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Article

Addressing Complexity in the Pandemic Context: How Systems Thinking Can Facilitate Understanding of Design Aspects for Preventive Technologies

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Abstract: The COVID-19 pandemic constitutes a wicked problem that is defined by rapidly evolving and dynamic conditions, where the physical world changes (e.g., pathogens mutate) and, in parallel, our understanding and knowledge rapidly progress. Various preventive measures have been developed or proposed to manage the situation, including digital preventive technologies to support contact tracing or physical distancing. The complexity of the pandemic and the rapidly evolving nature of the situation pose challenges for the design of effective preventive technologies. The aim of this conceptual paper is to apply a systems thinking model, DSRP (distinctions, systems, relations, perspectives) to explain the underlying assumptions, patterns, and connections of the pandemic domain, as well as to identify potential leverage points for design of preventive technologies. Two different design approaches, contact tracing and nudging for distance, are compared, focusing on how their design and preventive logic are related to system complexity. The analysis explains why a contact tracing technology involves more complexity, which can challenge both implementation and user understanding. A system utilizing nudges can operate using a more distinct system boundary, which can benefit understanding and implementation. However, frequent nudges might pose challenges for user experience. This further implies that these technologies have different contextual requirements and are useful at different levels in society. The main contribution of this work is to show how systems thinking can organize our understanding and guide the design of preventive technologies in the context of epidemics and pandemics.

Keywords: systems thinking; design; complexity; pandemics; COVID-19; preventive technologies; contact tracing apps; nudging; proximity detection

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1. Introduction

Epidemics and pandemics are characterized by great complexity, as the emergence process entails both biological and anthropogenic factors: pathogens that are compatible with human hosts combined with negligent human behavior, as well as socioeconomic and environmental drivers, such as escalating urbanization and increased global travel and commerce [1]. COVID-19 disease, caused by the SARS-CoV-2 virus, is an example of an emerging infectious disease (EID) that can spread rapidly and become a pandemic [2,3]. In the case of COVID-19, the initial emergence was unpredictable and accidental, i.e., when humans first came in contact with an unknown pathogen and when the infection was still latent. During the incubation phase, a high local and global mobility of infected humans, lack of prior knowledge of transmission routes, and limited immunity in the human population lead to an amplification effect, after which the infection outbreak progressed to an epidemic phase, and finally to a pandemic [1,2,4].

The pandemic caused by the SARS-CoV-2 virus exemplifies the challenges posed by epidemics and pandemics. These situations are defined by rapidly evolving and dynamic conditions, where the material world changes (e.g., pathogens mutate) [5], and in parallel, our understanding and knowledge rapidly progress. Preventive measures during the COVID-19 pandemic have included promotion of hygiene routines, such as hand washing and wearing a face mask, social distancing, different levels of lockdowns and implementation of various digital preventive technologies [6–10].

The aim of this paper is to describe a systems thinking approach to conceptually analyze the situation and find suitable leverage points for preventive technologies, and to explore and compare different design approaches focusing on their relation to systems complexity. Accordingly, this paper strives to contribute to a conceptual and theoretical understanding of how to approach wicked situations, such as epidemics and pandemics, and to provide guidance for design efforts in such situations in the future. The guiding question for this work is: how can we organize our understanding of a pandemic situation to identify and analyze points of leverage for the design of preventive technologies?

The analysis in this work is based on the perspective of a designer, and the focus is on the pandemic situation and how preventive technologies can be understood and designed in relation to complexity. More specifically, the focus is on wearable, proximity based and preventive technologies.

2. Research Approach

The research approach of this conceptual article [11–14] is to use systems thinking [15] in order to explicate underlying assumptions, patterns and connections within the pandemic domain, as well as to identify potential leverage points for design of preventive technologies. The conceptual contributions of this study are two-fold, including both describing and depicting the problem area, and distinguishing between different design approaches. According to McInnis et al. [11], these specific conceptual goals are called delineating and differentiating. Moreover, classifying the design variants and their implications indicates that this can be considered as a typology paper, as defined by Jaakkola [12].

This article follows a typical outline of a conceptual article, suggested by Rocco et al. [13], and Vargo et al. [14]. The introduction section defines the problem area and formulates the aim and the research question. In this study, the research process is based on a review of the relevant literature related to the problem domain, and the theories and models that constitute the theoretical lenses through which the problem domain is elucidated. The review of the literature is a prerequisite for application of these frameworks to the problem domain. The theoretical frameworks that are used in this study are complex adaptive systems (CAS) and the DSPR model [16,17]. These models are closely connected and they are considered suitable frameworks for conceptualizing complex systems [16,18]. Finally, the emerging conceptual ideas and contributions are synthetized in the discussion and presented as implications for designers and users.

