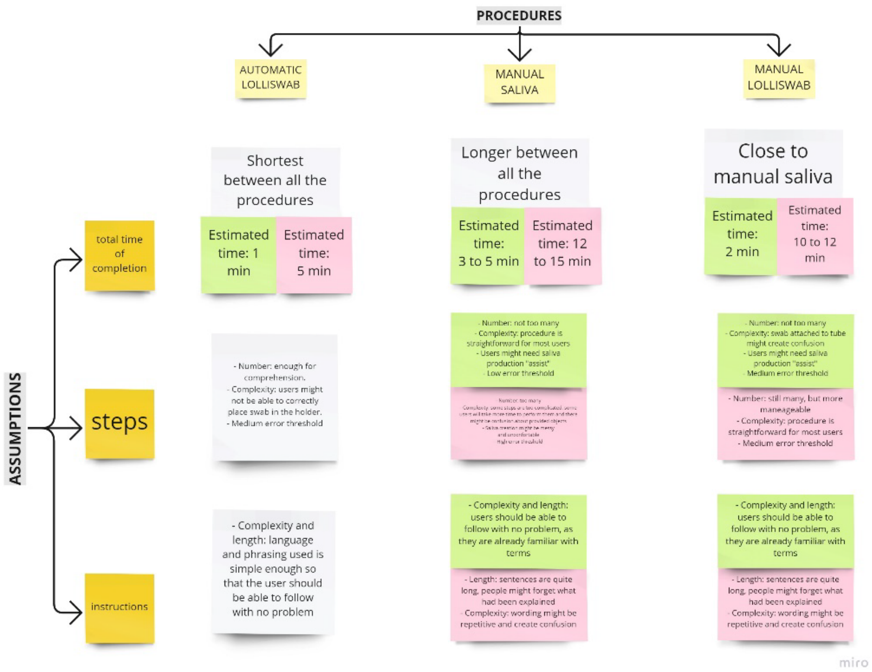


Figure 98 - Sample collection procedure assumptions.

A critical point we aimed to learn about was the total completion time, since it represented a fundamental requirement for understanding important specifications regarding the PCR machines, such as: number of patients per run, number of devices per booth and number of booths per location to reach desired test number in a day.

For example, the main objective to reach as per project deadlines, was the elaboration of 200 tests in 2 hours. This would mean 6 parallel booths, with 4 PCR machines for each booth, capable of collecting 8 samples (in 20 minutes) and elaborating them at a time in 40 minutes. Four 4 PCR machines would run in sequence so that the sample intake could be without continuous. Based on calculations, this configuration would consider around 5 minutes per person for the actual sample collection.

AUTHOR/RESOURCES

In this case I was the Author, and I was responsible for both the prototype design and development and session management.

Regarding the resources:

- A ‘service prototyping lab’ solution was selected, since the servicescape was deemed not immediately fundamental to reach the prototyping goals. The sessions were held in one of Diaxxo’s offices in the HCI building in the ETH Honggenberg Campus.
- Real users were involved, keeping as much diversity as possible, to address some specific hypotheses and needs as the sample collection procedure is the focal point of the service offering. A total of 21 people were involved, from both work travellers and leisure travellers, with a balanced mix of both genders. The age span went from 22 to 82 years old.
- The ‘staff’ heuristic was not present, as CHECKD. can be categorized as a ‘self-service’ type of service (Blomkvist, 2011).
- A mix of mock-ups and real props were used. Some devices that needed to be implemented did not exist yet (eg. swab collection mechanism), so they were ‘performed’ by me; others were too difficult to get, due to time constraints, or were not crucial touchpoints (Passera et al., 2012). Other elements, instead, were real, meaning existing biomedical products.

TECHNIQUE AND PROCESS

As the sample collection procedure can be considered a complex service encounter, we decided to use the experience prototype technique. This approach, proposed originally by Buchenau & Suri (2000), “tries to replicate an existing situation or construct a new one, in which participants can understand, in an embodied way, what it feels like to interact with something” (Arvola et al., 2012, p.2). It aligns with the need of evaluating this peculiar service moment, which is not a singular contact with a touchpoint, but a mini-journey, a sequence of interactions with various interfaces and objects. In the activity, I briefly introduced the meaning and purpose of prototyping, to then touch upon the general ‘booth’ concept, its link to Covid-19 and the number of procedures to be tested. Secondly, the procedures were simulated one after the other. Finally, an interview was carried out, starting with a very broad prompt question to allow ‘free speech’, to eventually pointing out specific questions, about steps’ details (safety, hygiene, instructions, comfortability).

FIDELITY-RESOLUTION

The prototype resolution was medium-low. In fact, the fidelity of distinct aspects, was mixed. The fidelity range for each dimension was based on testing goals, material/immaterial resources available and audience. A resolution graph was built, based on Passera et al., 2012 main idea, but combined with the fidelity dimensions proposed by McCurdy et al. (2006).

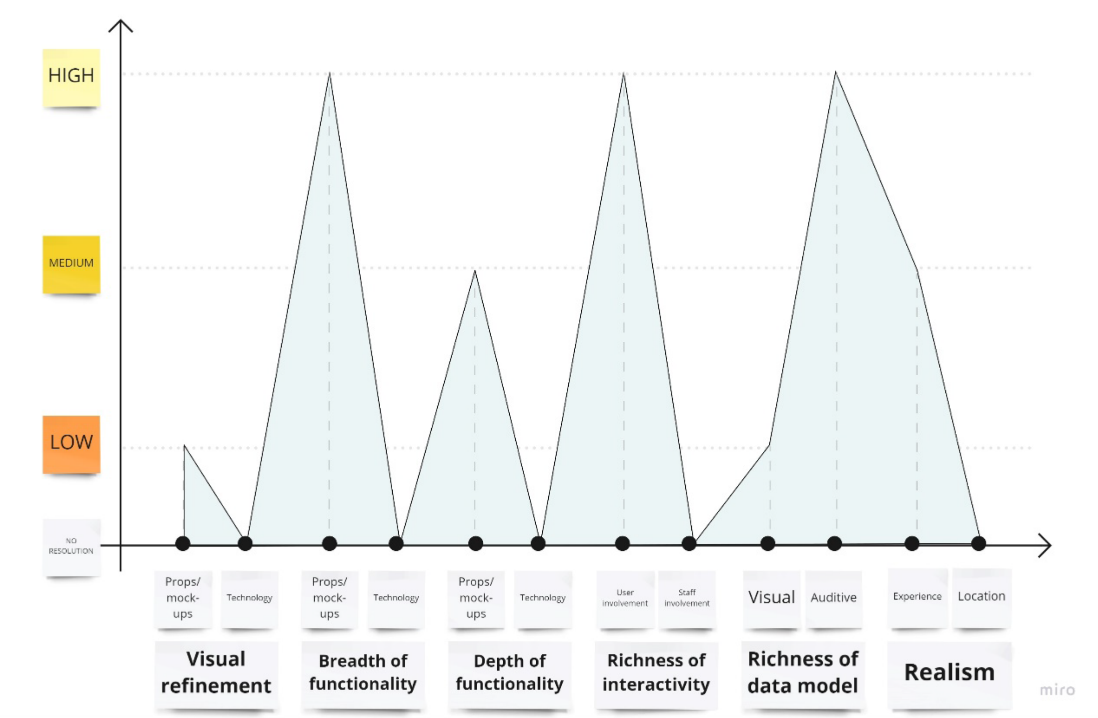


Figure 99 - Resolution graph of sample collection procedure prototyping.

In the low-fidelity range we positioned the look and feel of the props and the technology, realism of the location. They did not directly impact the aspects that needed to be observed and therefore deemed less relevant. The functionality of the props and the technology, and the realism of the experience were medium fidelity. For example, implementing a good level of functionality, for both technology and props, was critical to guarantee the correct timing of the procedure. Some elements, though, like the "proceed" button were kept analogic rather than digital.

To build the prototype I used simple materials, as the budget and the time were limited. Most 'backstage' elements (eg. swabs containers) were built with paper and/or cardboard. Swabs were personalized starting from existing biomedical products, but in one case (the ideal version), where a marker was used. The actual mechanics and the machine 'instructions' were carried out 'live' by the me, the main facilitator of the session. I was placed behind the panels to orchestrate the different elements, "faking" the automation system, and giving instructions by voice. No other video or audio support was given on purpose, so it was possible to understand the essential needs of the users on the matter.

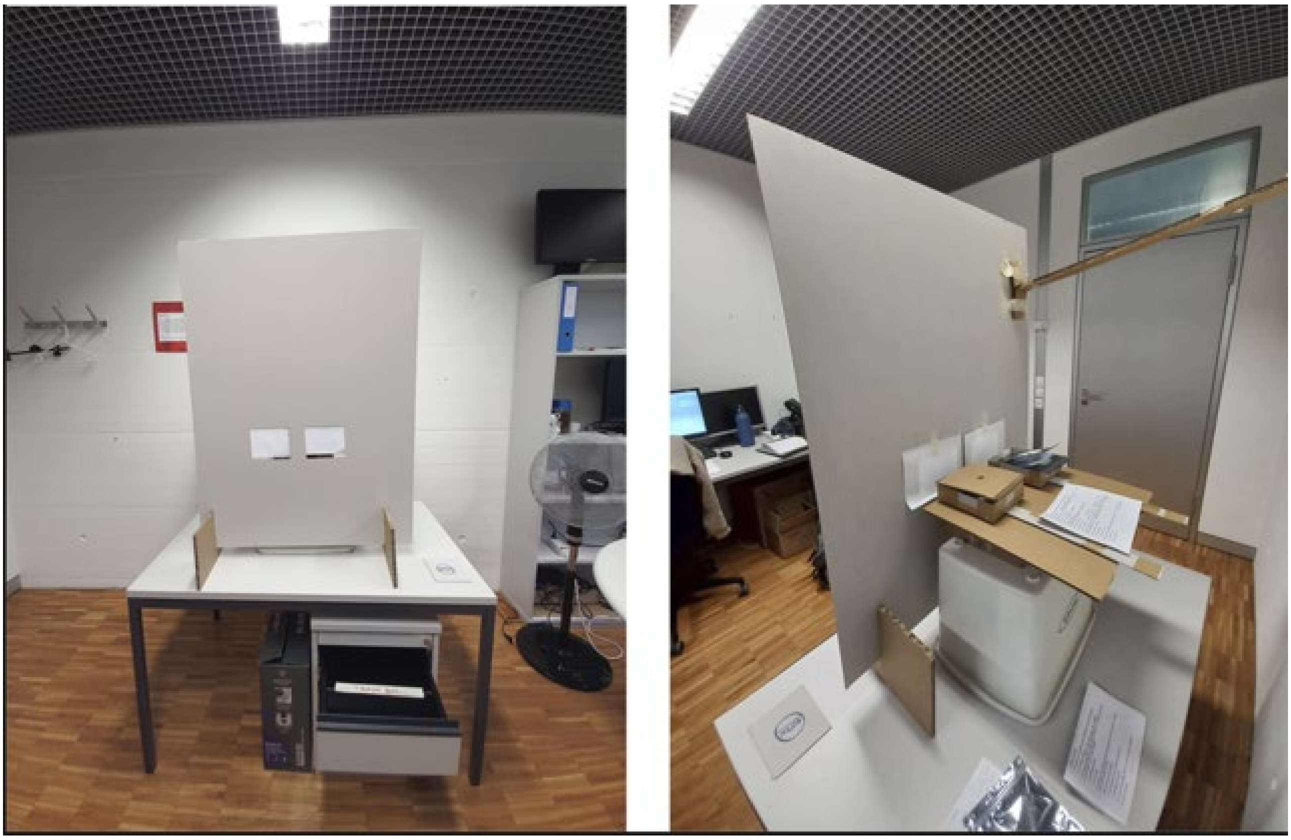


Figure 100 – Experience prototype setting, from the front and from the back. It is possible to see the simple material utilized in the construction: cardboard and paper mainly. Also the “machine automation”, despite being accurate in movement and timings, it was simulated with analogic methodologies (pushing manually the trays out of the panels).

VALIDITY

In this case validity was limited in the sense that the setting hardly approximated the intended implementation context, despite only real users were involved. The servicescape was not deemed a priority or for the goal of the prototyping moment. The feedback collected was jointly discussed with the stakeholders and the engineering team.

PLAUSIBILITY

Since the audience was kept into consideration while designing the prototype, as Blomkvist (2011) suggests, participants all provided very detailed and extensive feedback and engaged organically in explaining their own point of view.

These results were generated after the prototyping analysis. I carried out the latter in a second moment, following a simple procedure:

- For each participant a map of the sample collection procedure was made.
- I reviewed each session, as all of them were video recorded (with the permission of the participants); and noted in the map the following data:
    - Procedure Start // Procedure End

- Error/Problem
- Comments (positive, negative, …)
- Facial/physical reaction/behaviour (surprised, annoyed, confused, …)

- I noted the answers of the final interview.
- I added my personal comments and observations linked to each one of the areas (qualitative and quantitative)

RESULTS

Quantitative results collected were:

1. Total time of completion
2. Completions with/without errors
3. Number of errors (per procedure)
4. Types of errors (misunderstanding instructions, forgetting instructions, not following instructions, accidental)

Qualitative results were probed with open questions:

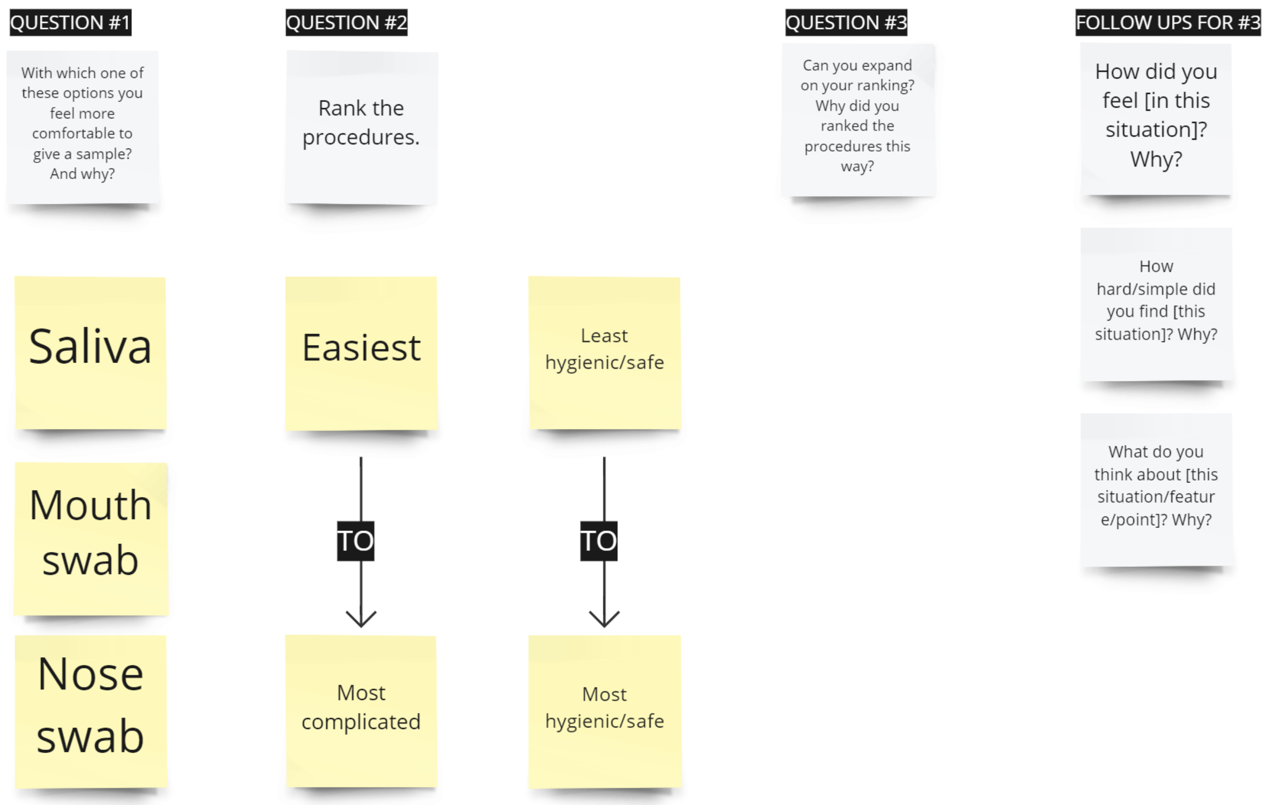


Figure 101 - Overview of questions asked to generate qualitative results.

