Received: 3 August 2021 | Revised: 25 May 2022 | Accepted: 11 June 2022

DOI: 10.1111/1468-5973.12423

ORIGINAL ARTICLE

WILEY

On organizational robustness: A conceptual framework

Yancong Xie[1] | Kevin C. Desouza[2] | Mohammad Jabbari[3]

[1]Centre for Organisational Change and Agility, Torrens University of Australia, Adelaide, South Australia, Australia

[2]QUT Business School, Faculty of Business and Law, Queensland University of Technology, Brisbane, Queensland, Australia

[3]Department of Management Information Systems, Université Laval, Quebec, Quebec, Canada

Correspondence
Yancong Xie, Centre for Organisational Change and Agility, Torrens University of Australia, Adelaide, SA, Australia.
Email: xieyancong@gmail.com

Funding information
None

Abstract

Understanding robustness and how organizations can configure and adapt is fundamental for their survival. In this paper, we build on the general system theory to conceptualize the underlying mechanisms of organizational robustness. We propose a framework that defines the fundamental notions and typologies of robustness— instrumental, structural, and cognitive robustness. We define mechanisms for these three categories of robustness as strategical mechanisms, functional mechanisms, and infrastructure mechanisms, and we explain how these mechanisms enable proactive, structured, or agile organizational responses to predictable and unpredictable crises.

KEYWORDS

conceptualization, general systems theory, organization design, resilience, robustness

1 | INTRODUCTION

Robustness examines how systems can remain stable in the face of uncertainties. Given the nature of volatility, uncertainty, and speed of disruption in today's environments, organizations are constantly challenged to maintain and bolster their robustness (Boyne & Meier, 2009; Suarez & Montes, 2020). It is thus important to understand how organizations can function, and even thrive, in the face of known and unknown perturbations in their environments.

The robustness concept has been adopted in different disciplines such as system biology (Kitano, 2004), control theory (Alippi, 2014), engineering (Fuchs et al., 2008), computer science (Sussman, 2007), statistics (Bradley, 1978), supply chain management (Durach et al., 2015), and many others. In management and organizational studies, robustness is predominantly examined in the fields of risk management and business continuity management (e.g., Durach et al., 2015).

Existing literature provides equivocal definitions for robustness and resilience (e.g., Rai et al., 2021; Ruiz-Martin et al., 2018). This paper clearly distinguishes the robustness concept because two concepts have a different emphasis (Maurer & Schumacher, 2018). When facing crisis, the main difference between resilient systems and robust systems is that resilience systems aim to *quickly recover operations* ***after*** *the crisis* with minimal impacts. However, robust systems aim to *continue operations* ***during*** *the crisis* while minimizing the impact. When it comes to dynamic and highly volatile environments, it is the capability to *maintain essential operations during the crises* that matters, not the ability to adapt post disruption (Miroudot, 2020). In addition, building robustness requires different capabilities and strategies which greatly motivates this study to conceptualize organizational robustness.

A robust system survives unpredictable crises as it can demonstrate functionalities to repurpose, innovate, and reorient system components (e.g., resources, processes, capabilities, and assets) in novel ways in an agile manner. The robustness property of a system tends to be less time bounded or crisis bounded, and it concerns the fundamental infrastructural design of a system (Kitano, 2004). Besides strengthening existing system capabilities to overcome crises, a robust system also aims to sharpen its general capabilities in signal sensing, information processing, decision making, resource coordinating, and operation adjusting processes, hence allowing timely reaction to the dynamics of crises. Robustness involves fundamental mechanisms and thus can provide more systematic explanations on how organizations approach stability and evolvability in various ways. An example of robustness is how radio stations continued their programs and even presented more programs and podcasts during the COVID-19 pandemic (Dias, 2020).

Unfortunately, in the current literature, there is a dearth of studies on organizational robustness, nor the extant literature captures mechanisms to achieve organizational robustness. Organizational robustness is examined only as the persistency aspect of organizational resilience (e.g., Durach et al., 2015), suggesting an inaccurate conceptualization of robustness. However, there is a lack of understanding on what the typologies of robustness are. To facilitate future studies on organizational robustness, this paper conceptualizes robustness based on the general systems theory (GST) and embed the ideas into the organizational context, by integrating the extant literature across (a multitude of) several disciplines. Our focus is on developing a general-purpose framework for organizational robustness.

The remainder of this paper is structured as follows. We firstly introduce the concepts of GST as the theoretical foundation of our conceptualization of robustness. We then define robustness, discuss the core elements of robustness, and finally arrive at a typology of robustness. After that, we discuss the antecedents of robustness with a layered view. We conclude this paper by outlining directions for future organizational robustness studies.