3. Literature Review

3.1. COVID-19 as a Wicked Problem

The COVID-19 pandemic can be considered a "wicked" or "super wicked" problem [19,20] due to its high complexity and the challenges it poses. The original concept of wicked problems was introduced by Rittel and Webber [21], who referred to the ill-defined problems of policy planning in social systems—as a contrast to clear, or "tame", problems of mathematics and science. Levin et al. [22], considered this description too general and focused on super wicked problems, using human-induced climate change as an example. These problems often lack a central authority to govern the problem, and those causing the problem are also the ones trying to solve it. In the context of the COVID-19 pandemic, Schiefloe [20] selected five characteristics of wicked problems: (1) they do not have a definitive formulation, and thus no distinct solution; (2) each wicked problem is unique and poses unknown challenges; (3) they cannot be solved by conventional analytic methods or rational decision-making procedures; (4) there are no true or false decisions, only be better or worse ones depending on the perspective. The actual outcomes can only be evaluated afterwards; (5) all actions may have unpredictable and irreversible consequences.

Auld et al. [19] applied four specific features to target the COVID-19 pandemic as a super wicked problem: (1) time is running out, i.e., actions must be taken within days or hours to prevent rapid spread of the virus; (2) virus spreads across borders, but there is no central global authority to govern pandemics and local governments cannot have full control over individual behavior; (3) those causing the problem are also the ones that want to solve it, i.e., individual behavior causes the virus to spread as people benefit from social networks, and only individual behavior change can restrict the transmission; (4) policies tend to irrationally discount the future and decisions often reflect limited time horizons.

3.2. Technologies for COVID-19 Prevention

The rapid evolution of the COVID-19 pandemic, including the dynamics between the natural phenomenon and our understanding of it, has created unique opportunities and challenges for technological advancement. Information systems scholars are encouraged to contribute their expertise and innovations to the design and use of various technologies to manage the pandemic and to analyze the potential challenges and consequences of this technological advancement [23,24]. Since the turn of the millennium, digital technologies have played an increasingly important role in public health work. However, since the start of the current pandemic, wearable technologies have been rapidly developed and extensively implemented to support a range of preventive measures [10,25]. This has led to the emergence of a new field of research that has grown substantively since 2020. While there are emerging empirical experiences [26–28], theoretical and methodological considerations are needed for understanding, learning, and to enable the abstraction of knowledge from this situation to future ones. Epidemics and pandemics are a part of our history and new pathogens and mutations will continue to disrupt us in the future [29]. As vaccines are not always available at the onset of a new outbreak, the ability to quickly identify critical leverage points and design successful preventive tools will be important in fighting future crises.

Contact tracing apps (CTAs), which are digital versions of traditional contact tracing practices, have been widely used as a preventive technology during the pandemic. However, these solutions have been criticized for being based on inadequate understanding of both the pathogen and the social reality [30,31] and for not considering the long term consequences [24]. It has also been pointed out that those responsible for designing these technologies were lacking systematic guidelines due to the rapidly developing situation [32]. The main purpose of CTAs is to track an infected individual's contacts with other people and to alert those who have been exposed to the virus, requesting them to quarantine and seek testing [28,33–35]. However, the use of contact tracing technologies has raised many concerns and discussions about ethics, privacy, feasibility, and effectiveness [26,27,36–39]. In addition, user oriented research has reported misconceptions about the CTAs and their preventive function [40].

An alternative approach is to use a proximity-based technology to nudge users (e.g., using audio or vibrating alerts) when they are too close to other people, allowing them to immediately move to a safe distance [41–43]. However, this approach has not been as widely described or discussed as CTAs. CTAs and nudging technologies are further described under Section 4.2.3.

3.3. Systems Thinking for COVID-19 Prevention

Systems thinking approaches have been applied in multiple studies to understand and describe the nature of the pandemic [2,30,44,45]. In general, systems thinking is used to elucidate complex real-world problems based on the concept of a system. A system is demarcated from its environment by boundaries, although open systems can also interact with their environment. A system comprises several components (subsystems and system parts) and in order to understand the system's overall structure, behavior and outcomes, it is crucial to examine the relationships and interactions between the components [15,17,46].

Systems thinking can also aid the design efforts for COVID-19 prevention by facilitating a more holistic understanding of the overall situation and how technologies can aid in the situation, as well as the opportunities and challenges that may arise when preventive technologies are introduced [47] to an already complex situation. In this paper, the term design is considered to be a broad concept, in line with Simon's [48] definition: "to design is to device course of action aimed at changing existing situations into preferred ones". This means that design can involve approaching a problem with the purpose of improving the situation, as well as making decisions about the functionality in a specific technology.

3.4. DSPR Model and Complex Adaptive Systems

In this study, the DSRP model (distinctions, systems, relations, perspectives) [17] is used. The DSRP model is a relatively recent development in the field of systems thinking and can be used to describe and analyze how things are organized in both nature and in minds [16,49]. This makes the DSRP model particularly useful in the problem domain, which consists of both real-world parts (e.g., humans, pathogens, technologies, societies, health care systems) and our understanding of these parts. The latter includes the mental models we form of their relationships and interactions (e.g., how a designer or user visualizes how pathogens spread or how technologies work).