INSIGHTS AND FINDINGS

Procedure #1: Manual saliva

This procedure was rated as the most complicated and least hygienic by users, as it entailed the use of saliva and spit, which is connected to lack of safety from contamination. This is supported by a success rate of 14.2% and a high number of errors recorded, with only 3 participants completing it without errors.

The procedure is defined as “long” by participants, with the longest time recorded being 4.05 minutes.

Users find the procedure confusing, with too many steps and tubes to juggle. They cannot perform any task without placing things down on a flat surface. Although instructions are given at the right pace, it is hard to follow as many elements are distracting, resulting in users losing sight of the instructions and doing things incorrectly. Using the booth increases anxiety, which is something that all the participants agreed would be present when using it for the first time. Users show signs of insecurity and constantly question themselves. Pouring liquids is a source of anxiety for most of the users.

The most common errors were caused by accidents, misunderstanding instructions, and forgetting instructions and doing only what they remembered. Other common errors include using surfaces to carry out the procedure, resulting in spare parts that had to be thrown away, assuming next steps incorrectly, incorrectly handling the funnel, dropping caps and packages, spilling preservation liquid, pouring liquid into the machine instead of inserting the tube, and struggling with opening packaging.

Procedure #2: Manual lolliswab

The second procedure was rated as the preferred by all users, deemed way easier than the first procedure, and considered the most hygienic by slightly more than half of the participants. This was due to the fact that some did not feel completely safe with the swab being “open” inside the package, despite it being completely sterilized. The steps were described as less complex and appreciation for that was expressed, as well as for the “painlessness” nature of the procedure. Users appeared more tranquil and confident in carrying out the steps, with no particular impediments even for older users.

However, some people felt uncomfortable because they were scared of touching the swab with their hands. Despite the reduce number and more simple actions, people still made mistakes.

This procedure had a success rate of 33.3%, with seven people performing it without errors. The timing for the procedure ranged from 1.11 min to 2.29 min, generally shorter than the first procedure. One specific point that emerged was related to "terminology": people were confused about the difference between "cap" and "swab", as they were essentially the same thing. Moreover, users were slightly puzzled when unscrewing the cap with the swab. The mistakes made in this procedure were similar in nature to the “Manual Saliva” (misunderstanding of instructions, accidents, forgetting instructions), but the maximum number of mistake in a procedure was less, with only 2 errors.

The most common errors included: not throwing away the swab in the end and leaving it around, putting the swab under the tongue before the time count, anticipating steps, and dropping the swab. Overall, the second procedure was rated more positively by users than the first procedure, with fewer steps and a more straightforward process, but still had some relevant percentage of mistakes.

Procedure #3: Automatic lolliswab

The third procedure was the one that was found to be the easiest by all participants and described as "extremely intuitive", requiring no effort, and straightforward. Furthermore, the participants appreciated the minimized errors that the procedure offered. Even the older users did not encounter difficulties in understanding the instructions and carrying them out correctly. This finding contradicts the assumption that older people would have trouble correctly "centering" the cap when delivering it to the machine.

An interesting point of debate emerged: some users found the instruction of "not touching the red strip" intimidating and scary, preferring another approach, such as "touch only this top part" type of instruction. The procedure was considered less hygienic than the “Manual Lolliswab” because people wandered about what happens to the swab when it is inside the machine and they were afraid that it might be contaminated.

The third procedure was the fastest, with one participant completing it in just 57 seconds, while the longest was 1.38 minutes. The success rate was also the highest, with 66.6% of the participants successfully completing it without errors. Only 7 people committed mistakes, and even in those cases, the mistakes were minimal, with the most common mistake being placing the swab under the mouth before the count start, which did not significantly affect the completion of the procedure.

General to all procedures

During the study, all participants expressed the need for more variety regarding the “medium” communicating the instructions. While voice guidance was considered fundamental, users also deemed of invaluable aid in comprehension also videos, static illustrations, and text.

Most participants felt that the instructions were sufficient but desired “even more”, preferring redundancy to feel more secure over doubt. Specifically, they requested to be reminded to dispose of parts that were no longer necessary. Although the instructions were given with a constant flow, participants preferred a procedure that allowed them to proceed at their own pace, with slower or faster moments.

Participants had differing views on the "beeps" and other machine feedback; some found them helpful in framing the steps and guiding timings, while others were neutral to them. The presence of two openings for incoming and outgoing elements was viewed positively by most participants, as it helped distinguish between "clean side" and "dirty side". This increased also their trust towards the machine, as a clear separation was linked to less possibility of contamination. However, some participants preferred having only one opening as it conveyed a greater sense of professionalism.

The use of the tube without the cap was accepted by most participants, but some connected it with a higher possibility of contamination. Some were uncertain if they had understood the instructions correctly when prompted to insert it “without the cap” into the machine, most found it highly unusual, but accepted it anyways.

Participants expressed the need for more functionality, such as buttons to repeat instructions, adjust volume, and an emergency or problem button in case of difficulty, such as dropping the swab or making a critical mistake and needing support or further instructions.

4.4.3 Prototyping #2: the full CHECKD. Experience

POSITION IN PROCESS AND PURPOSE

The sample collection prototyping and its results posed the ground to carry out the whole service experience prototype of CHECKD., which chronologically took place right after. We proposed it as a consequential step of the ‘zoom-out’ approach previously described in order to explore and evaluate the service from a holistic perspective. The aim was to better understand the effectiveness of the designed product-service system (eg. what components worked or did not) and the experience at the different service moments. More in general, it aimed to get actionable insights and concrete recommendations to improve the whole user journey.

AUTHOR/RESOURCES

I was the Author and the responsibilities, the same as the sample procedure prototype.

Regarding the resources:

- In this case, the location is ambiguous. Since CHECKD. can be defined a ‘location-oriented service’ (Blomkvist, 2011), executing the session in a realistic context was necessary. Primary sites for CHECKD. are transportation hubs, which were not easily available. The session was therefore held in a university area, which is an actual secondary-choice location for the real CHECKD. booths. For scenario-building purposes, we applied modifications to the environment and mainly considered it as an airport, but during initial parts of the prototyping, that entailed the user being ‘at home’.

- Real users were involved. This time, due mostly to time constraints, hard-to-reach site and length of activities, we had to restrict the user categories and focus mostly on younger people, both for business and leisure travel, which were easily reachable available to collaborate. A total of 14 people were involved in the prototyping sessions, with a balanced mix of both genders, from 21 to 33 years old.
- The 'staff' was not present, as Checkd. can be categorized as a 'self-service' type of service (Blomkvist, 2011). 4. A mix of mock-ups and real props were used. Most of them were real (eg. computer, screens, suite case, hand-sanitizers, gloves, swabs), but, similarly to the first prototyping session, some were 'mocked'. In fact, specific machines for sample analysis and other automated systems (eg. automatic doors, swab collection) were not yet developed or easily implementable, so they were again enacted and orchestrated by the Author.

TECHNIQUE AND PROCESS

In this case the idea was to prototype the full-service experience. This means that it was necessary to simulate, in the prototype, the various service moments of the journey, the interactions, the touchpoints and, most of all, their relationships in time. We therefore chose to adopt the Service Walkthrough technique, as it allows to represent the ideal service journey "in an embodied and holistic way" (Blomkvist & Bode, 2012, p.1). Starting from the ideal customer journey, we selected critical service moments that could enact the most basic scenario, with the rule of having at least one from the three main service encounters (pre, during and post service), to then create all the artifacts and props necessary to give life to the 'surrogate' (Blomkvist, 2014) and find ways to coherently and smoothly orchestrate all the mise-en-scène.

The participants were first introduced to the activities with a brief description of service prototyping, followed by the proposal of a set scenario (Covid-19 certification needed for a travel) and establishment of three main goals (with the main one of obtaining the fit to fly certification):

1. understand what the service is about/how it works;
2. book a test appointment;
3. go to the appointment.

We provided the users with a laptop and an interactive, but wireframe-level version of the CHECKD. website, where they started the roleplay exploring the website. They continued going through the registration procedure, where they had to engage with multiple document mock-ups and spend time typing in real information, to then carry out the booking procedure. After they received their personalized booking confirmation (programmed email sent by the Author during the prototyping session) the Author would 'push' the scenario forward in time, at the day of the booking and invite the user to autonomously reach the location, by following the instructions on the email, also providing contextual props (suitcase, bags, phone). Different wayfinding elements were placed along the way to guide the user. Once reached the location the participants would ‘check-in’ at the booth, go through the full swabbing procedure and receive, on the spot, another personalized email with their fit-to-fly certification. Finally, we carried out an interview, by initially asking a very broad prompt question to allow free speech, to eventually pointing out specific questions, about the different aspects of the experience. At the end of the interview, a small moment was dedicated to the presentation of three different visual interpretations related to the product-service system. Some specific brand identity elements were ‘parallel prototyped’ (different brand versions) and the participants were invited to provide their feedback.

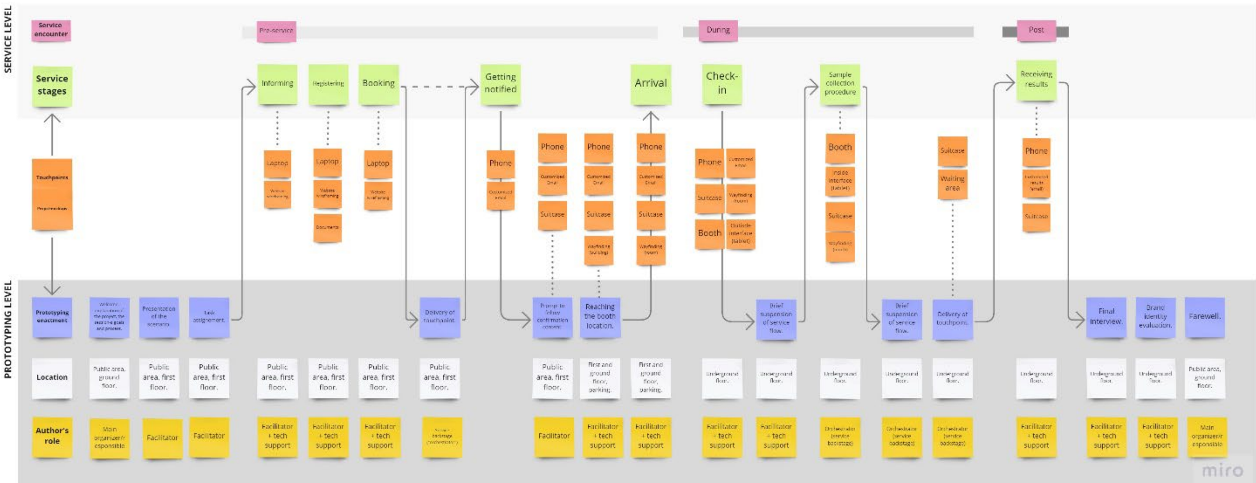


Figure 102 - Service walkthrough overview.

FIDELITY-RESOLUTION

The prototype resolution was medium-high. Also in this case, the fidelity range was triangulated based on the testing goals, the material/immaterial resources available and the audience. As previously, the fidelity of distinct aspects was mixed. We positioned at the medium-low level the look and feel of the technology and the realism of the experience. Medium-high fidelity was kept for the props functionality and look and feel, along with the technology’s functionality and realism of the location. In the case of Checkd. the servicescape and its elements - ambient conditions, spatial layout and function, sign, symbols and artefacts (Bitner, 1992) - were extremely important, as they had a high degree of influence on the users, their feelings, their understanding of the service and their interaction with the touchpoints. A 1:1 scale prototype of the booth was built, as close as possible to the exemplar design regarding the aesthetics, but using simpler materials (metal and wood), that still allowed for a certain degree of flexibility and possibility of changing single aspects without affecting other parts. Real objects were placed inside the structure and also outside, to replicate an ideal airport waiting area. Wayfinding and other signage were created with paper and placed in various points. Other elements were reproduced with a 3D printer, to be more durable and practical in supporting the Author in the simulation of the background mechanics. The Author, also in this case, from behind the panels, 'role played' and moved the different elements. To allow high fidelity functionality of the swabs, instead, we created them in a sterile environment, with real biomedical products, so the users would be able to actually carry out all the procedure steps (eg. hold the swab under their mouth). Of the three digital artifacts we developed (Checkd. website, booth outside and inside interfaces) the look and feel were low fidelity (wireframing only) as it was not critical for the successful execution of the service experience. Of higher fidelity, were, instead, the depth and breadth of both information and functionality, due to their being interlocked with other service moments.