2 | GENERAL SYSTEMS THEORY

To conceptualize organizational robustness, we draw on concepts from GST (Kast & Rosenzweig, 1972; Skyttner, 1996). According to GST,

- *System*: is a composition of interrelated components that work together to transform inputs into outputs to achieve collective goals. Systems are made up of smaller subsystems and can also be part of a supra-system.
- *System Environment*: A system operates within an environment that is defined as the real world—excluding the components of the system—but includes all conditions, circumstances, and factors that the system does not have control over them. A system can influence its environment or can be influenced by its environment.
- *System Boundary*: determines what is inside and what is outside of the system. In other words, system boundary helps separate a system from its environment.
- *System Function*: refers to the process of transforming inputs into outputs including system trait, behavior, structure, and activities.

Systems can be classified as *open* or *closed*. Any system to accomplish its collective goals must interact with its environment. The nature and the level of interaction between the system and its environment is defined by its boundaries. The boundary around any system can be either 'open' or 'closed'. A *closed system* is a system that has rigid and impenetrable boundaries that limits its interactions with the environment. Closed systems operate on their own with little or no influence from the outside world. An *open system*, however, has permeable boundaries that are open, to some extent, that makes it possible for various forms of interactions such as exchange of information, energy, or material with its environment. The main characteristics of open systems are controlled by environmental information and are fueled by some forms of energy. However, closed systems are only open to the input of energy (Skyttner, 1996).

Open systems can be further defined as *reactive* or *proactive* systems. Skyttner (1996) proposed two types of loops, which he termed as feedforward loop and feedback loop (see Figure 1 for distinction). The feedforward loop is related to a planning process in preparation for future eventualities. It simulates the actual process and provides expectations, which will be later compared with the actual outcomes to provide control insights. However, with feedback loops, systems use post hoc outputs and compare them with goals or standards for controlling. Systems are proactive if they tend to incorporate more feedforward loops, while reactive systems tend to incorporate more feedback loops.

Regarding the intensity of self-regulation, proactive systems will have stronger impetuses to plan and adjust system processes, to achieve system goals in an effective and efficient way. Proactive systems thus may have more intensive self-regulation, highlighted by more implemented feedforward loops and feedback loops as well as higher volume and velocity in these loops.

A system is a collection of subsystems of a lower order that are highly integrated to accomplish an overall goal (Kast & Rosenzweig, 1972). The changes in one subsystem may change the nature of the overall system. A system can also be part of a suprasystem. System functionality and its boundary demarcate the system from its environment. As presented in Figure 2, when a particular subsystem is the scope of the evaluation, the rest of the components will act as the environment. Environment can be categorized as *static* or *dynamic*. In a static environment, the regulation, that is, how environment defines the goals of a system

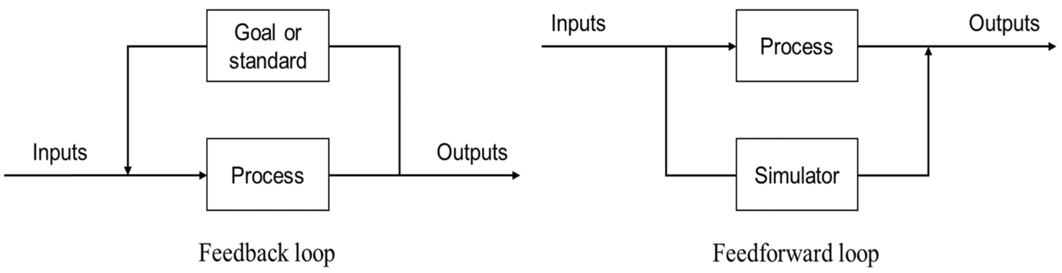

FIGURE 1 The distinction between feedforward loop and feedback loop adopted from Skyttner (1996, pp. 48–49)