The model also has the benefit of being easy to understand for non-experts, and it is general enough to apply on most real-world situations [16,49]. The DSRP approach considers systems thinking as an emergent property of the four distinct cognitive patterns. Each pattern comprises two co-implying elements [17], as shown in Table 1.

Table 1. The four patterns and eight elements of the DSPR model [17].

Pattern	Elements	Description
Distinction (D)	Identities (i) and others (o)	Definition of the boundary between identities that are included in the system and the other entities.
System (S)	Parts (p) and whole (w)	Identification of separate parts and how the parts are lumped together into wholes.
Relationship (R)	Action (a) and reaction (r)	The dynamics of a system that define how parts are related to other parts and to systems, and how an action of one part leads to a reaction of a related part.
Perspective (P)	Points (r) and views (v)	Distinctions, as well as how we define systems and relationships, are made from different points so that they create different views.

The patterns and elements can be used in non-linear order during the modeling process, they are interdependent with various co-implications [17,49]. By analyzing the system parts and their connections, we define our assumptions of the real-world problem and make them visible. This process can make us aware of discrepancies between the real world and our mental models of it, and guide us in updating our knowledge based on current evidence [17,18].

Complex adaptive system (CAS) is a specific type of open systems that is a central part of the DSRP approach [16], where systems thinking itself is considered as a CAS. CAS is also considered as a suitable conceptualization of many health problems where linear thinking has failed in grasping complex health challenges [50]. Epidemics and pandemics are examples of such problems. CASs are typically systems comprising individual agents that follow simple rules, but their interactions lead to complex macro-level outcomes, i.e., emergent properties [46]. A CAS can comprise separate subsystems, and each of them can constitute a separate CAS. The resilience of CAS is based on the ability to interact with the environment and adapt to endure internal and external changes. Due to the complexity, CASs are closely related to wicked problems [51]. The conceptualization of CAS aligns with the nature of epidemics and pandemics. A pathogen's relation to the hosts can be defined as relatively simple and rule based. However, as interaction continues, individual hosts adapt their behavior, pathogens mutate, and as infections spread in society and become epidemics or pandemics, complexity increases, and the situation develops into a wicked problem. Since we cannot control the evolution of pathogens, it is plausible to target preventive actions towards to the behavior of individuals and the societal factors that cause the spreading of the disease [1,52,53].

4. Applying CAS and the DSRP Model

In this analysis, the pandemic is considered as a CAS, and DSRP is used to identify and model some of the complexity in more detail, i.e., to shed light on some of the key parts, their relations, their interactions, and different perspectives. It is suggested in this paper that the DSRP model can be used in a design process to better understand and define the situation and identify potential leverage points. The model can also be used to clarify perspectives and assumptions underlying different design perspectives. In addition, the DSRP model frames a comparison of two design approaches in relation to complexity and the context of a wicked problem. Finally, the paper outlines how a systems thinking approach can support in building a mental model of the situation, to find suitable leverage points, and to clarify assumptions that underlying various technological designs.

4.1. The System and Its Parts

When we model the COVID-19 pandemic as CAS, we consider biological, human, and technological agents that are embedded and acting in the human society.

The biological agent is the pathogen that is dependent on hosts, which in this context refers to human individuals. Hosts make up the physical infrastructure, i.e., human social system, in which a pathogen can travel, transmit and reproduce so that the pandemic is able to develop [4]. Applying the CAS perspective supports us in understanding how a pandemic becomes more complex as it evolves, since the interaction between the key parts (hosts and pathogen) causes both the pathogen to adapt (mutate) and the individual to react and adapt to the threat, and subsequently the society to respond in different ways. Moreover, psychological aspects of the host, such as their understanding of the situation, and their subsequent behavior, will affect their social activities and interactions with other humans [53]. The social level includes any encounter and interaction between two potential hosts, which may involve a risk of exposure. Most commonly, the interactions involving transmission take place between close contacts meeting indoors [54] or interacting for prolonged times, such as between family members, friends, colleagues, or students [55]. The social level comprises various subsystems organized in a society, which is the highest level in this analysis, and can be considered as a complex system as well [44]. The societal level of a pandemic involves a range of aspects that can affect the transmission of a pathogen. This can include economic aspects, infrastructure and housing, access to health care, demographics, culture, socioeconomic aspects, and government guidelines. These aspects interact with the social level and can affect transmission via the changes in social contact patterns [9]. For example, a school closure or stay at home orders can decrease the number of physical meetings between people which can reduce the risk of transmission.

To manage the social interactions between individuals, various preventive and wearable technologies can be embedded in the social and technological infrastructure. Technologies can be designed in various ways and can be used to control or alert human hosts or to track social interactions between them. Depending on how a technology is designed, the relations between parts of the system will change, and the boundaries of the system might need to be expanded. This will have implications for the complexity of the situation, as well as our ability to understand it and make predictions on potential effects and challenges arising from the introduction of a preventive technology. This is further described in the sections below.