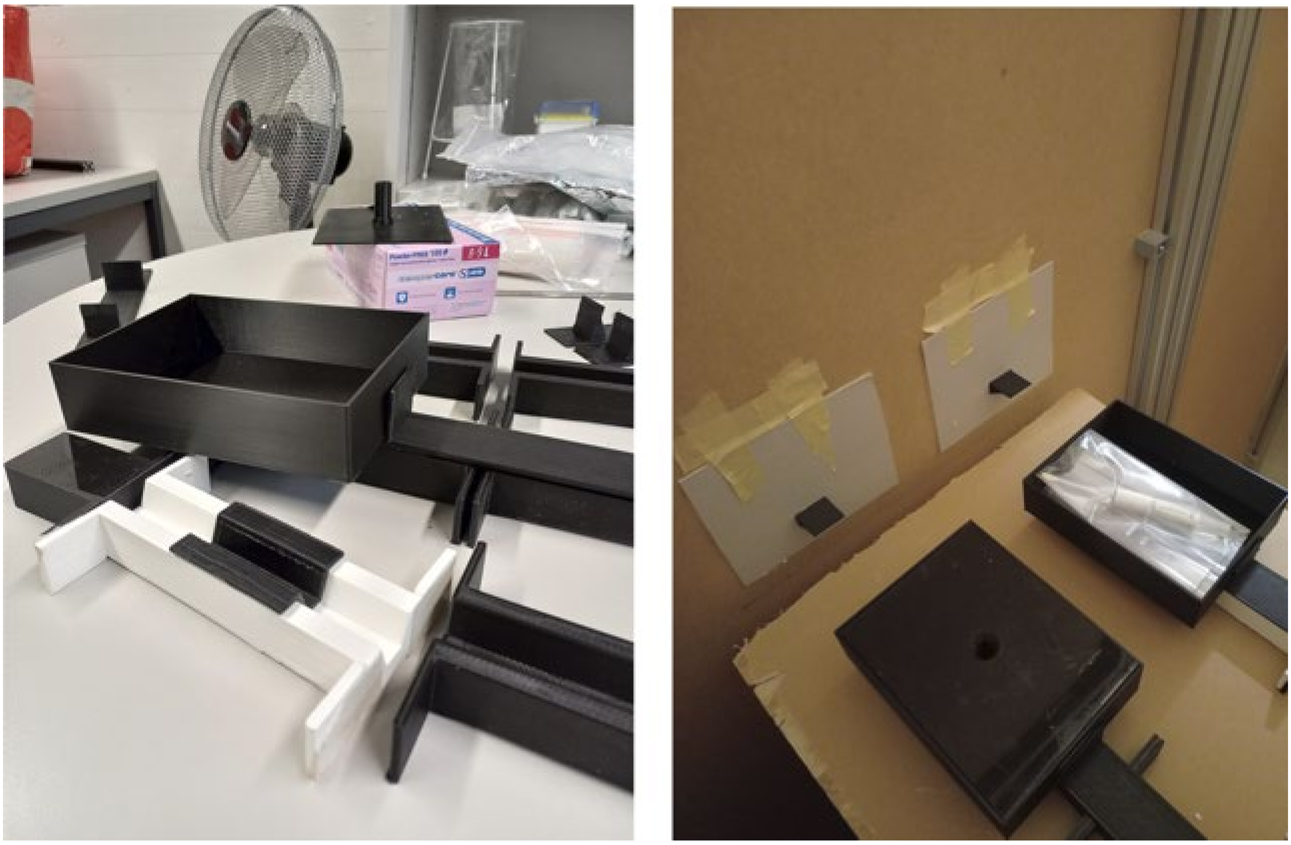


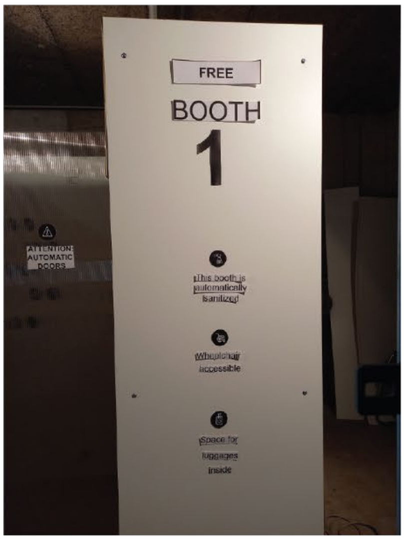
Figure 103 - Some props used to replicate the machine movements.

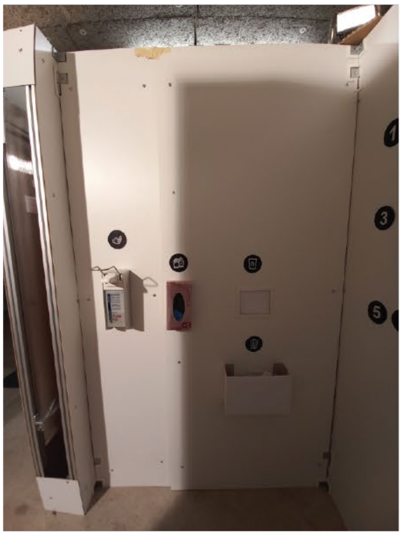

CHECKD.
WITH BO OKING
FREE
BOOTH
1


CHECKD.
fast Covid-19 molecular test
POWERED BY
diaxxo


CHECKD.
WITH BO OKING
Please follow the directions
on the instructions screen


ATTENTION AUTOMATIC DOORS
ATTENTION AUTOMATIC DOORS


FREE
BOOTH
1
This booth is automatically sanitized
Wheelchair accessible
Space for luggages inside




Luggage space

Figure 104 – Overview of the 1:1 prototype built for the service walkthrough. In order are shown: the front view, that the user encountered as soon as they walked inside the door; booth outer panels, with check in procedure doors and other signage; booth interior, with sample collection procedure steps.

VALIDITY

Concerning the validity, despite the larger context and location surrounding the prototype were similar to the implementation ones, aspects of the servicescape and other influencing factors could be replicated only in a limited manner. Moreover, it was taken into consideration that, although real potential customers were involved, they only represented a few user categories, and gave feedback only from their perspective.

PLAUSIBILITY

Since the audience was kept into consideration while designing the prototype, as Blomkvist (2011) suggests, the participants all provided very detailed and extensive feedback and engaged organically in explaining their own point of view.

RESULTS

Quantitative results

Time:

- browsing,
- registering,
- booking,
- check in,
- sample collection.

Errors

- presence (Y/N)
- number

Qualitative results

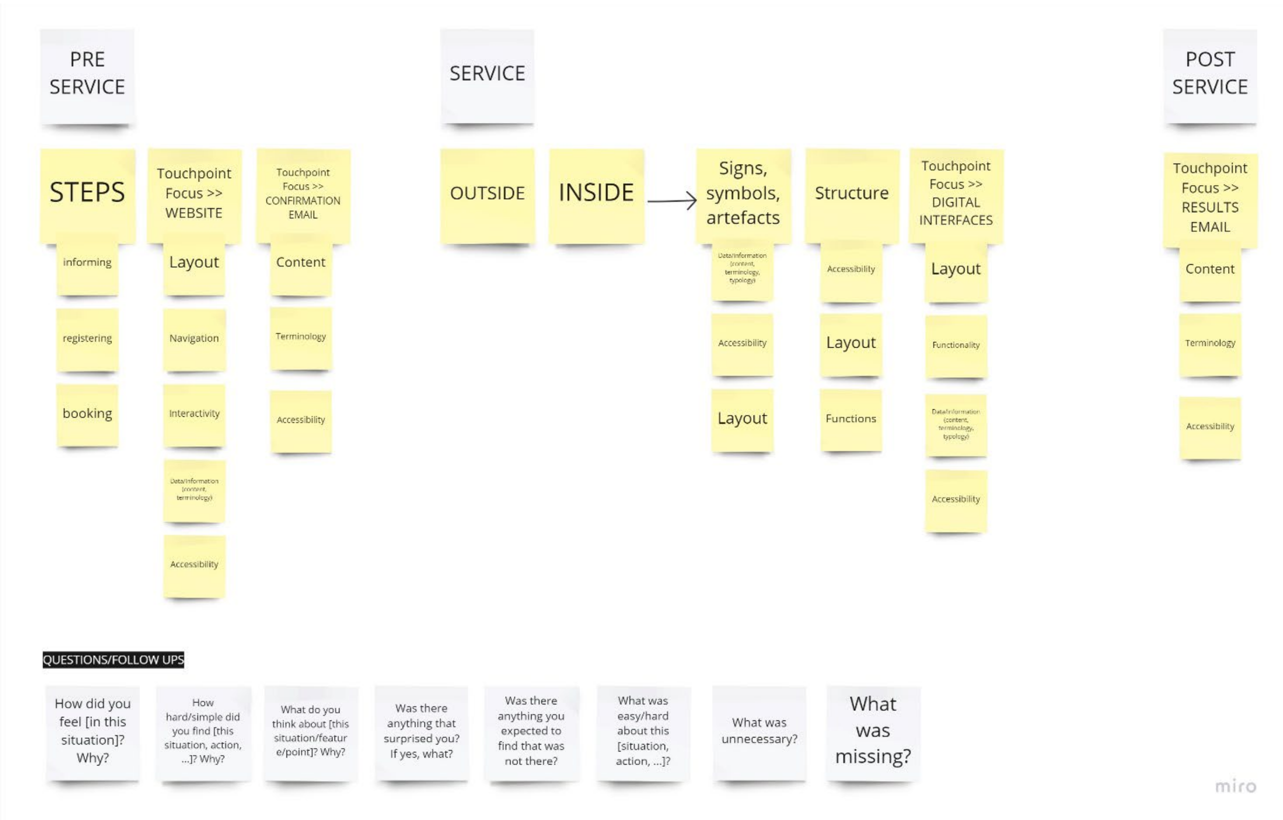


Figure 105 - Overview of final interview to gather qualitative results.

These results were extrapolated after the prototyping. I carried out an analysis in a second moment, following a simple procedure:

- For each participant a map of the service experience was made.
- I reviewed each session, as all of them were video recorded (with the permission of the participants); and noted in the map the following data:
  - Procedure Start // Procedure End
  - Error/Problem
  - Comments (positive, negative, …)
  - Facial/physical reaction/behaviour (surprised, annoyed, confused, …)
- I noted the answers of the final interview.
- I added my personal comments and observations linked to each one of the areas (qualitative and quantitative)

INSIGHTS AND FINDINGS

Browsing – general

Browsing the website was the activity with most difference in recorded times. The participant which took longer time to explore the pages browsed for 22.34 minutes, while the shortest only 1.15. Most of the participants limited themselves to the "minimum" necessary pages, meaning the "how it works" and only occasionally the sample collection procedure page. Only two participants browsed through all the pages, reading almost everything from top to bottom. In these two cases particular appreciation was given to the “about” page, the “certificate” page and the “why us” page. The “learn” page was also deemed useful, but the terminology used to refer to it was not clear, therefore not “inviting”.

Browsing – information and content

Overall users considered the quantity of information adequate, especially in the “how it works” section, and most users found the illustrations interesting, as they gave a more approachable vibe to the booth. However, they would like more information regarding extreme cases such as being late to booking, how to act with registration of kids, if it is possible to cancel bookings and re-book, and hours of service. The interface was deemed to be consistent and the naming conventions to be clear and easily understood. Regarding the features, they expressed the need to have an emphasis on the benefits and disadvantages of each (for example they wonder why the service costs so little). Few people expanded on the “learn more” about the procedure and only one person suggested to provide clearer instructions for using the swab test and making it clear that it should not be put in the nose. Additionally, users prefer a positive and reassuring tone over a "don't be scared" message.

Browsing – interactions and layout

Numerous were the comments regarding the website UX, despite the majority of the users found it to be user-friendly and intuitive. Some of the most relevant findings were linked to some specific interaction issues, such as users not understanding when to scroll, open the home page or go back one step. They all appreciated the “cleanliness” of the structure and expressed a preference for simplicity and ease of use, but highlighted the need for more images and colors (which was expected, as the prototype used a wireframing and not final designs). They specifically emphasize the importance of summarized information and a simple layout. Other points that were touched upon were: clearer visual distinction between the two booking options and more explanatory text to accompany the navigation arrows.

Browsing – functionalities and service

Regarding the two different service offerings, out of the 14 participants, 9 preferred to use the "CHECKD. with booking" option to ensure that they would get their appointment and test done on time. Three participants were comfortable using both options depending on their situation; they were those who frequently travel for leisure and are not overly concerned about being late for their flights, or know how to deal with unexpected situations. Two participants preferred to use the "CHECKD. walk-in" option as they tended to forget to book in advance and preferred getting “the job done” on the spot.

Participants valued knowing the details of the booth booking and procedure process in advance, mostly to avoid frustration. They proposed expanded functionalities that would allow them to have airline website and CHECKD. fully compatible. For example, proposed options were: check for test availability and book testing slots simultaneously when booking flights, based on flight number and location receive best booth where to test, clear timelines and suggestions for when to arrive at the airport, book multiple slots when taking multiple flights, especially for return flights when they are in a foreign country.

Participants were particularly interested in the “location” page section and deemed it to be one of the most important parts of the website. They wanted more information on testing facility locations, including a map or directory, and the ability to book directly from the location if necessary. They also wanted to see in advance the service status information, such as whether the booth is broken, fully booked, or in maintenance, and the website should indicate if there is a queue and how long it is.

Sense of reliability was frequently mentioned, especially in connection with two particular aspects. First, the presence of multiple booths in different locations and parts of the world. Second, the presence of certifications and privacy pages. The latter are seen as incredibly trustworthy and are sign that a company takes data protection seriously.

Finally, participants wanted easy access to extra information and support in case of any issues or questions, possibly with a chat or a phone operator.

Registering

Close to assumptions, the average timings for registration proved to be 6.55 minutes.

During the registration process, participants found that the passage of video verification was the most challenging step. Many of them misunderstood when the procedure was starting, causing them to miss their cue to frame the documents or frame them incorrectly, despite the numerous warnings provided on the previous pages. Therefore, all participants suggested having more detailed explanations and guidelines on how to properly frame the documents. Some participants even proposed having guides directly on the screen and using illustrations to help them through the process. Overall, participants found the registration process to be simple and familiar, which they appreciated. However, they also wanted clear “feedback” during the process and the ability to edit their information before submitting it. Some participants made mistakes while typing and were unable to edit their details, which they found frustrating. Therefore, including an option to edit information before submission would be beneficial.

Booking

Similarly to the browsing, the booking phase presented different timings. The quickest participants completed the activity in 1.07 minutes, while the slower took 11 minutes. This suggests that some users might take more time to decide how to schedule their appointment, but overall, the procedure is very fast. No errors were registered.

To streamline the booking process, some users suggested the option to reserve their appointment for a limited time before registering. This would save them the hassle of going through the entire registration process only to find out that there are no available spots to book. Overall, the booking process was considered very simple and common.

A particular point of surprise was the payment methods. As users have varying preferences when it comes to payment methods and some prefer not to provide their card information the “choose to pay in person” was always positively commented, even if it means arriving early at the location. The option to pay in different currencies, even outside of the local area, was also highly valued by users.

In terms of touchpoints, most participants preferred using a web browser and a laptop to browse and find more information about the service. They also found it easier to complete registration and booking on a laptop, as it allows for better document framing and easier navigation between pages. Only a few users expressed a preference for downloading an app from the beginning, with most stating that they would only download it if they used the service frequently and if it streamlined certain processes.

Check-in

The average time spent on this task was 1 minute and 6 seconds. The registered time of check-in was reflected in the comments and observations.

Users found the overall procedure to be fast and reasonable, with clear information and minimal steps. None appeared to be either confused or insecure and no errors were registered. However, they suggested adding a reminder or notification to help users better understand the process before entering. Additionally, users recommended providing a QR code with a link to the sample collection procedure steps to help streamline the experience.

One area where users expected higher functionality was in the scanning system. Specifically, users expected the system to start on its own rather than requiring them to be the actual initiators of the procedure. This would make the process even more seamless and efficient for users.

Figure 106 - Users during the service walkthorugh. From the top: user during the browsing and registration procedure; user reaching the booth location and approaching the structure; user doing the check-in procedure.

<u>*Sample collection procedure*</u>

The sample collection procedure in this case, as previously described, was the improved version of the “Manual Lolliswab”. This time, virtually no errors were registered, between all 14 participants. Of instrumental help were the interface on the inside, with audio and visual aids. Users found invaluable the possibility of following step by step the instructions, in a both structured but “personal” pace. Users also appreciated the presence of “repeat” button and “emergency” button, as well as change of language. Those elements provided a sense of security and care from the service.

Users expressed several points regarding the hygiene and user experience during the procedure. Firstly, they suggested having additional sanitization stations before exiting the booth to ensure proper hygiene. Secondly, the option to use gloves was appreciated, and some users even used sanitizers multiple times during the procedure. However, users were left with gloves on because instructions did not explicitly tell them to remove them, leading to confusion.