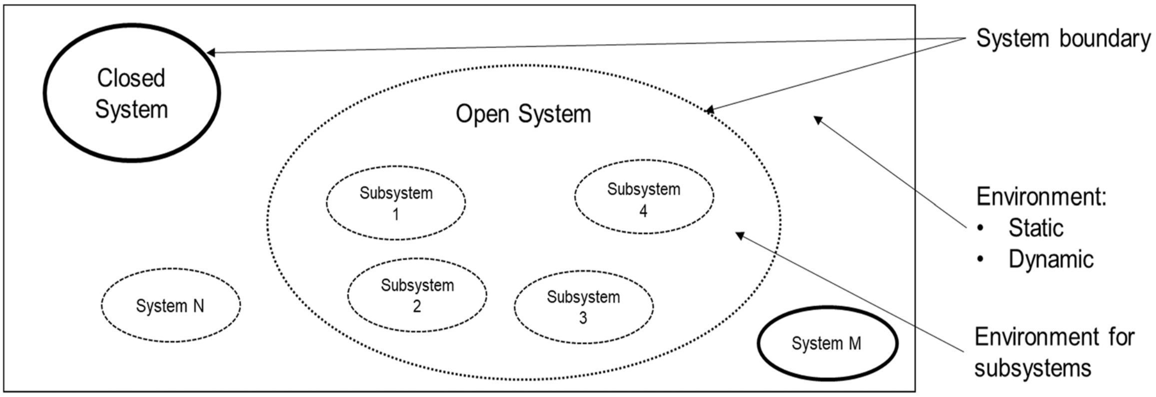

FIGURE 2 System boundaries and system environments adopted from Kast and Rosenzweig (1972)

and how environment exchange matters, information, and energy with the system, largely remain stable or predictable. However, a dynamic environment is more volatile and turbulent.

In a static environment, an open system tends to passively respond to environmental inputs to achieve an equilibrium. Since regulation in a static environment largely remains stable, the equilibrium that an open system aims to achieve tends to be fixed. When an open system deviates from its goal, it simply bases on feedback to mitigate the deviation to re-achieve equilibrium. Further, if an open system has already achieved its goal, it has no incentive to change as the desired equilibrium remains unchanged due to the static environment.

However, in a dynamic environment, as environmental structure and behaviors can change, the regulation from the environment on an open system can also change. This has three important implications. First, when a regulation changes, the goal of an open system can change as well. Therefore, a dynamic environment will impose higher requirements on an open system to achieve equilibrium in a faster and more effective approach. Open systems may, thus, wish to develop stronger skills to foresee deviations and better prepare for changes. Second, the change of environment may redefine its interactions with systems. Consequently, the effectiveness of system functions can be greatly affected. Open systems thereby need to develop higher flexibility and innovability to adapt to the new environment. Third, if environment is dynamic, open systems can have the opportunity to change environment through their interactions, which further changes the regulation influencing these systems again. Open systems can thus intentionally change their processes to achieve an equilibrium, through a bottom-up and then a top-down approach. Therefore, whereas open systems tend to passively respond to environmental inputs to achieve an equilibrium in a static environment, they tend to be more proactive in a dynamic environment. For instance, consider humanitarian services (open systems) in Nigeria and their response plan to deal with starvation (static environment) (Kallon, 2020) versus humanitarian services in the world to deal with emerging strains of coronavirus (dynamic environment).

3 | DEFINING ROBUSTNESS

We provide different definitions of robustness across different fields in Table 2. We adopt, and build on, the robustness definition from system biology. Kitano defined robustness as ‘a property that allows a system to maintain its functions against internal and external perturbations’ (Kitano, 2004). This definition is the most inclusive and encompasses many other definitions of robustness (see Table 1). Building on Kitano's work, we define robustness as *a property that allows a system to maintain its functions to achieve system effectiveness against perturbations in an environment.*

Four elements of robustness based on our definition are *system*, *effectiveness*, *perturbation*, and *environment*. Any organization is a system of individuals and groups with different skills and knowledge with the coordinated effort to mobilize resources and produce output through a continual process of interactions (March & Simon, 1993; Selznick, 1948). Therefore, we use the terms system and organization interchangeably.

3.1 | System effectiveness

System effectiveness refers to the criteria of a system's success in operating its functions. System effectiveness can be intuitively understood as its problem-solving capability, quality of its output, and systems stability in maintaining its functions (Srinivasan, 1985). Kast and Rosenzweig (1972) suggest three levels to analyze system effectiveness—the level of the *environment*, the level of the *social organization* as a system, and the level of the *subsystems* (e.g., human participants) within the organizations. Different levels of analysis may suggest a different focus on an organization's capability in terms of effectiveness. For example, organizational effectiveness at the individual level may suggest the stability of individual's performance within the organization, immune from uncertainties. In comparison, organizational effectiveness at the environment level may suggest the stable contribution of organizations to the environment. Organizational effectiveness at both levels is different from the notion of organizational effectiveness at the organizational level. Notably, a lower level of analysis can be covered by a higher level of