4.2. Distinctions

Distinctions clarify the boundaries, i.e., what is included and what is not included in a system of interest [17]. We can use distinctions to define the key parts of the system that were identified in the previous section.

4.2.1. The Pathogen

The pathogen of interest is the SARS-CoV-2 virus that causes COVID-19. SARS-CoV-2 spreads mainly by droplet spread, using exhaled respiratory droplets to spread from one person to the next. In the beginning of the pandemic, the main part of transmission probably occurred through this route and took part between close contacts [3,55–58]. Other forms of transmission also exist, but they require other actions for prevention [58] which are not the focus of this paper. In this analysis, we focus on designs targeting human-to-human transmission via droplets, which takes place between close-proximity contacts, such as <2 m [58].

4.2.2. Human Hosts

Human hosts and their interactions are the key focus of this analysis. During an outbreak of infectious diseases, humans can be categorized into infected, recovered and susceptible [59]. It is worth noting that animals can also host zoonotic viruses, such as SARS-CoV-2 [3], but the human hosts are in focus in this analysis.

When designing preventive measures to protect human hosts, we can focus on individuals in a specific setting, e.g., a workplace, school or people attending an event at a specific time. Or we can include the whole population in a country or region. Depending on how we design the preventive action, the information we need to make this distinction becomes more or less important, as exemplified in the section about technologies below.

4.2.3. Technologies

In this analysis, we focus on proximity based, preventive technologies. Proximity based technologies focus on estimating proximity (distance) between two individuals, for example by Bluetooth or ultra-wideband (UWB). By this function, a wearable technology can provide feedback about the physical distance between users and facilitate various preventive approaches.

A common and extensively discussed technology in this category is contact tracing apps (CTAs) [33,60–62]. An alternative design concept can build on the same type of hardware (proximity detection) but focus on the behavior of the user. We refer to this as a nudging technology (NT) due to its focus on changing behavior [41]. This approach is compared to contact tracing and discussed primarily in relation to preventive approach, timing of the feedback, and implications for systems complexity.

A basic idea behind digital contact tracing, such as an app-based contact tracing system, is that if two individuals interact within close proximity (e.g., <2 m), for a substantial time (e.g., 15 min), the system logs the encounter as a potential exposure event. If any of these individuals subsequently tests positive for the virus, the system sends out an exposure alert (a warning of potential infection) [38,47]. Consequently, the second individual can isolate, seek testing, and avoid further transmission to others, and so, by tracking infections, the chain of transmission can be stopped [63].

Another way of preventing transmission is to provide the user with a direct warning (a nudge) whenever two individuals are too close to each other, so that the user can immediately increase the distance and avoid exposure. A nudging technology (NT) can be based on the same or similar hardware platform as CTAs, such as a mobile phone or a wearable device. However, an NT provides a slightly different function, and thereby a different preventive logic. By changing the timing of the feedback and providing it earlier, the NT can facilitate physical distancing to prevent transmission of the virus (primary prevention), compared with contact tracing which focuses on tracking infections (secondary prevention). The NT approach focuses on designing behavior by providing a direct notification if distance is breached, but it does not necessarily require tracing and storing any data on contacts or interactions. This alternate approach has mainly been described in theory [41,42] and some versions have been tested in laboratory settings [43]. There are also examples of available wearables in the market employing this approach, and various devices have been implemented in real-life settings [64]. Compared with CTAs, the research on this approach is scarce, but evaluative studies are emerging [65]. Below we analyze some of the key differences between a CTA and NT approach.

Using the distinctions (D) concept, we can identify that access to specific information is an important requirement for CTAs. If a CTA is introduced, there must be a way to distinguish between infected individuals versus others for this preventive system to be meaningful [59]. Therefore, this system requires that tests with sufficient sensitivity and specificity are available to the users. This further implies that the contact tracing system is dependent on individuals' access to health care or other testing infrastructure, which identifies demands at the societal level. Furthermore, enough individuals need to be tested, which might be a challenge if the virus causes silent infections (none or vague symptoms) [47,63,66]. Therefore, the success of a CTA system might be connected to the display of symptoms and the properties of the virus (the interaction between the host and the pathogen). What is more, a certain percentage of individuals in a population need to use a contact tracing system, for it to be efficient as a preventive measure [63]. This requires widespread acceptance and adoption in the public. Furthermore, the users need to understand the system, use it correctly, and adhere to the feedback from the system. Examples where this might fail are described in the section about perspectives (P) below.