Additionally, the use of a saliva generating solution during the procedure produced mixed reactions. Some users used it out of curiosity or necessity, while others did not because they felt they could generate enough saliva. However, users found this step useful and appreciated it as a touch that improved accessibility.

Lastly, some users forgot to retrieve their belongings from the booth, suggesting that a reminder to not leave them behind is necessary.

Regarding times, the average time spent carrying out the procedure was 5.21 seconds, which unexpectedly matched the most hopeful assumptions. Regardless, it is necessary to take into consideration that the divergence with times was relevant, as some users took as much as 7.17 minutes while other little as 3.27 minutes.

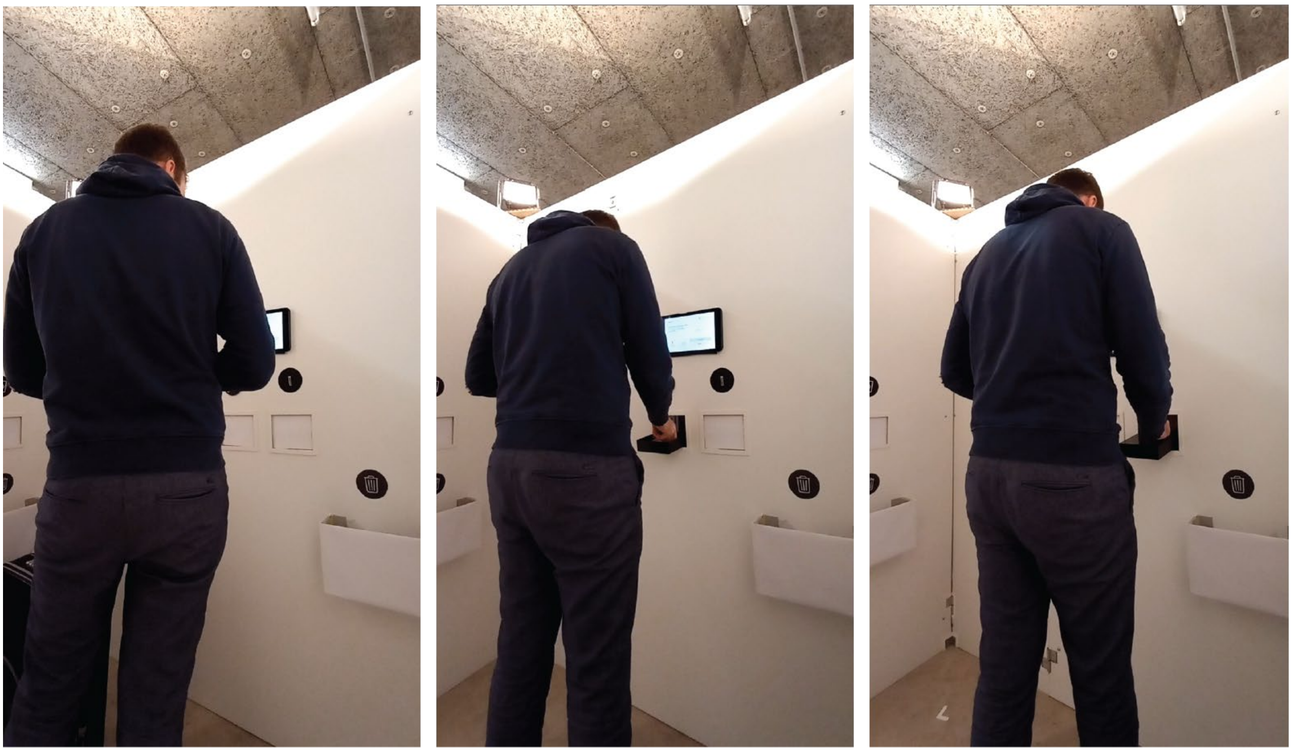


Figure 107 - User during the sample collection procedure. Initializing it; collecting the lolliswab package; placing the tube into the machine.

<u>*Other touchpoints*</u>

- Certificate page. The “certificates” page was one of the most critical aspects of the prototyping, despite it being of less importance compared to the rest. Participants expressed confusion about the difference between completed and confirmed bookings and did not understand properly how to use the page. They suggested making it simpler and more intuitive, as its function was still valuable. Moreover, some felt uncomfortable with personal details being visible on the certificates page.

- Receipt email. Most participants found the email professional and serious, but way too long. They suggested dividing information over multiple PDFs or making it more visual. Some participants scrolled mindlessly and missed important information about their booking, such as the bar code and attachments and did not realize it until they needed to approach the next step of the experience. Overall, the attachment with instructions on how to reach the booth was deemed very useful and multiple times it was proposed to increase its functionalities with a link to Google Maps that directly brings to the location.

- Results email. Participants found the results certificate structure familiar, but were confused by the terminology "detected/not detected." They expressed how the wording of the test result could be clearer and more straightforward, as users found the current phrasing confusing. The most common desire was to have either "negative" or "positive" with bold colors and clear font, and asked if it was possible to have it directly in the email text and not only in the PDF.

Interior and Structure

All participants positively commented on the spacious interior, which allowed for proper movement and was suitable for wheelchair users and those with multiple items of luggage. They also appreciated the accessibility of the booth and found the privacy level offered by the structure more than enough, even with transparent doors. Although more than one user expressed concern about the open ceiling.

Users appreciated the space for the luggage inside: they felt unsafe leaving their luggage outside and would naturally place it in the dedicated spot when entering without needing to read wayfinding information. Some users found themselves reaching for a hook. They suggested providing one to place jackets and other items temporarily.

One criticality was related to elements' layout: all the users struggled with having the sanitizer and gloves on the opposite wall of the actual screen and procedure, and suggested changing their location to the side of the main inside screen, to avoid jumping back and forth inside the booth and minimizing losing time.

While users found the icons and numbers depicting the steps under each element useful, they found the signage on the inside front wall listing the same aspects to be redundant and not necessary.

Wayfinding and Servicescape

Users appreciated the adequate signage outside the structure, with big numbers and clear "definition" of the booth with booking to avoid mistakenly queuing for the wrong booth. They also appreciated the outside screen that displayed the current status of the booth, such as "occupied" or "free."

Users suggested having more horizontal and vertical signage, such as more spots on the ground with specific information, posters, and small totems with QR codes, to make wayfinding easier.

Brand identity

The three different color palettes elicited various opinions and associations from the users.

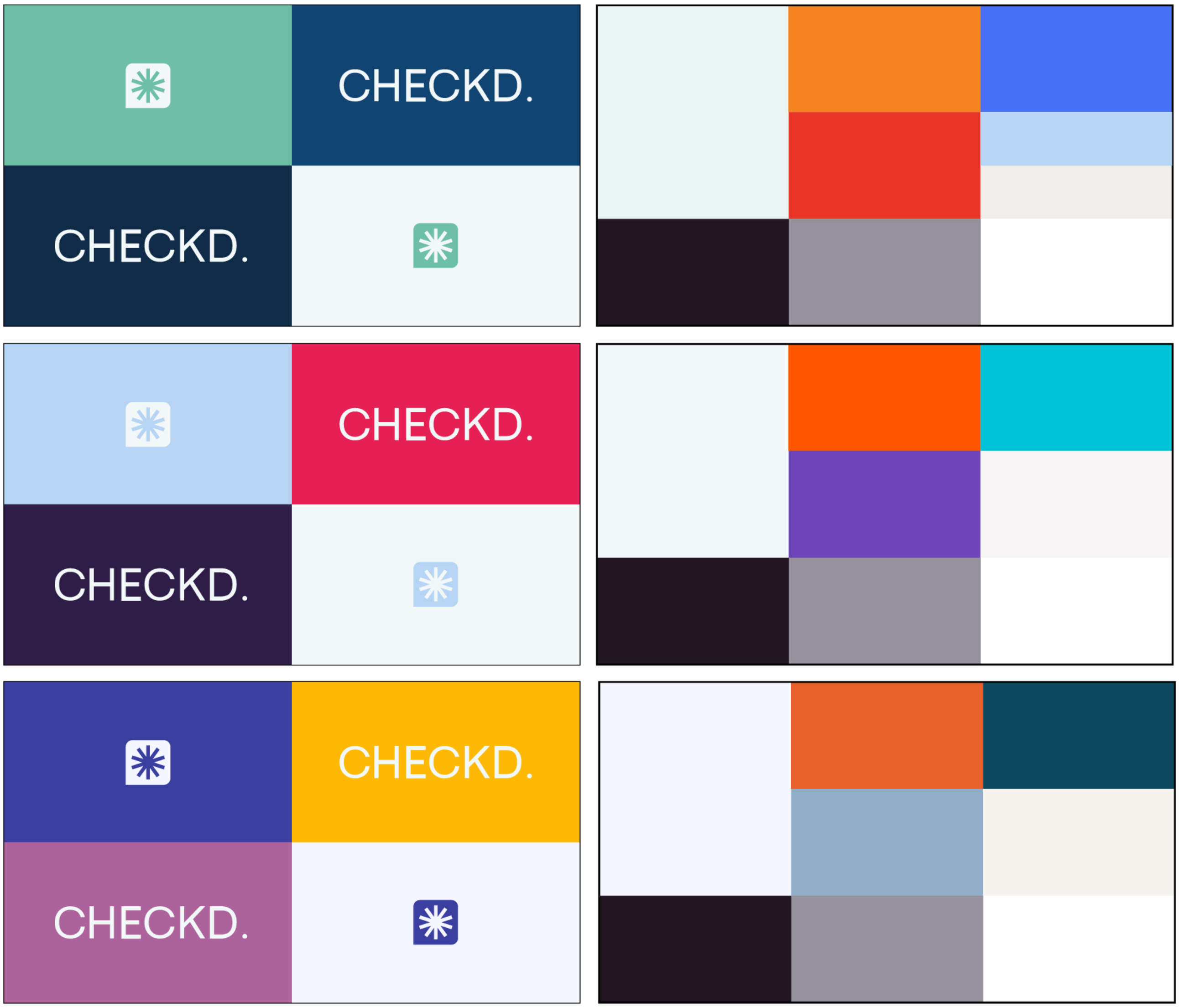


Figure 108 - Palettes shown to the users.

The first palette, characterized by “med tech colors”, was chosen as the most fitting by 10 participants. It was viewed as professional, conveying a serious and reliable message, which could benefit medical or health-related businesses. However, some people found it boring, while others associated it with hygiene and cleanliness, reminiscent of a pharmacy or hospital.

The second palette, which featured a bright red color, was viewed negatively by most of the participants, who found it too dynamic and unsettling. The red color was perceived as unstable and associated with bad situations, prompting some people to suggest using green instead. Blue in the color palette was seen as complementary to red, evoking a laboratory setting and conveying a dynamic message. A few participants suggested magenta as an alternative to red.

Finally, the third palette, which incorporated yellow and orange, was not well-received by all the participants, who found it too bold and attention-grabbing. The third color palette was deemed “out of scope”, more suited to startups, rather than businesses aiming for a serious or professional image.

4.4.4 Recommended implementations

Following the prototyping activities, the last step of the project was the definition of future steps. To ensure effective implementation of the insights gained from the study, the results were shared with the stakeholders and used as a basis for developing a set of guidelines for the next iteration of the project. Overall, a second prototyping phase would be advised.

With Checkd. the test situation corresponded to the real implementation context only in certain aspects (mainly superficial and related to the ‘look and feel’). Many other different factors that usually shape the original servicescape (eg. airport) were not implemented, despite being highly influential on the service experience and the customer successfully reach their goal. When approaching service prototyping it is necessary to keep into consideration that iterations are fundamental, as the complexity of services themselves cannot be fully understood in one round. It is acceptable to have limited validity within the first iterations, but it should be increased as they go along.

In the case of Checkd. it would be interesting to do more service walkthrough iterations, each time adding more variables (eg. waiting time, random errors and failures, ambient sounds or having more users from different categories do the walkthrough at the same time) that raise the level of realism of the environment, but still in a “protected” environment.

The ideal and ultimate testing session right before implementation should, instead be high fidelity:

- be in a real location;
- with fully functional automation;
- with definitive materials;
- include as much user categories as possible;
- include the “walk-in” option and all its variables.

Regardless of the possible future prototyping opportunities, after identifying the areas that needed improvement, a comprehensive list of points, aspects, and details of Checkd. was drafted. These guidelines can serve as a checklist, a series of improvements to implement aimed at enhancing the project's effectiveness and efficiency. They can serve as a reliable reference for informing the next prototyping stages, but can, especially, inform the direct development of a viable solution that can be completed within the required short-time constraint of one year.

Service

- Provide deeper integration between CHECKD. and external/third party websites that offer flight booking:

    - Recommended booth locations (both in the city/country and in the building itself) based on flight number or route.

    - Multiple booking appointments based on route and layovers.

- Provide the possibility of booking before registering, allowing a temporary “slot reservation” (maximum 15 minutes).

- Provide detailed service status information through different touchpoints:

    - General status: Active, not active.

    - Current status: Occupied, free, maintenance.

    - For walk-in: live occupancy rate.

- Allow integration of CHECKD. generated fit-to-fly certification with existing “certificate-management” apps and certificate generating app.

- For users who request help from the booth itself (see point: ** add point) have operator that offers remote assistance, or calls on site support (eg. airport security).

- Allow users to signal operational problems with the booth, through the app with a dedicated area on both website or app (button or section).

- Provide way to continue registration and verification to mobile (with QR code), when started originally on desktop.

- Implement a way for users to leave reviews, through multiple touchopoints.

Backstage processes

- Automatic redirection of user to another booth in case the one they are using has operational issues (and therefore needs to be put into maintenance mode).

- Set time slots based on 10 minutes a person.

- Optimal number to provide for each location (to ensure 200 tests every 2 hours): Add how many booth (both walks ins and booking) with how many diaxxoCare inside.

- Provide phone/remote operator for direct contacts and extra information.

- Provide phone/remote operator for emergency assistance.

Booth

- Improve waste indications, detailing more how to carry out a proper disposal (eg. with signs that say “only dispose of swabs in here” // “only dispose of saliva tubes in here”).

- Move the position of the waste bin to be enclosed in the wall of structure, rather then suspended from it, to avoid people taking things out of it.

- Remove the “full process” icons from the center wall

- Keep and upgrade with number the icons who tag the elements

    - Still, “sticking” to the wall or engraved.

    - Backlit interactive cut-outs that blink when they are required in the procedure steps.

- Move sanitizer and gloves on main wall, to minimize movements inside the booth.

- Remove the shelf from the right wall and place a hook instead.

- Increase the size and height of the luggage signage.

- Incorporate a motion or proximity sensor, which would alert users to sanitize their hands prior to touching the screen as soon as they enter the booth. Additionally, install a sensor on the sanitizer dispenser to activate the procedure only when the user has sanitized their hands. Once the user has sanitized their hands, the system can prompt them to also use gloves for added protection.

- Add a directional indicator, such as a starting point arrow, to guide users towards the gloves and sanitizer.

- Upgrade the hand sanitization station, utilizing either UV or spray technology, within the confines of the structure (”encased”).

- Lower the doors.

- Add a “closure” on top of the booth, with a glass with a one-way window.

- Automatic activation of outside scanner when code is properly framed.

Wayfinding

- Relocate the booth number to the left side of the structure, following the natural reading flow.