If a nudging application is implemented, the system provides a warning directly when a proximity threshold is breached (e.g., 1.5 m). The basic idea behind such a system is that users should keep distance from all potential hosts, to avoid transmission. A critical difference between CTA and NT based systems is that the NT approach does not require additional information to distinguish between infected and non-infected persons. The aim is not to track the pathogen, but to support individuals in maintaining enough distance [41]. The NT system is therefore less dependent on other infrastructure in the society, which changes the boundaries of the system, and some of the complexity is reduced. With fewer dependencies on other systems and less need for information, the NT system has fewer potential sources of failure. Furthermore, direct feedback is more straightforward than a process involving many steps over longer time intervals, which can be a benefit in relation to users' understanding. Thus, they are easy to implement [64], which is beneficial from a time perspective. The weakness of this approach would be similar to that of CTAs: enough individuals, at least in a specific setting, need to wear the technology and keep it active, which puts demands on acceptance. Moreover, the system needs to perform well in detecting and rapidly reacting to close-interactions. Depending on how challenging it is to maintain physical distancing, frequent alarms might also be an issue, from a user experience point of view [41]. Frequent alarms might challenge adoption and adherence, which puts requirements on the context of use where this might need to be controlled. This also indicates that the technology is better suited for specific places and for a limited duration in time.

In Figure 1, we show the distinctions and key parts in the pandemic system (the pathogen (P), human hosts (H), and technologies (T)), as well as the relationships between the parts. This visualization can help us to identify potential points of leverage, where technologies can aid in the situation. Feedback based on the proximity detection between technical devices (T–T) will inform human hosts (T–H), and at the same time affect spatial relations between the hosts (H–H), and subsequently also the human relation to pathogen (P–H), i.e., the transmission routes.

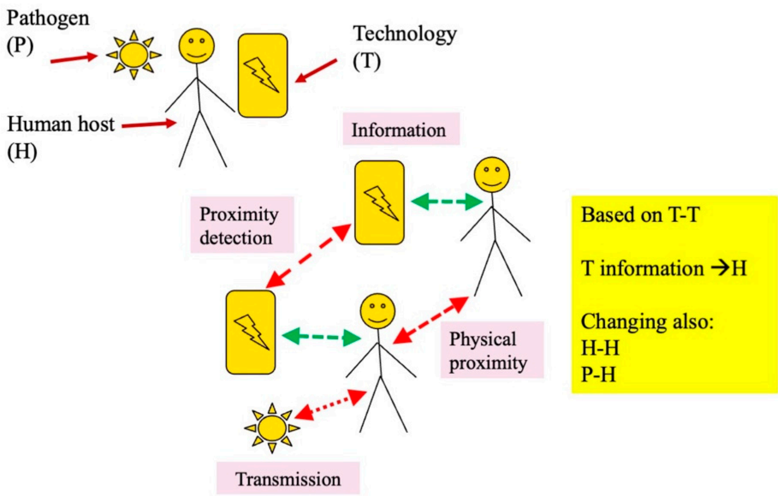

Figure 1. The key parts in the pandemic system (the pathogen, human hosts, and technologies) and relations between the parts.

4.3. Relations

There are three relations of interest in this analysis, as shown in Figure 1.

The first is the relation between pathogen and the human hosts (P–H), which concerns how the virus can infect a new human, i.e., the routes of transmission. This is the key issue in a situation involving infectious diseases, and it sets the direction for the rest of the analysis. Therefore, it is critical to investigate and define this type of knowledge before starting any design effort. It is important to clarify our assumptions early in a design process, as this can help us identify knowledge gaps, misconceptions, or if a solution is not useful under specific conditions. Based on the knowledge defined in the beginning of the pandemic, we have chosen to focus on human–human transmission by droplet spread. It is worth noting that other types of transmissions are not included here, which sets up limitations for a design based on these assumptions. For example, if knowledge changes, or in environments where other forms of transmission may dominate. For example, if fomite transmission would dominate, a design based on human–human proximity would not be useful.

Secondly, the spatial relation between humans is of interest since this affects the virus's ability to transmit. As we cannot see or approach the pathogen directly, we need to track or change our behavior as humans. Based on the dominating transmission route described above, it is logical to focus on the physical distance between humans, as close encounters appear to be a risk factor.

Third, the relation between humans and technologies provides the basis for a technological intervention. For example, it determines how and when the technology will provide feedback to a user. In this analysis, we consider two different ways that technologies can interact with the user. The first involves tracking close encounters and providing feedback afterwards, if one of the involved humans is found infected (CTA). This system requires more information, it is more precise (only feedback when infection is positive) but also slower from a preventive standpoint (warning is provided afterwards). The second approach involves providing feedback to everyone who is too close to potential hosts (NT). This approach focuses on preventive behavior rather than infection and requires no information on infection status of those involved. The basic assumption is that all close encounters can be a risk. This approach is less precise, but also less complex, as it does not require access to testing. Therefore, it is faster from a preventive standpoint (direct warning and feedback on behavior), as shown in Figure 2.

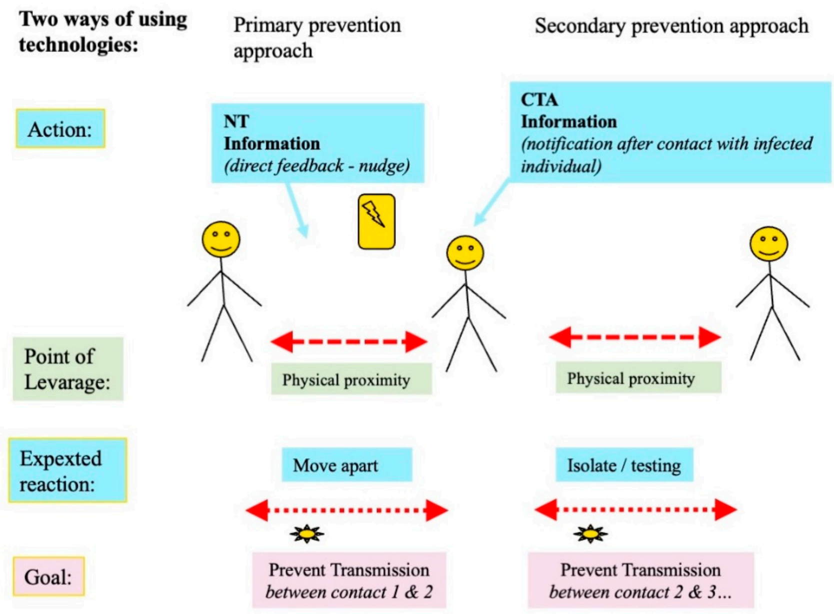

Figure 2. Two different design approaches, nudging technologies (NT) and contact tracing apps (CTAs).

4.4. Perspectives

Perspectives consist of a point and a view. The Point includes who is looking from where, and the view involves looking at what [67]. This paper is written from a design perspective, in which design implies striving to change or improve something. The view includes the relations between specific parts in the pandemic situation. We discuss how and from where we need to approach the situation (and some of its parts) to understand it better before we try to change it by design.

Within the COVID-19 situation, we have so far focused on the relation between the pathogen, humans, and personal preventive technologies. By defining how we perceive and understand the situation, its key parts and relations, we make our own assumptions, i.e., our mental model of reality, more visible. This can increase the awareness of the structure of our own knowledge and its gaps and provide a frame for assessing and updating our understanding of a problem. This iterative relation between a problem and our cognitive understanding of it is defined as the system thinking loop [67]. In a situation such as a pandemic, both nature and knowledge develop at a high speed, making it even more critical to be aware of our own assumptions and limited knowledge.

However, it is not enough for a designer to understand the nature of the problem and to continuously assess their own mental model of it. The designer must also understand, at least to some extent, how the intended users think as well. There are examples where there has been a mismatch between the purpose of a technology and users' understanding of it. Empirical examples can be found in the literature about COVID-19 apps. Some studies in this field showed that misconceptions about the CTA technologies are widespread [40]. Some of the most serious misconceptions involved the apps' purposes, where a substantial number of respondents believed that apps could warn users about infectious individuals [68]. These findings imply that their mental model of the preventive process did not align with that of the designers, and such misconceptions can have severe consequences in an infectious outbreak.

Perspective taking can enable designers to increase their understanding as well as their empathy for the users [69]. This concept can support in understanding and investigating different mental models of the problem.

The application of the DSPR model on the pandemic situation is summarized in Table 2.

Table 2. Application of the DSPR model on the pandemic.

Pattern	Pandemic
System (S)	Complex adaptive system. Root causes: pathogen–human interaction, human–human interaction. Subsystems and key parts in analysis: societal level; social level; pathogen, human hosts, preventive technologies.
Distinction (D)	Droplet spread of SARS-CoV-2 virus; infected and non-infected human hosts; contact tracing and nudging approaches.
Relationship (R)	Relations: human–virus; human–human; human–technology. Action–reaction: Primary prevention by nudging; secondary prevention by contact tracing.
Perspective (P)	Design perspective; awareness of different mental models; understanding the technologies.

5. Discussion

In the preceding analysis, we discuss some of the complexity involved in epidemic situations, how we can approach the problem to gain a more holistic understanding and identify potential leverage points. Epidemics and pandemics are defined by rapidly evolving and dynamic conditions, where the physical world changes (e.g., pathogens mutate) [5] and, in parallel, our understanding and knowledge rapidly progress. This creates a multidimensional and complex situation that is challenging to grasp and approach. As previously described regarding wicked problems, many of the characteristics apply to the COVID-19 situation, especially when technological systems are to be rapidly implemented in an already complex situation. To exemplify, we can use some of Schiefloe's characteristics [20]: there is no definite formulation of the pandemic, and no model or depiction can encapsulate the whole situation. This points to the importance of clarifying the perspectives, including the points and views when approaching and discussing this problem. We can never understand or see the whole problem, not even using systems thinking. Moreover, as there is no distinct solution to a wicked problem, no technological intervention will solve a pandemic. Their effects cannot be evaluated until afterwards, and both design approaches discussed in this paper might have unintended consequences. What we can do is discuss, compare, and synthesize what we know to date, which can be clarified using models of systems thinking. A systems thinking model can highlight some critical aspects, in particular those concerning relations between parts, which can improve our understanding when we design for complex problems. The DSRP model provides us with a framework to map and describe mental models of the situation, including the view and focal points using the perspective (P) concept. In a design process we can clarify what is and what is not included by making distinctions (D), how parts are organized into wholes using the system (S) concept, and our current understanding of how these parts interact using the Relation (R) concept.