- Enhancing the availability of ground signage throughout the area, featuring directional arrows, booth numbers, and information indicating that users can bring their luggage with them.

- Incorporate clearly labeled signage indicating the entrance flow with directional arrows to guide users through it.

- Provide QR codes or posters that offer users a preview of the next steps in the process prior to entering the booth.

- Add floor or booth signage indicating the start of the process, with clear instructions such as 'Start Here' in front of the outside screen.

Touchpoint: website

- Improve overall readability, clarity and user-friendliness of website content and structure:

    - Change “our expertise” into “why us”.

    - Change “learn” into “official certification”.

    - Reduce text length on “our expertise”.

    - Use positive-leaning sentences.

    - Add scrolling cues on every page.

    - Increase explanatory text below the navigation arrows.

- Implement more detailed functionalities to the “locations” page:

    - Filters and search bar.

    - Multiple view: world map and list divided by country.

    - Click-to-expand buttons on location, with information related to how to reach (google maps link).

    - Click-to expand button on booth, with information on status, how to reach (map) and direct option to book.

- Provide FAQ page.

- Change terminologies in “my certificates” page and improve overall readability and clarity, removing bookings history and only displaying certificates.

- Add extra graphics and illustration to the verification procedure, as an overlay of the camera, to guide the face and documents framing process.

- Show multiple times the guidelines on how to carry out properly the verification procedure.

- Provide more feedback regarding correct procedure of verification.

- Add more detailed information to the website clarify the following scenarios:

  - In the case of lateness, it should be clearly expressed that if a person arrives more than five minutes late, they will lose access to their booking/the booth.

  - Explain what happens if the person before you is late.

  - For parents accessing the booth with or for minors, what to do and how the process works.

  - What to do in case of emergencies, so to ensure that all visitors feel safe and well-informed.

  - Recommendation on when to arrive at the location.

Touchpoint: email - receipt

- Improve overall readability by adding images and graphics to break up the text and make the email more visually appealing and concise.

- Keep payment receipt separate from the email text and add it as a separate attachment.

Touchpoint: outside interface

- Automate the scanning process to begin upon detection of the code.

- Implement a separate procedure for minors to ensure the process is appropriate for their age group.

Touchpoint: inside interface

- Enhance the user interface with detailed representations, such as 3D elements, mini videos, or animations, and utilizing blurring effects to ensure clarity of instructions.

- Add a 'problem' button to the interface that provides users with guidance on how to address potential issues during the process. Possible scenarios to include are:

  - I dropped my swab

  - I spilled the preservation liquid

  - My swab broke

  - I put the swab in the nose instead of in the mouth

  - I cannot produce enough saliva

- Adding an emergency button, but not in the digital interface, which can be used to quickly open the door in case of need.

- Include a final reminder on the interface reminding users to collect all their items before leaving the booth.

- Change terminology from 'stir' to 'turn' to ensure clarity of instructions.

- Include information in the instructions that informs users that it is safe to swallow the saliva solution.

- Include information in the instructions that informs users to dispose of the gloves in the end.

- Implement a separate procedure for minors, ensuring that the process is appropriate for their age group.

- Add a step in the procedure that instructs users on how to properly remove their gloves.

- Include a procedure control that will automatically repeat instructions if the user does not take any action (such as touching a button) for 15 seconds.

- Include directional information when referring to specific items within the booth, such as 'on your left,' 'on your right,' 'at the top,' or 'at the bottom.

Touchpoint: email – results

- Change terms in email text "detected" or "not detected" to more easily understandable terms: "positive" or "negative”.

- Provide explanation on how to read the .pdf, "detected" or "not detected”, which are mandatory by law.

4.4.5 Reflections on the process

In prototyping Checkd., the Service Prototyping Practical Framework (Passera et al., 2012) represented an effective guide to orient my choices (for example it inspired me to apply the two techniques of experience prototyping and service walkthrough), and after its application I had the chance to better reflect on some issues that became important takeaways useful to implement our research. One first takeaway relates to the relationship between purpose and fidelity level.

The low resolution of the prototypes and their related mixed fidelity did not hinder the right execution of the procedures and their correct evaluation. It affected the precise understanding of some secondary elements, but it was evocative enough to reach the desired goals. The users did not advance any kind of comment regarding the materials or the simple set up of the environment. They approached the situations proactively, not only providing numerous and detailed feedback on the existing, but also proposing new ideas and concepts. Keeping some elements in the low-fidelity range helped in leaving space for interpretation and exploration from the user's perspective, that without prompts engaged physically with the prototypes and their elements to perform or show their own personal opinions. The users always searched, look up/for/to the physical prototype: they would grab props, point to exact elements or 'role play' to show how they would change/do differently some actions.

Overall, verbal comments had always something interlocked with the physical layer. The same reasoning was also true for the functionality level of this touchpoint. A 'missing' functionality sparked more natural comments than a working one. In some cases the users had to be prompted, for example with the question 'what do you think it is supposed to happen when you (…)?/ what would you expect?', but most of them naturally filled the missing holes, proposing novel perspectives. It is interesting to highlight that prototypes that were mainly thought with an 'evaluation' purpose naturally shifted towards being more 'explorative', due to the fidelity level of the prototypes themselves. This led to a more participatory design dimension, highlighting the need of carrying out additional co-design activities about some specific service moments and touchpoints. We may argue that in this case the boundaries between co-design and prototyping were blurred, as we continuously 'moved' between testing activities and re-designing them with the help of the users-participants.

Another aspect that supported this prototyping-purpose transformation was adopting a technique of usability testing, the 'think aloud' protocol, where the user voices what they are doing, thinking or feeling while solving a task or a problem (Someren et al., 1994). Applied to both experience prototyping and service walkthrough, it gave the ability to participants to be more comfortable and empowered in externalizing their own personal opinions.

A second takeaway concerns iterations of service walkthroughs and servicescapes: it is vital to prototype as soon as possible to advance in the project (Blomkvist et al., 2012), even if the fidelity level is very low, it is better to test some crucial service moments and, if needed, to come back and co-design and re-design some elements and test them again, along that continuous flow between co-design and prototyping that was mentioned before.

Finally, a third takeaway relates to the role of the Author. Passera et al. (2012) and Blomkvist (2011) provide similar descriptions about the Author and identify he/she as the person in charge of designing the whole service prototype and taking decisions regarding all possible alternatives. In the case of Checkd. the Author, me, was not only the actual creator (who took care of the planning and definition of the prototyping sessions), but also the 'facilitator' and the 'orchestrator'. We think that the role of the Author is extremely important especially in medium-low fidelity prototypes that typically simulate situations in which his/her intervention is needed to make the service mechanisms work. It is important to educate and prepare the Author in play different roles, by supporting he/she in such continuous shift between being present to support and follow the users and jump into role-playing moments where he/she takes up roles of the experience itself, becoming as sort of orchestrator/director of the whole mise-en-scène. Such perspective is strictly connected to what McElroy (2017) suggests at the beginning of her book: it is fundamental not only to prototype and have a personal mindset toward prototyping, but above all to develop an actual culture of prototyping. This is even more important in the service design discipline, in which the combination of tangible and intangible elements creates a great complexity and generates the need of setting a constant feedback and user testing loop. In this context, the Author is not only a facilitator and an orchestrator of the prototyping process, but he/she should also become advocate of a broader prototyping culture that allows to better advocate the user, who should be always placed at the centre of any (service) design actions.

5. THE OUTPUTS: CHECKD.

5.1 The Product-Service-System

CHECKD. is a service that aims to revolutionize Point of Care (PoC) testing with a new innovative technology by commercializing stand-alone, fast PCR testing stations. This technology could radically disrupt our understanding of epidemiology and prevent the uncontrolled proliferation of infections. The service works towards multiple goals:

Firstly, it seeks to reduce the costs for the healthcare system by offering a PoC PCR device that can deliver high-quality PCR tests in totally autonomous way. This will not only reduce the burden of test processing on humans, but also reduce the need of resources, time, personnel and logistic efforts. In turn it will ease the incoming of people in hospitals and the potential following hospitalizations.

Secondly, CHECKD. aims to make quality COVID-19 testing more accessible. Currently, the most feasible way to test large parts of the population is through rapid antigen tests that are cheap and do not take much time. However, the biggest disadvantage of these tests is their low accuracy compared to PCRs, which have a specificity between 80-100%. By offering PCR tests with a sensitivity of over 90% at very low costs, CHECKD. can help reduce health inequalities and the spread of the virus in environments where test accessibility is lower.

Third, despite the state of the art of PCR technology and its high accuracy, constant human intervention, long processing times, and high costs for tests and equipment make rapid and widely-distributed testing impossible in many countries. Still, fast, cost-effective, and accurate testing is a key building block in combating pandemics today and in the future. Especially when done in “large-scale”, testing is an effective mechanism to reduce the spread of infectious pathogens like the COVID-19 virus and monitor the presence of diseases in the population.

In this regard, CHECKD. can be a tool for crisis management and a way to control the virus better: it can minimize the risk of spreading infections by allowing fast and streamlined mass-scale population testing. This will have a positive impact on communities, businesses, universities, and other wide organizations and keep them open and out of lockdown.

To explain more in detail what CHECKD. entails an offering map was developed.

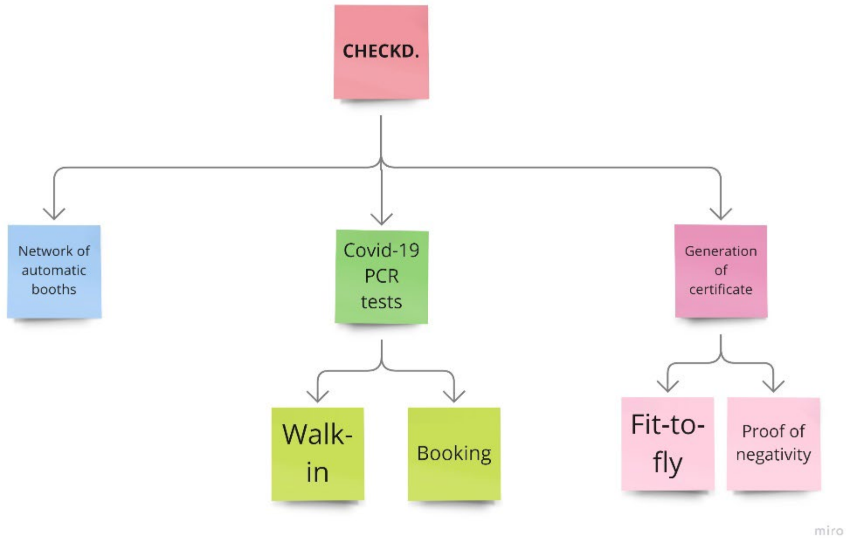


Figure 109 - CHECKD. offering map.

CHECKD. is a service that provides autonomous COVID-19 PCR tests through fully automatic booths, enabling users to generate official and compliant certificates of negativity that are valid for 72 hours at a very affordable price (15 CHF a test). The service operates via a network of booths located in various cities and countries. CHECKD. booths will be initially available in capital and/or main cities, starting from Switzerland and the neighbouring nations. The prime location where CHECKD. booths are places are airports and other transportation hubs, followed by convention centers, universities and malls. offering two types of booths: “CHECKD. booking” and “CHECKD. walk-in”.

- CHECKD. booking. This booth allows users to reserve a slot for their test and take it at the location.

-CHECKD. walk-in. This booth allows users to take a test without booking in advance.

In both cases, the overall process from registration to results is extremely fast. CHECKD. processes and delivers results and the certificate directly to the user, in less than one hour through their preferred channel. Moreover, the procedure that is offered is simple, straightforward, and saliva-based, making it painless and kid-friendly, while keeping the quality high. The tests are highly accurate and reliable.

CHECKD. primarily targets travelers, including frequent and casual travelers for business or leisure purposes. The service's certificate is considered a “fit-to-fly certification”, which can be used as an official proof of negativity for travel purposes.

CHECKD. also caters to individuals who wish to undergo a "health check" or get proof of negativity for a specific reason unrelated to travel. The first category may include people who want peace of mind, have had positive contact with COVID-19, or are exhibiting potential symptoms. The second category includes people who want to participate to specific events or have to follow guidelines imposed by work employers.

Overall, CHECKD. aims to provide a convenient and accessible solution for COVID-19 testing while prioritizing user experience and compliance with regulations.

THE EXPERIENCE

To better frame how users interact with CHECKD., a user journey map (CJM) was developed. It visualizes the experience of a customer as they interact with a service, thorugh a diagram or illustration that outlines the various touchpoints and stages of the customer's journey, from initial awareness of the service to post-service follow-up. In this case a generic CJM is presented.

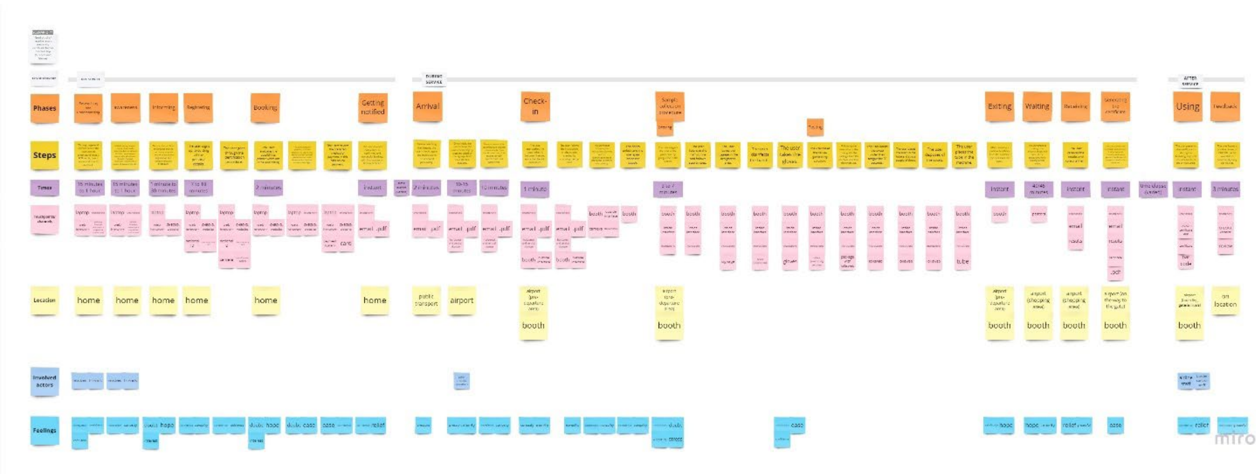


Figure 110 - CHECK. customer journey map.