It is important to note that all preventive approaches need to be substantially discussed in relation to social, legal, and ethical perspectives. The technological approaches discussed in this paper involve many sensitive issues, such as tracking of contacts, information about infectiousness, and/or repetitive irritating alarms which may cause frustration or stress. The context of use is a pandemic which has severely harmed and killed thousands around the globe. Although the ethical perspectives are not the focus of this paper, we want to highlight that there are many aspects that need to be analyzed before any preventive technologies are implemented. For example, we need to consider the seriousness of the situation (is it necessary?), the potential effectiveness of an intervention (is it useful?), the cultural context (is it appropriate?), and the acceptance among the public. Morley et al. [36] have provided an extensive list of guidelines for contact tracing apps, which cover some of the examples above.

The perspective from which we approach the problem will determine which systems and subsystems are visible at different levels. Some of these systems are described in Sections 3 and 4.1. For example, if we focus on the societal level, a pandemic is extremely complex and multiple levels and systems are involved. The CAS concept helps us to understand how complexity increases as parts and subsystems interact, adapt, and create emergent properties. This results in a wicked problem that becomes more difficult to intervene in and increase the risk of unintended consequences. In the current paper, we have focused on the root causes on a lower level, where it is possible to intervene with design. By using the DSRP theory, the key components of the system can be identified, and distinctions can be made to clarify some of the problem's conceptual space and the knowledge structure we base this understanding on.

In this analysis, we focus on the interactions between the pathogen SARS-COV-2, on human beings, and on preventive technologies (CTAs and NTs). Based on existing knowledge on transmission routes, we have identified close-proximity interaction between humans as a problem, where we can leverage interventions. Technologies provide us with tools which can modify this interaction. It is worth noting that this point does not reduce the complexity of the problem, but rather shifts the focus from the societal level (where the emergent properties of the interactive parts are beyond control), to the interaction between three specific components (humans, pathogens, and technologies). By investigating the relations between these components, we can identify some potential leverage points, and thus distinguish between different preventive logics.

There are many dimensions that need to be further investigated and discussed in relation to these technologies, and their potential implications for humans, organizations, and societies. While NTs are less covered in the literature, CTAs are widely discussed in relation to, e.g., attitudes [40], privacy [37,70], and ethics [36,47], and literature on the preventive effects is emerging [26,27]. What is less discussed in previous literature is the topic of complexity in relation to the different designs and preventive approaches.

In this paper, we show that the boundary of a preventive technology will change based on how it is designed, particularly in terms of the timing and purpose of the feedback. For example, these two approaches have different requirements concerning the amount and form of information needed. CTAs will require more information to make distinctions between humans (infected vs. not infected) [59], which requires multiple steps in the preventive process. A technology that focuses on tracking infectious individuals will expand the boundary of the system to the societal level, requiring the addition of new components and relations to other systems (testing, health care infrastructure, etc.), hence the understanding from the user needs to be more advanced [47]. Furthermore, the user needs to accept the technology, adhere to every step in the process, understand the purpose [40,47], and thus the preventive logic, to avoid misconceptions. This makes the system more complex in both in reality and mind. Some of these challenges might explain the lack of effectiveness of some CTAs [26,71,72]. With more distinct system boundaries, the preventive process can be easier to control, and thus less complicated to understand. An NT might offer an alternative which is more in line with the users' idea of the preventive logic.

Implications

Based on the analysis, we can identify two points of leverage for prevention in a pandemic situation, and how small changes to the design can result in different preventive logics. These two approaches have different implications for complexity, so their contextual requirements will differ. The requirements below focus on boundaries and systems complexity emerging from relations between the components: pathogen, hosts, and technologies. CTAs can be a suitable technology in a society where enough individuals are likely to use and understand them (access to technologies, technological literacy), where tests are easily available and reliable, in a situation when contact tracing will be useful, and infected individuals are likely to notice symptoms, seek testing, and notify others about their status.

An alternative approach is to provide direct feedback on distance [41,43], using the NT. This requires no information on infections; therefore, such a system would be less complex (fewer relations and dependencies to other systems), hence it would be easier to understand both purpose and process. However, since no distinctions are made between infected and non-infected persons, the system will provide more frequent alarms. This may lead to irritation and lower adherence. Therefore, such a system would be better suited in a context such as:

If the situation is more urgent, in a well-defined context (specific place), for short-term use (restricted time of day), in a situation when droplets spread is most likely to dominate (specified distance), where there is enough space to maintain physical distance, where devices can be handed out, and adherence can be checked.