THE PRODUCT (BOOTHS)

The service offered by CHECKD. is mostly enabled by a physical complex product: the booth. The “booths” can be defined as small, temporary structures that contain all the necessary elements to perform an accurate Covid-19 PCR test and generate an official certification. They fall under the category of Point-of-Care health solutions, as they are compliant with different official requirements, such as STARLITE, CLIA and ASSURED. CHECKD. booths were designed to fit both human and machine needs: for the latter with the goal of providing a pleasant, simple and memorable experience; for the former, aiming for an efficient and scalable setup. The booth can be considered as a stand-alone singular product, or be considered part of an array. The optimal number of booths to ensure enough thruoutput is defined in relationship to the occupancy and use of the location itself, with a minimum of 8 booths for the location with most people presence. The optimal configuration of the booths will depend on the space available in the location and will be researched, discussed and planned with the referents of the location itself. This idea applies for both CHECKD. booking and CHECKD. walk-in. In this section only CHECKD. with booking will be detailed:

Structure

CHECKD. booths are, overall, a simple, semi-open temporary structure, with physical dimensions of 215x210x210cm (height, width, and length), while the volume is 9.0345 m^3. They feature a squared plan that resembles a cube,

The main characteristic of this structure, which explains its shape, is its being modular. This was an important aspect to consider and respect, as it is one of the fundamental concepts that allow it to be deployable as a PoC testing station, according to official regulations. The booths are an made up of modular parts: it entails a total of twenty singular vertical panels and a separate element for the top, which includes a main frame and a aperture (window). Modules are designed and built to internal "standardized specifications", allowing them to be easily interchanged and or replaced with other modules, allowing for flexibility and customization. The panels, in fact, can be combined with other panels, therefore giving the possibility of joining more CHECKD. booths together, in different configurations. Moreover, the shape itself and the space it occupies aids in simplification of user flows, as its familiarity and "normalcy" can better guide the user and support them in understanding its usage.

These panels define the perimeter actually utilized by the user and the space that is, instead, dedicated to the containment of: automation system (sample collection, sample preparation and sample processing), digital elements (screen), storage (waste, consumables, packages).

Materials

When it comes to the construction of the overall structure, there are two different categories of materials that can be used to make the panels: all metal, specifically aluminum, or plastic. The top window, on the other hand, is made of glass, with a thickness of 6mm, and is covered by a one-way mirror film. The doors are made of 40mm clear frosted acrylic sheet, which is a type of opaque plexiglass. These kind of materials and their physical characteristics made them prime choices for the structure as they are durable, easy to clean and can reduce cross contamination and infections.

Layout and components

Regarding the layout, in the outside it hosts the check-in procedure components (instructions screen, verification camera, scanner) as well as the entrance (automatic doors).

- Instructions screen: touchscreen display where the check-in interface will be portrayed. It is characterized by the presence of speakers, due to the fact that users can also activate audio instructions.

- Verification camera: connected to the verification system and provided by the verification software company. It is the same system as the one used in the registration. It will constantly record and analyze data, in order to associate the person to the test and to verify their identity, to eventually be able to generate the certificate.

- Scanner: automatically starts reading data when detects familiar and verified bar code.

- Doors: doors will be governed by an automation system connected to the check in screen. They will be locked throughout the whole procedure when a user is inside and in-between two users. They will unlock only if the data regarding the identity and the booking of the person, which are scanned in the check-in, are verified. Moreover, they will unlock only if the presence of a singular person is detected. The only exceptions will be set previously, during registration, therefore allowing the correct procedure (eg. presence of a minor).They are a key element to ensure accessibility and reduce risk of spreading the disease.

- Wayfinding/signage:

- left side: multiple writings on the left panel function as “descriptions” the different components, in order to clarify doubts the users can have and streamline the procedure. More general and “first look” information are displayed on the top part (booth type).

- right side: at the top stands the indication of the booth status (free, occupied, maintenance, not active), as well as the booth number and the internal details (sanitization, wheelchair accessibility, space for luggage).

- doors: a warning is portrayed, in order to emphasize paying attention.

- floor: floor signage will provide assistance and guidance (affordance) in understanding the steps and flows of the procedure. First on how to properly wait and stand in line, then where the overall procedure starts (check-in screen) and where it proceeds (doors).

The inside, instead, is characterized by the front wall, which is the first element the user sees when they enter with the main components necessary to carry out the sample collection procedure (hand hygenization, gloves dispenser, lolliswab tray, tube tray, waste bin, instructions screen); the left wall, where optional elements are placed (saliva generation slot, waste bin); the right wall, where additional elements that support the experience are placed (a hook and space for luggage).

- Instructions screen: touchscreen display where the sample collection procedure interface and steps will be portrayed. It is characterized by the presence of speakers, due to the fact that users can also activate audio instructions.

- Hooks: multiple hooks will be present, at different heights, to allow for flexibility.

- Space for luggages: the space takes into consideration the standard dimensions of travelling suitcases and can host up to three luggages of different shapes and measurements.

- Hand hygenization: this nook encased into the structure is made of a system that provides an sanitizing solution, that includes standard formulations (ethanol (ethyl alcohol), isopropyl alcohol (isopropanol), water, glycerin and fragrance). It is equipped with sensors that will detect the presence of the person's hands and a system that will distribute the solution automatically upon this hands detection. Only the automation system positive feedback of hand hygenization will prompt the instructions screen to proceed to the next step ("forcing" the user to carry it out).

- Gloves dispenser: standard, nitrile, latex free, single use and disposable gloves will be provided as an optional element and in multiple sizes.

- Waste bins: waste bins, similarly to the hand sanitization space, will be encased in the booth structure, to ensure cleanliness standards and lower the risk of contamination. Two bins are provided, to avoid their filling up too quickly and keep different types of waste separated.

- Saliva generating solution slot: this element resembles a vending machine slot, which deploys the singular use packages. It will be managed by an automation system and will provide visual (blinking green light) and audio (positive beeping sound) feedback when activated.

- Saliva generating solution: this packages (plastic packages) will contain a squeeze-like tube with a solution made of 80% still water and 20% sodium chloride (salt). Drinking this simple solution will trigger a response in the salivary glands, causing users to produce more saliva. This is because the salt on the tongue draws water out of the surrounding cells through the process of osmosis. As a result, the cells become dehydrated, which triggers a signal to the brain that prompts the salivary glands to produce more saliva to moisten and protect the cells.

- Lolliswab tray: in its neutral state the tray hole will be hidden by a protection lid (that avoids people reaching into the machine). It will appear only in the moment when it is necessary. It is governed by an automation system and will slide out of the structure with the package containing the lolliswab once the user is ready and has activated the procedure with the screen buttons. The tray features weight sensors that will detect and calculate the weight in them in order to determine their position. Once the package is removed (and the weight is not there anymore), the tray will slide inside the structure again and close the protection lid.

- Lolliswab package: the lolliswab package will be an existing manufactured product (ORAcollect•DNA by DNAgenotek). It is made of one sterile package, and a one use collector. The collector "lolliswab" entails a regular soft swab and tube containing NA preservation liquid .

- Tube tray: in its neutral state the tray hole will be hidden by a protection lid (that avoids people reaching into the machine). It will appear only in the moment when it is necessary. It is governed by an automation system and will slide out of the structure once the user is ready and has activated the procedure with the screen buttons. The tray features a flat surface with a hole in the middle. To determine the open/close position, it features both weight sensors (detect and calculate the weight) and tube-tray interlocking system. Once the tube is properly inserted the tray will slide inside the structure again and close the protection lid.

- Other elements:

- Camera: 360° camera will be placed inside, as it is necessary to continue the identity verification during the whole procedure, to ensure complete reliability.

- Lights: white LEDs will be placed in the upper corners in order to provide sufficient visibility, in addition to the natural light coming in from the window.

- Emergency button: this button is necessary in case of extreme situations. It will unlock the doors and signal to the maintenance and support staff that is has been pressed and their presence is required immediately on site. It will also transmit an audio message that prompts the other users outside to keep distance from the booth and be ready to offer assistance (if possible).

- Speaker: the speaker is positioned so that a remote staff person can offer live and personalized assistance in case of particular situations (connection with operator activated with the instructions screen).

Functionality dimensions [backstage]

- Safety [related aspects: structure, materials, components]. The shape and placement of the different elements, both in the outside and in the inside do not compromise the safety of users. When waiting outside, patients will be standing according to the provided wayfinding (ground and vertical signage), at a safe distance from themselves (minimum required: 1 meter) and from the booth itself (minimum required for safe exit from the booth in case of emergency: 2 meters). This allows to keep out of harms and accident's reach: the user, the other customers waiting in line or present in the space and reduces risks also for the "host" location space and staff.

- Security [related aspects: structure, digital infrastructure, components]. The 2 meter distance that must be kept between people in line and customers checking in allows for both privacy and

- Hygienic measures [related aspects: structure, materials, components]. Low infection risk is the ultimate goals of CHECKD. booths, first of all for the users themselves. Because people have to wait in line, a maximum 3 people will be allowed (as per instructions) and ground or vertical signage will provide information about the mandatorily of wearing a mask if you show symptoms. Moreover, the booths ensure the health safety of maintenance staff, facilitating the safe handling and disposal of biological waste. It plans for constant deep disinfection from the maintenance staff.

- Privacy: privacy on the inside is still somewhat assured despite the booth being semi-open, due to the transparent panels. It is counterbalanced by the need of not enclosing the space and making it too claustrophobic.

- Security and transparency: from a physical point of view, the structure offers tilted screens that limit the possibility of showing sensible data when checking-in into the booth. On a more general level booths and the overall system is equipped of measures that ensure that data is only accessible to authorized individuals or systems, and that the service is not vulnerable to attacks or other malicious activities. Transparency is also promoted, as it is considered a key pillar to build trust and maintain accountability.

- Accessibility [related aspects: structure, materials, components]:

- “physical” aspect: the structure is designed to respect basic accessibility standards, facilitating the experience for the whole persona spectrum. Its dimensions are compliant with public spaces regulations, that can host up to a person with wheelchair and a person with two minors. Components (emergency button, screens, sample tray, hooks) heights and positionings are so that can be accessed by a person on a wheelchair. Doors are automated, which entails people not to carry out any kind of action to open them.

- “digital” aspect: all the components and digital elements follow accessibility standards in terms of color contrast, font size, and use of images and videos to convey information. This includes providing audio version of written text, as well as options to adjust volume. Clear and simple instructions are provided, avoiding complex or technical language, to cater users with different cognitive abilities. Most importantly, language change option is provided.

- Aesthetics [related aspects: structure, materials, components]. The structure despite its simplicity offers a distinct and recognizable shape and form, which will impact user interest in using the booth and building trust. The concept is inspired by the new aesthetic of Diaxxo products and features a base color of white, as well as a more organic form. It wants to retrace the clarity and straightforwardness of the brand identity, making it even more linear and unpretentious. Interfaces are also kept minimal. They aim to be aesthetically pleasing and emotionally engaging (providing support for users who may experience anxiety, stress, or other emotional challenges), but at the same time facilitate accessibility.

- Adaptability [related aspects: structure, materials, components]. The structure is designed with future needs in mind, so that it can be easily modified or updated as technology or other factors change. Moreover, it can expanded or reduced in size to meet changing needs, without requiring major modifications.

- Maintenance [related aspects: structure, components]: the structure offers an easy and straightforward path to access the “backstage” area of the booth, that houses the machines and the consumables. This area will only be accessible from the inside. The booth, in fact, might be placed in different configurations, therefore restricting entry from the “exterior” panels. Opening modules (joint-based) secured with locks will be the connection.

- Production/manufacturing [related aspects: structure, material, components]: overall, the booth structure must be custom made based on specific technical drawings and the production is outsourced. Regardless, manufacturing costs and time are kept as low as possible. Between the two main materials, metal is the less expensive option, but entails a lengthier process. The plastic option is the opposite (more expensive, but faster). Both the options permit easy replication and rely on the fact that the structure is made with the least possible parts (both in number and type), to simplify the process. Some elements regarding the automation system will be outsourced, while others will be produce in house as well as the consumables and other sample processing related components. Finally, certain elements are “standard” issued products, that are bought by suppliers (gloves, screens, lolliswab).

- Maintainability: the booth is designed to be reliable and durable, able to withstand regular use over a long period of time. It is also easy to repair, with fewer repairs needed overall and simple repairs when necessary, resulting in a low operational cost. The modular structure is also highly portable and it is able to be transported and relocated to different sites with ease. It is designed for quickness of operation, with simple assembly and disassembly that can be accomplished by just a few people (reduced labor and material costs).

Figure 111 - Render on CHECKD. with booking in a possible airport location.

HOW CHECKD. WORKS

To provide an overview of the Checkd. product-service system a system map was developed. A system map is a visual representation of the different components of a service system, including the actors, activities, resources, and interactions involved in delivering the service. It supports in understanding the complexity of the service system and how different elements are interconnected.

The system map typically consists of nodes and links that represent the different components of the system and the relationships between them. Nodes can represent actors, such as customers, employees, or partners, or they can represent activities, resources, or other elements involved in the service delivery. Links, on the other hand, represent the interactions or flows between the different components.

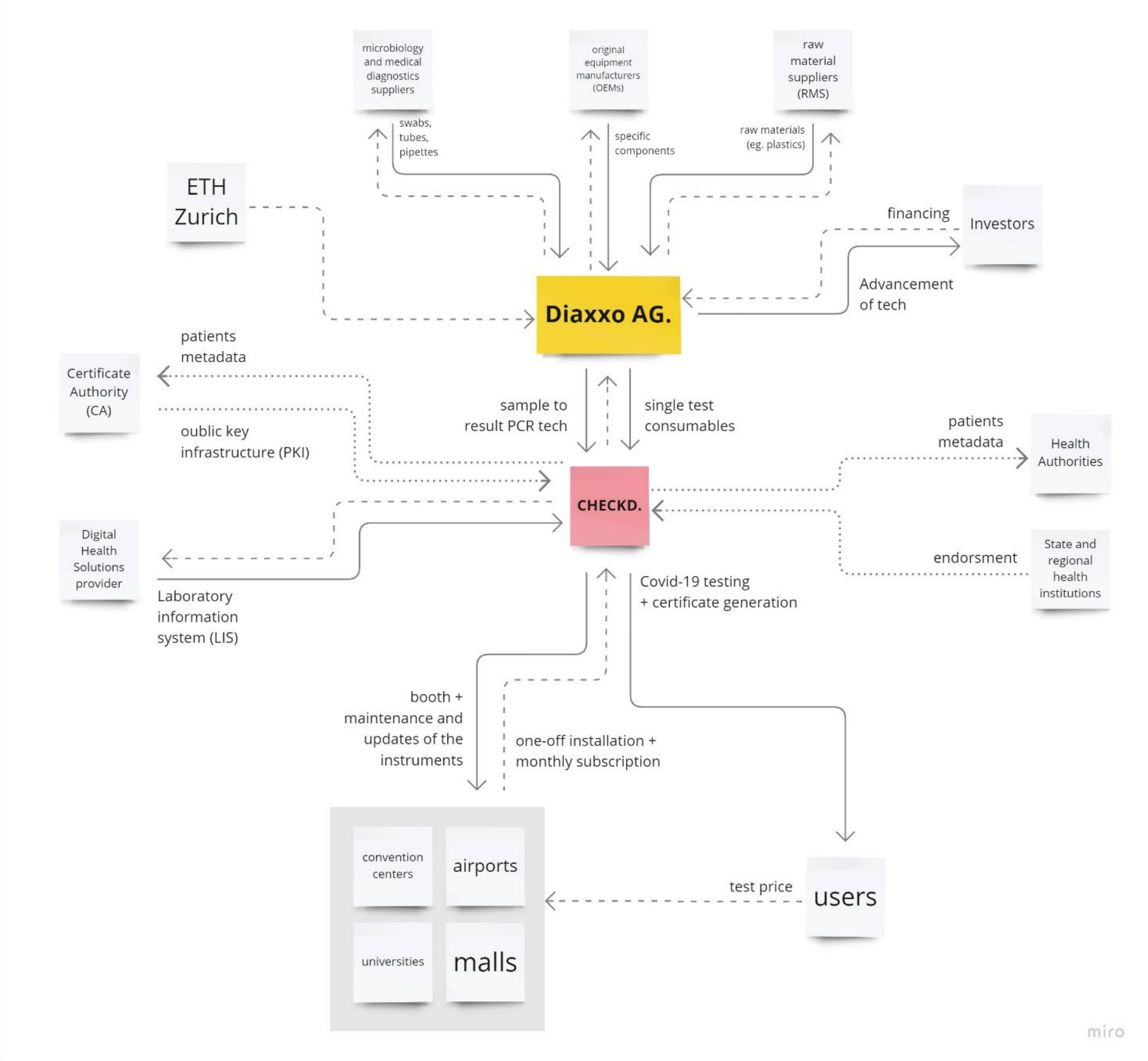


Figure 112 - CHECKD. system map.

Moreover, to better understand how the user experience is enabled by the service provider, a service blueprint describing the actions played by the user and the service provider was developed. Bitner (1992) describes the service blueprint as a tool that provides a visual representation of the entire service process, including all the physical evidence, customer actions, and employee activities involved in delivering the service. It typically consists of several layers that represent different aspects of the service process, including the customer actions, employee actions, support processes, and physical evidence. The blueprint also includes a timeline or sequence of events that outlines the order in which different actions occur.

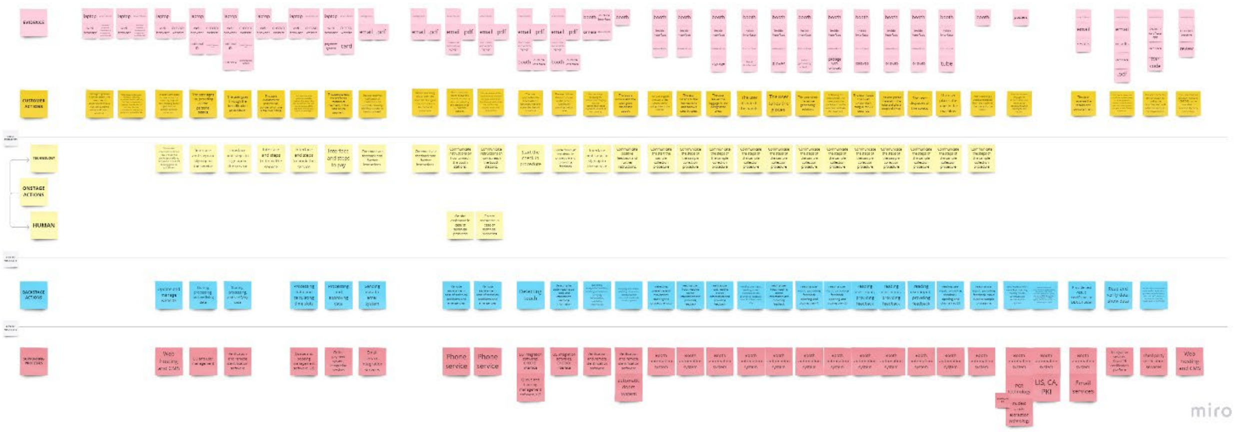


Figure 113 - CHECKD. service blueprint.

Moreover, a touchpoint directory was also developed, as a comprehensive list or inventory of all the different touchpoints involved with Checkd.

5.2 The communication

BRAND IDENTITY

Developing a proper brand identity is particularly important when it comes to services linked to the medical world and takes on even more relevance when it is referred to a brand new and particular service. In the case of CHECKD. a coherent and captivating brand identity is critical to build trust with the end consumer as people rely on it to ensure their health and wellbeing.

Moreover, Covid-19 testing is a crowded marketplace. A well-defined brand identity can help differentiate a medical testing service from its competitors. By developing a unique brand identity that emphasizes CHECKD. special value proposition, such as speed, accuracy and convenience, it can help stand out from the crowd and attract more customers.

Another important aspect is to keep it consistent across all touchpoints, including advertising, packaging, and customer service, ensuring a cohesive and memorable brand experience. This consistency can help customers recognize and remember the brand, which can lead to increased loyalty and repeat business.

First of all, a CHECKD. vision, mission and values are outlined:

Vision

To help create a world where diseases can be controlled in a faster, more efficient and more secure way.

Mission

To make advanced diagnostics accessible even to laypeople without the need for human-supervision.

Values

- Safety and security. Our primary objective is to provide a sense of safety and security to our users, ensuring that they don't have to worry about any potential risks or dangers while using our services.

- Reliability and trustworthiness. We take our business seriously and strive to demonstrate our competence and commitment to delivering high-quality services. We are committed to ensuring that every aspect of our service is of the highest standard.

- Accuracy and accountability. We believe in being transparent about our processes and using state-of-the-art technology. At the same time, we hold ourselves accountable in the rare case of anything going wrong, and we take responsibility for our actions.

The naming and the overall brand identity try to reflect what sketched by the mission, vision and values. The concept revolves around the idea of simplifying and making more approachable the word “test” and its process, switching to “check”, which is more an amicable synonym. From “checked” (which reminds of a fast and easy procedure) the final "e” was removed. The end dot is added to give a sense of "straightforwardness" and efficiency.

A strong brand identity can help build trust with potential customers by conveying professionalism, reliability, and expertise.

With the logo, the logotype and the palette the idea is to convey:

- Professionalism and expertise. In the healthcare industry, there are often strict regulations and guidelines that govern advertising and marketing practices. A well-developed brand identity that takes these regulations into account can help ensure compliance and avoid legal or ethical issues, as well as the application of state of the art technology.

- Efficiency. This is also reflected in the design of the product, which would likely prioritize clean lines, a minimalist color scheme, and an intuitive user interface.

- Trustworthyness. The repeated assurances of transparency and trustworthiness suggest an aesthetic that prioritizes honesty, reliability, and professionalism. This is reflected in the use of clean, sans-serif fonts, muted colors, and a simple, no-nonsense design approach.

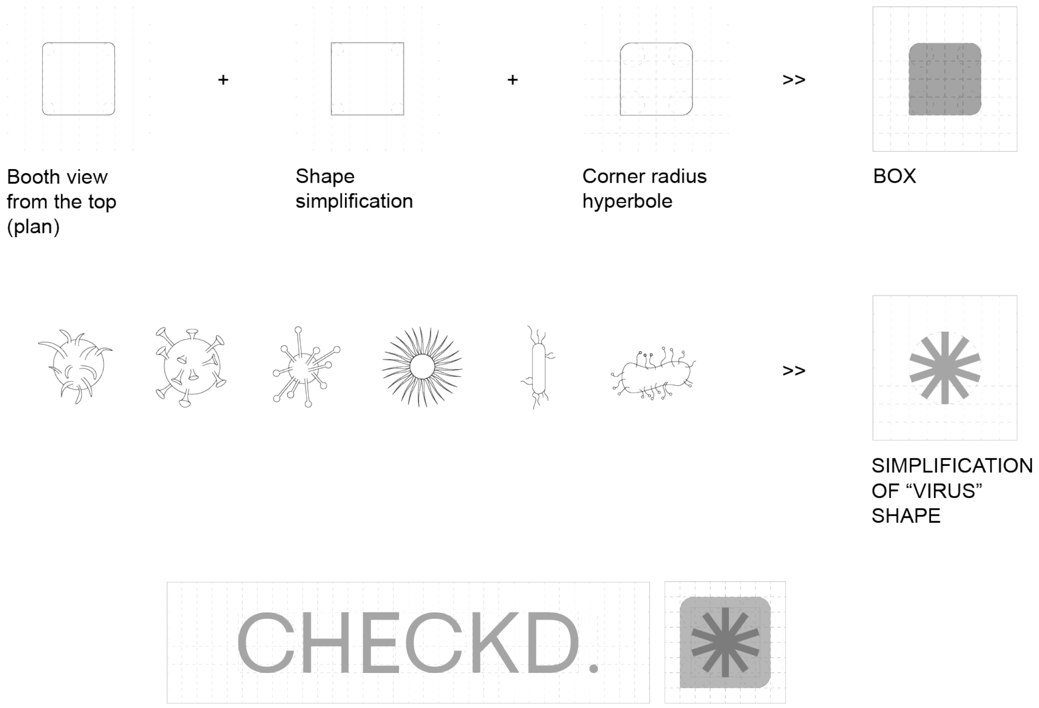


Figure 114 - CHECKD. logo construction.

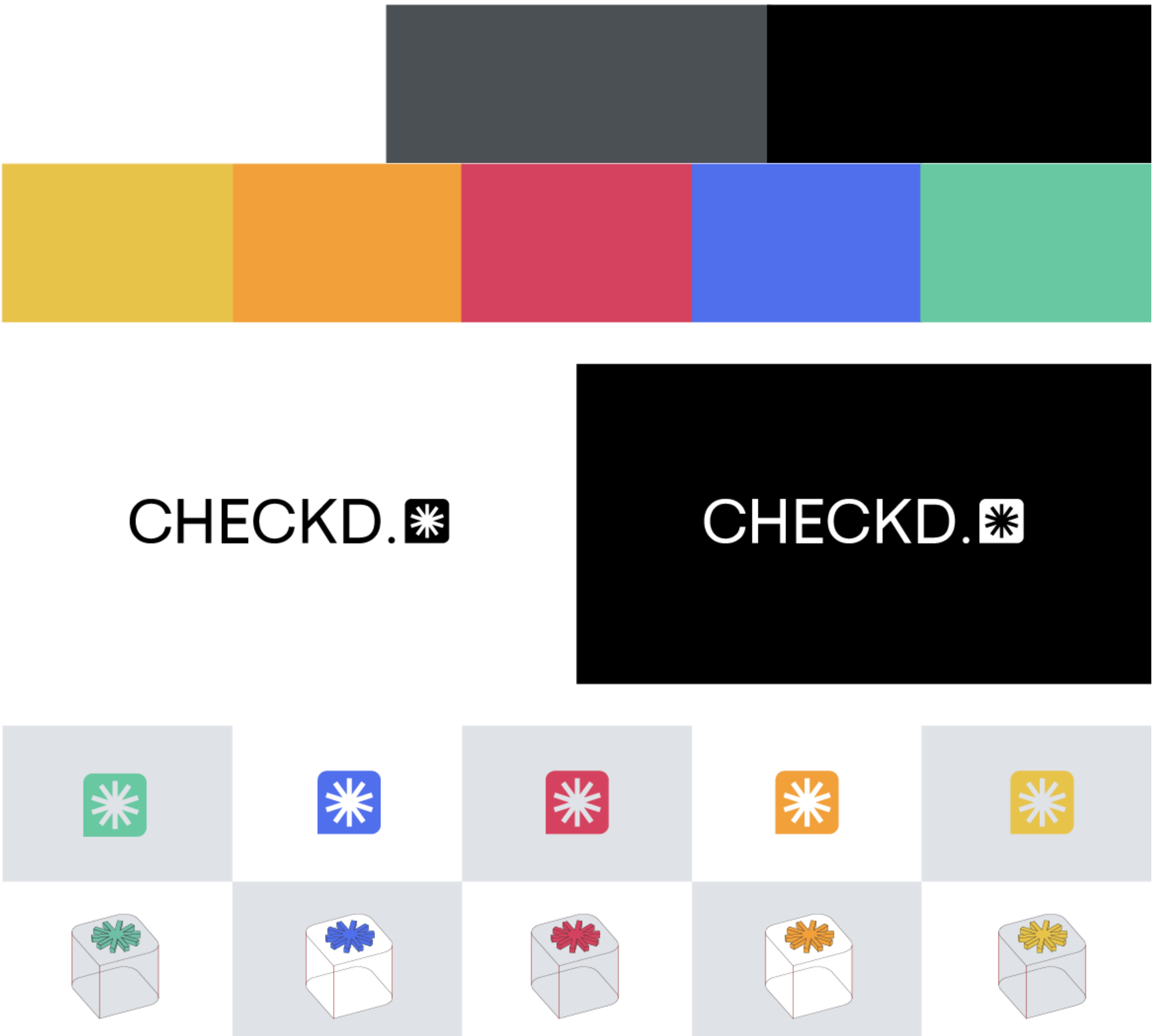


Figure 115 - CHECKD. color palette.

COMMUNICATION STRATEGY & MARKETING

Some guidelines related to a marketing and communication strategy:

- Since CHECKD. booths will be mainly located inside an airport the marketing strategy should focus on reaching out to travellers by using airport-specific media channels such as airport magazines, digital display ads in the airport, and their social media channels.

- The marketing strategy should highlight the benefit of its being a network, and emphasize that travellers can get tested quickly and easily right before their flight.

- The marketing strategy should provide clear and concise information about the different testing options available, including the types of tests offered, the cost, and the processing time for results.

- Language should be simple, straightforward and approachable, in order to make people feel at ease and attracted to the booths.

- Utilize Social Media as they can be a powerful marketing tool to reach out to potential customers. The testing service should have a strong social media presence and use it to share information about testing options, highlight customer testimonials, and offer promotions to followers.

- CHECKD. should build a stronger and more definitive partnership with airlines, in an ideal solution. In a short-term vision, it should consider partnering with them at least to promote the testing service to their customers. This can be done by offering special promotions to airline customers.

5.3 Business model

From the economic and financial perspective, a business model canvas was developed, to describe how the service generates value and its revenues.

A Business Model Canvas is a strategic management tool used to describe, design, challenge, and pivot a business model. It is a visual template consisting of 9 building blocks that describe the key elements of a business model, including customer segments, value proposition, channels, customer relationships, revenue streams, key activities, key resources, key partnerships, and cost structure.

According to Osterwalder et al., (2015), the Business Model Canvas "helps to create and differentiate business models, to focus on what is important in each business model, and to align the elements of the business model with each other". The Canvas is a visual representation of a business model that helps to simplify complex concepts and communicate ideas effectively.

Value proposition

Our automatic booth for disease testing helps people who want to take a highly reliable and accurate test for Covid-19, rapidly, in total autonomy and privacy. We offer a Point-of-Care rapid sample collection and analysis, with results digitally and on-site in less than one hour, eliminating long waiting and processing times of traditional labs.

Key partners

- Diaxxo AG.

- RMS.

- Medical diagnostics products suppliers.

- OEMs.

- CA.

- ETH Zurich.

- Health authorities and institutions.

- Investors.

Key activities

- Management.

- Maintenance and support.

- Marketing & communication.

- Sales.

Key resources

PHYSICAL

- Sample collection interface and automation.

- Sample preparation technology and automation.

- PCR technology and automation.

- Booth structure.

- Consumables.

- Raw materials.

- Medical devices.

INTELLECTUAL

- Patented PCR technology.

HUMAN

- Remote assistance staff.

- On-site maintenance staff.

FINANCIAL

- Payment/selling system.

Customer relationships

B2C

- Automated services.

- Personal assistance.

- Self service.

B2B

- Leasing.

Customer segments

- Travellers (business/leisure – occasional/frequent).

- Laypeople.

Channels

- Website & app.

- Online booking system.

- Booths.

- Social media.

- Sponsor institutions (eg. ETH Zurich).

- WOM.

Costs

INITIAL COSTS

- Booth structures and components.

- LIS.

- Verification and identification software.

FIXED COSTS

- Technology components for maintenance.

- Consumables.

- Staff salaries.

Revenues

- One-off installation fee.