Using the DSRP model, we have identified some potential leverage points as well as challenges and opportunities that different preventive approaches entail. Furthermore, the model can help in identifying some of the perspectives we need to consider, such as the perspective of the designer (including their views on key parts of the problem, the type of knowledge needed to design, and the assumptions being made), and the perspective of the users (including how they perceive the problem and their understanding of different technological solutions). By defining and modeling these aspects, we can strive to understand and align the views of the situation as well as the ideas behind different designs. This can help us avoid misconceptions, identify drawbacks of different approaches, and to improve or re-design technological interventions as both circumstances and knowledge evolves. We illustrate these perspectives in Figure 3 below.

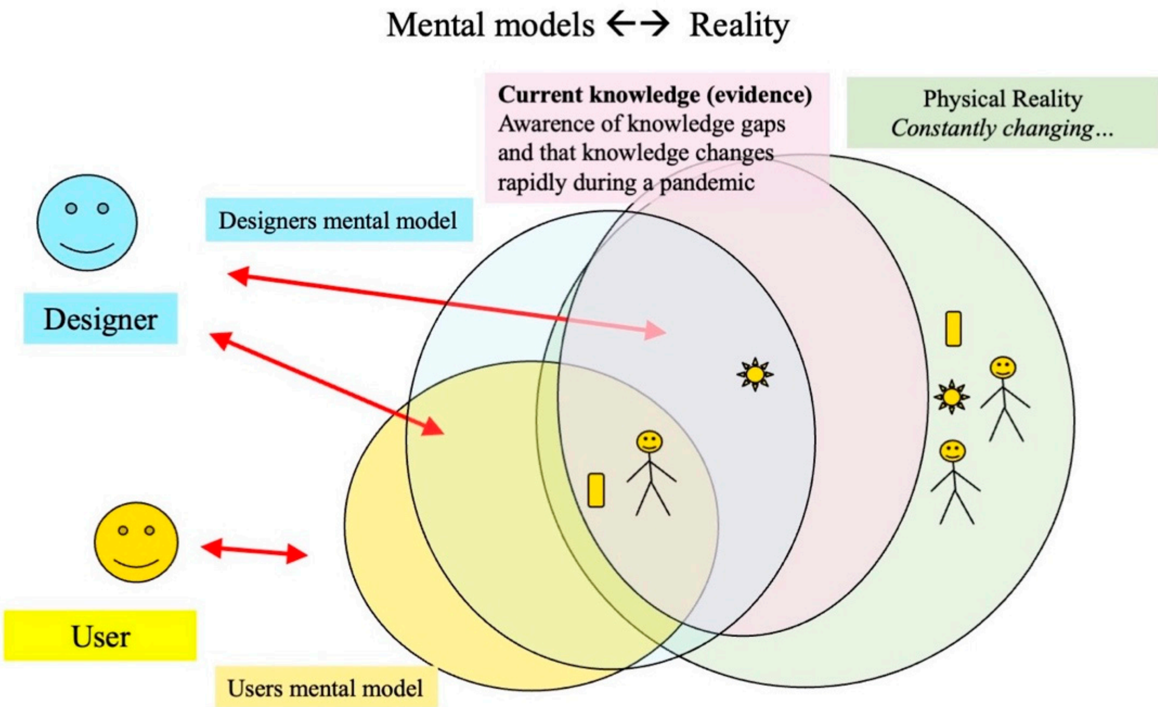

Figure 3. Mental models of the situation. The designer needs to build a mental model based on current knowledge of a rapidly evolving situation and try to gain knowledge about users' mental models. If these do not align, problems and misconceptions can occur.

6. Concluding Remarks

A pandemic is a complex situation, involving many dimensions and interacting parts. This paper argues for the importance of explicitly clarifying assumptions underpinning preventive designs, which is critical for understanding and scrutinizing the mental models at play. By organizing and modelling our understanding of a complex situation, we can identify discrepancies between designers and users' mental models and clarify the benefits and drawbacks of different designs.

The question guiding this work is—how can we organize our understanding of a pandemic situation to identify and analyze points of leverage for design of preventive technologies?

In this paper we describe how a systems thinking approach, using the DSRP model, can aid in organizing our understanding of key parts and their relations in a pandemic situation. By modelling these structures, we identify points of leverage for preventive technologies. Furthermore, we analyze how different designs entail different preventive logics, with implications for both material and cognitive complexity.

The analysis shows that CTA and NT approaches express different preventive logics, based on the timing of the feedback. The CTA approach will involve more complexity, and the requirements for such a system need to be met at the societal level. An NT approach can operate using a more distinct system boundary, which implies easier implementation and control. However, the potentially repetitive feedback implies more challenges to user experience, and therefore such a system is a better fit for specific places and situations. The main contribution of this work is to show how systems thinking can organize our understanding and guide the design of preventive technologies in the context of epidemics and pandemics.

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