- Subscription for maintenance and technology updates.

- Consumables (single-use and one-per-test).

- Funding.

6. CONCLUSIONS

6.1 Process and project conclusions

Ultimately, with this thesis an automated booth for COVID-19 testing was created through the implementation of a human-centered and holistic approach, building up from a concept that initially lacked any connection to human needs, empathy, or behaviors. The project idea, in fact, was born because of a fascination with a particular technology rather than the value it could create, which is often the case in an environment dominated by a strong technology-push approach, such as the R&D sector of medical devices and diagnostics.

The implementation of a Service design mindset and approach brought what was a "just a pure business value proposition", "fasTest", to a full-fledged and comprehensive product-service system that is now CHECKD. Especially, understanding users was vital in this project, as the service involved multiple layers, and it was highly required in the process of transition from old object-behavior-narratives to new the new one.

The development of CHECKD required blending service design, user experience and interface, interaction design, product and architectural design, as well as an understanding of engineering perspectives and technical complexities, such as automation and biology limitations. At the same time, time constraints, commitments towards investors and sponsors, limited budget and resources deeply affected the course and evolution of the project iself. Collaboration between the design team (the author) and the multiple engineering teams was essential to produce the best results with what was available, and finding a middle ground to build on was critical.

As mentioned multiple times during this thesis, the Service Design approach does not entail a linear process, and does not follow a strict structure. Instead, it consists of various “activities” that shape and bend around the course of events, often repeating and over-imposing. In this project, the team had to deviate from the usual path taken in Service Design and create their own very flexible approach: despite attempting to follow a methodology, real, practical projects differ from concepts and visions and scenarios and often involve difficult decisions and unforeseen issues that must be accepted and overcome in order to carry on.

The initial "evaluation" phases reduced the scope of the project and focused on an actual, viable path that was more manageable and applicable. Service design helped to bring the project down to earth and ground it in reality. The exploration phase, especially, defined the project boundaries, outlined the context and current situation, and added value and a broader scope. It also brought in the most important missing actor: the user. Conducting user research was crucial to understanding people's behaviors, experiences, and practices with existing options and services, and imagining how to improve them with new experience levels and interaction modes.

Facilitating co-design processes among people directly affected by the service was critical, as it challenged all assumptions made in the original design, such as the use of spit and saliva and the need for privacy and “analog” artifacts. In this regard, greater attention was given to the design of material and digital touchpoints, as well as the servicescape, meaning where service encounters take place.

Iteration was critical to the project's success, involving studying and redesigning service encounters and elements based on user feedback and inputs.

Due to time constraints and being the only designer working on the project, the output of the thesis could only reach a certain level. While it could potentially be implemented at a product-service system design level, it lacks the operational part. Additionally, the design and prototyping only focused on the "booking" version of CHECKD, while the "walk-in" version was left behind due to practical limitations. In that regard, more detailed definition of the on-site registration and identification with a totem would be needed, as well as a review of the wayfinding and signage system.

6.2 Possible future developments

6.2.1 The booth’s ideal version

The development of CHECKD. does not stop with this thesis work. As seen with the desk and user research and the provided insights, there is plenty of evidence that a solution able to deploy fast, affordable, fully automated and accurate PCR testing for Covid-19 would bring great benefit to the society at large. This not only because it is an effective tool during critical and emergency situations, such as the Covid-19 pandemic, but because it could bring positive impacts also in much simpler, daily-life scenarios, such as participating safely to an event.

As previously explained, though, the “final solution” presented in chapter 5 was drafted to fit the current and short-term expected state of the technologies and provide a mid-term goal that was feasible and reachable in a very small amount of time. To do this, some insights generated from the co-design session were excluded temporarily, but not definitively discarded and can be utilized to define what would be the real end goal, the booths “ideal” version that can be attained on long-term plans.

On a first, simple level, a point to develop and implement is possible subscription packages, mainly for very frequent travellers or families.

On a second level. the main implementation would be scaling and expanding the booth system at a world-wide level, with a network of booths in each continent, that the user can access wherever and whenever they much desire. At the same time booths should be placed in new locations, such as hospitals and care centres, to support and facilitate testing even more and broadening its reach to new users.

Finally, a third point, probably the most important, would be deploying the “automatic lolliswab” sample collection procedure. This aspect entails the greatest, most challenging and time and resource consuming activities: researching, designing, developing, prototyping, manufacturing, testing, certifying (officially with different health institutions and certificates) and patent a brand new and ad hoc swab able to collect saliva or mouth fluid and snap closed with a hygienic, one-use system. At the same time a totally revised automation system would need to be developed, as well as a management for the cartridge system, that would allow the processing of one sample at a time, rather than pooling eight together first. In this case the user would really be performing minimal and basic actions, making CHECKD. even more easy to use and the procedure less prone to errors and accidents.

Despite the best efforts, this vision is still far ahead, but not unreachable.

6.2.2 The booth applied to other illnesses

“According to the World Health Organization (WHO), infectious diseases continue to be the leading cause of death worldwide, accounting for around 17 million deaths annually”[54];

[54] https://www.who.int/news-room/fact-sheets/detail/infectious-diseases

CHECKD. deployed for Covid-19 testing is only one example, one application that such PoC PCR station could achieve.

As seen at the very beginning of the project, during the brief and counter brief framing, many are the options, as the PCR technology can work with any infectious disease. All are promising and could be potentially disruptive: local/regional control of spread of a disease, enable testing in hard-to-reach location with limited resources, mass-test and treat to diminish reservoir of persistent infections and accelerate towards elimination, prevention of misdiagnosis and uncontrolled spread of diseases.

Three main blocks of potential applications are worth future work and exploration:

- "Malaria remains a major public health problem, with an estimated 229 million cases and 409,000 deaths reported in 2019."[55]: Flu, malaria, cholera, yellow fever, monkeypox and other travel related illnesses. In this case, the work would be very similar to the one done with CHECKD., but with a particular attention and sensitivity towards the locations where these illneses are coming from and implementing new service levels (such as “packages” of different tests in the same booth).

- CHECKD for developing-countries and their endemic illnesses, such as borrelliosis, schistosomiasis, ebola and zika. This is probably the most challenging and complex step to follow as it would require intense user research with a very volatile and difficult to reach target, as well as design and prototyping on site. Structure and materials would have to be reviewed and upgraded, as well as the overall product-service system and user-machine interaction (instructions, verification procedures, medical products, maintenance), mostly because some of the illnesses can be detected only from a blood sample, which is highly different from “simple” saliva.

- "The majority of STIs have symptoms that may not be recognized as an STI. As a result, many STIs go undiagnosed and untreated, which can lead to severe health consequences and contribute to ongoing transmission of the infections."[56]. All STIs, with the most common and diffused first: Chlamydia, Gonorrhea, HPV and HIV/AIDS. This case falls under the “delicate” design areas, as these diseases can still be perceived as a taboo topic in many environments. New desk and user research would be a needed starting point, as well as partial re-design of the structure. This kind of diseases, in fact, might require intimate swabs. This calls first of all for a booth that can ensure total privacy (and therefore that cannot be “transparent” on any side), and second, that can be carry out a fully automatic disinfection procedure (meaning, it has to be “air tight”). Moreover, despite the possibility of keeping a base from the service-system design with CHECKD. many parts and details would obviously need to be adapted and changed to the specific needs of this target users, along with the overall marketing and communication strategy.

[55] Malaria (who.int)
[56] https://www.who.int/health-topics/sexually-transmitted-infections#tab=tab_1

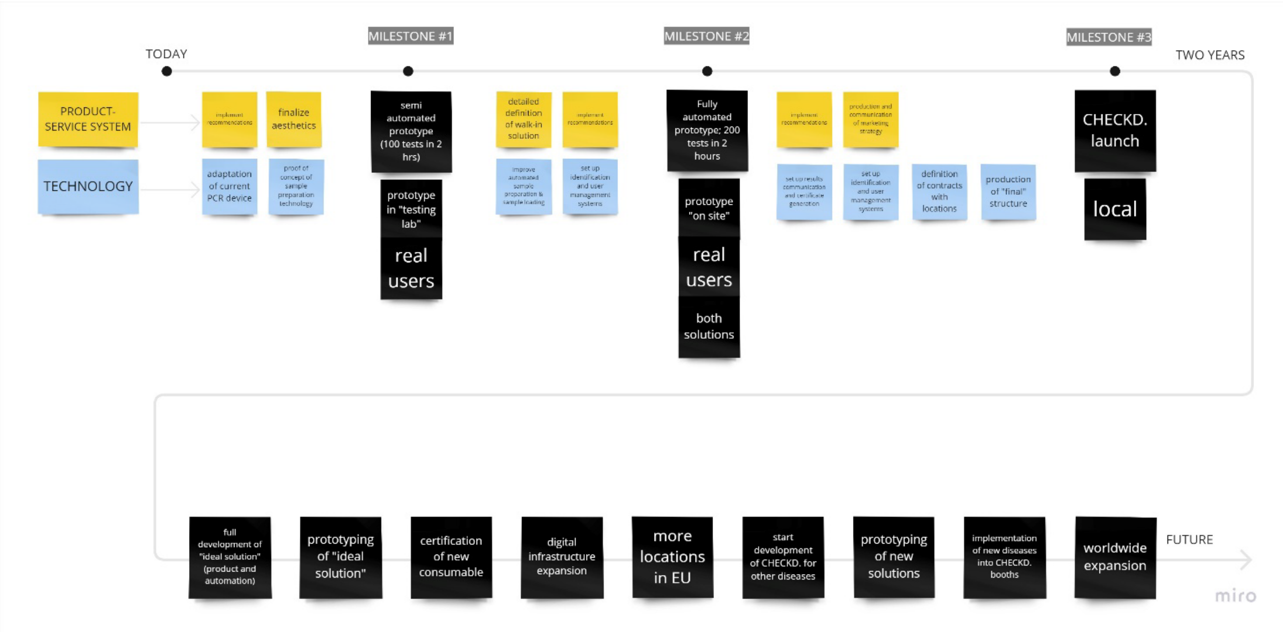


Figure 116 - A proposed roadmap for implementation and future developments, that spans over a time period of two years to bring the product to the market.

6.3 A personal reflection

Working on Checkd was a transformative experience for me as a service designer. The challenges and tests that arose throughout the project provided invaluable opportunities for growth, both as a professional design practitioner and as an individual. Through this experience, I realized the importance of “owning” theoretical knowledge and not just using it as a reference. To utilize it, to bend and shape it to your needs, its deep understanding is necessary, otherwise it is only a bland repository of tools and processes.

My fortune in this project was in finding incredible project partners who possessed open-mindedness, unwavering passion, and a genuine interest in their work and discipline. This environment was inspiring, and not a single day lacked excitement and desire to carry on with the project. Moreover, as an added benefit, my general knowledge on the most disparate technical topics expanded considerably as a result of this exposure, from mechanical engineering, to biomedical and biochemistry topics, until more practical aspects such as 3D printing and construction working. Despite the difficulties and hard moments, I do not regret any minute of it and would happily engage in it again.

GLOSSARY

Abductive reasoning → Form of logical inference or hypothesis generation that involves forming plausible explanations or hypotheses based on limited information or incomplete data. It is a type of reasoning that is commonly used in scientific research and problem-solving.

Affordance → Poperties or characteristics of an object or environment that suggest how it can be used or interacted with. They are the perceived or potential uses or actions that an object or environment affords to a user, based on its physical or perceptual properties. Affordances can be visual, tactile, auditory, or other sensory cues that signal how an object should be used or manipulated.

Analytes → Analytes are substances or chemical compounds that are analyzed or measured in a laboratory test or assay. They can be found in biological samples such as blood, urine, or tissue, and can include molecules such as proteins, enzymes, hormones, drugs, or metabolites. Analytes are often used as biomarkers to diagnose diseases or to monitor the progress of a treatment.

Antibody → A protein produced by the immune system in response to the presence of a foreign substance, called an antigen. Antibodies recognize and bind to specific antigens, marking them for destruction by other immune system cells.

Antigen → A substance, often a protein or a carbohydrate, that is foreign to the body and can stimulate an immune response, resulting in the production of antibodies.

Assay → A laboratory test or procedure that measures the presence or concentration of a substance or the activity of a biological process.

Automation → The use of machines, robots, or computer programs to perform tasks that were previously done manually by humans.

Biomarker → A measurable substance or characteristic in the body that indicates the presence or progression of a disease or condition, or that can be used to assess the effects of a treatment. Biomarkers can be proteins, DNA, RNA, or other molecules.

Boundary objects → Physical or digital artifacts that are used to facilitate communication and collaboration between individuals or groups who may have different backgrounds, perspectives, or goals. Boundary objects are often designed to be flexible and adaptable, allowing them to be used in a variety of contexts and by different stakeholders. In design, boundary objects can take many forms, such as sketches, models, prototypes, diagrams, or software tools.

Co-creation → Process of working together with users or other stakeholders to create a design or product. This can involve gathering feedback, conducting user research, and involving users in the design process to ensure that the final product meets their needs and expectations.

Coreography → The way in which different elements of a design interact with each other. This can include things like the placement of buttons on a website, the flow of a user's journey through an app, or the layout of a physical space.

Immunoassay → A laboratory test that uses antibodies to detect and measure the presence or concentration of a substance, such as a protein or a hormone, in a biological sample, such as blood or urine.

Multiplex → A laboratory technique that allows multiple tests or analyses to be conducted simultaneously on a single sample or platform, often using microarray or bead-based assays.

Ontology → A formal system of categories and relationships that represent the concepts and entities within a domain, such as a particular field of knowledge or a database.

Pathogen → An organism, such as a virus, bacterium, or fungus, that can cause disease or infection in a host organism.

PCR // RT-PCR → Polymerase chain reaction (PCR) is a laboratory technique used to amplify a specific segment of DNA through cycles of heating and cooling. Reverse transcription PCR (RT-PCR) is a variation of PCR that is used to amplify RNA sequences by first converting them into complementary DNA (cDNA) using reverse transcription. Both techniques are widely used in molecular biology and diagnostics to detect and quantify DNA or RNA sequences, including those from pathogens.

Prototypes → A prototype is a preliminary version of a design or product. It can be a physical or digital model that is used to test and refine the design before it is finalized.

Reagents → Chemical substances or compounds that are used in laboratory assays or experiments to detect, measure, or analyze the presence or properties of other substances, such as biomolecules, cells, or pathogens.

Sensitivity → In laboratory testing or diagnostic assays, sensitivity refers to the ability of a test or assay to correctly identify individuals who have a particular condition or substance, often expressed as a percentage. A highly sensitive test will correctly identify almost all individuals who have the condition or substance, with few false negatives.

Specificity → In laboratory testing or diagnostic assays, specificity refers to the ability of a test or assay to correctly identify individuals who do not have a particular condition or substance, often expressed as a percentage. A highly specific test will correctly identify almost all individuals who do not have the condition or substance, with few false positives.

Stakeholder → Person or group of people who have an interest in a project or product. They can be anyone from users to investors, and they can have different levels of involvement and influence on the design process.

Taxonomy → Process of organizing and classifying information or data in a structured way. In design, taxonomy is often used to categorize and organize content or design elements, making it easier for users to navigate and find what they need.

Tools → Tools refer to the software or hardware used in the design process. These can include anything from design software like Adobe Photoshop or Sketch to physical tools like 3D printers or laser cutters.

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