TABLE 1 Definitions of robustness across scientific disciplines

Discipline	Definition of robustness	Source
System biology	The ability to buffer variations generated by molecular noise, genetic polymorphism, or environmental fluctuations was termed robustness	Barkai and Shilo (2007)
	Robustness is the persistence of an organismal trait under perturbations	Félix and Wagner (2008)
	Robustness is a property that allows a system to maintain its functions against internal and external perturbations	Kitano (2004)
	Robustness, the ability to maintain performance in the face of perturbations and uncertainty, is a long-recognized key property of living systems	Stelling et al. (2004)
	Robustness can be defined and measured as the average effect of a specified perturbation on a specified phenotype	Masel and Trotter (2010)
	Robustness refers to the property of a system to produce relatively invariant output in the presence of perturbation	Gursky et al. (2012)
	A trait is robust to a genetic or environmental variable if its variation is weakly correlated with variation in that variable	Nijhout (2002)
	A biological system is robust to mutations if it continues to function after genetic changes in its parts	Wagner (2005a)
	Biological systems, from macromolecules to whole organisms, are robust if they continue to function, survive, or reproduce when faced with mutations, environmental change, and internal noise	Wagner (2005b)
Control theory	A robust system will be able to somehow resist a set of perturbations by providing a graceful loss in performance	Alippi (2014)
Engineering	The design [of a robust system] should be safeguarded against uncertain perturbations	Fuchs et al. (2008)
Statistics	The robustness of a statistical method is related to several classical parametric tests on means and the population assumptions of normality and equal variances	Bradley (1978)
Supply chain management	Robustness refers to the ability of a supply chain to resist or avoid change	Durach et al. (2015)
Ecology	Robustness means the capacity of a system to absorb stresses and continue functioning	Lamberg et al. (2009)
Computer science	Robust computing systems must continue to meet user expectations despite rising levels of disturbances in the underlying hardware	Li et al. (2009)
	A robust system should have a high general utility that does any particular job very well	Sussman (2007)
	An algorithm is robust if its solution has the following property: it achieves 'similar' performance on a testing sample and a training sample that is 'close'	Xu and Mannor (2012)
Economics	Robustness refers to the insensitivity of the results of inference to alternative specifications	Woodward (2006)

analysis. For instance, organizational effectiveness at the individual level can be one aspect of organizational effectiveness at the organizational level, while the opposite may be untrue. When individual staff remains stable under uncertainties, organizations can remain stable. However, the stability of organization may not suggest the stability of all individual staff (Leana & Barry, 2000). In this paper, we take the *organizational level of analysis*.

When examining organizational effectiveness as a closed system, maintenance has a strict notion, suggesting the continuity of system outputs. When system functions are maintained, system functions are supposed to generate consistent system outputs, given the variance of system inputs to some degree (e.g., Lu & White, 2014; Neumayer & Plümper, 2017). From this perspective, the notion of system effectiveness is more related to reliability. The intention to ensure system effectiveness is mostly for enabling the external validity of the system such as an economic prediction model (e.g., Lu & White, 2014).

In comparison, from the perspective of an open system, maintenance may have a broader notion, suggesting the emerging continuity of system functions (Kitano, 2004). This notion can cover the notion of closed systems. If the continuity of individual outputs is enabled, the emerging continuity is obviously ensured as well. However, emerging continuity does not always necessarily require the continuity of individual functions/system outputs (Kitano, 2007). For example, an organization may adjust organizational operations to cope with an economic recession, to achieve continued survival (Frick, 2019). From this perspective, the notion of system effectiveness is more related to system stability. The intention to ensure system effectiveness is to establish organization's capabilities to continue core business to reach long-term business goals without disruptions.

3.2 | Perturbation

Perturbation of a system refers to any deviation of internal or external factors of a system that can potentially affect system effectiveness (Masel & Siegal, 2009). Immune from perturbation is the objective of system robustness. Therefore, a system may have different degrees of robustness if it demonstrates differential levels of reliability/stability against varying perturbations.

In terms of the source, perturbations can be categorized as *internal* or *external*. Internal perturbations are the disruptions of internal system components or system processes (e.g., Bieliaieva et al., 2020). Internal perturbations do not affect the interactions between systems and external environment. Therefore, addressing internal perturbations only requires restoring existing system functions to enable the path from system inputs to the expected system outputs. Against internal perturbations, systems may rebuild disrupted system functions or adopt innovative alternatives to re-enable the same calculative logic of system functions.

In comparison, external perturbations refer to the disruptions of overarching environmental settings or the interactions between system and environment (e.g., Masel & Siegal, 2009). External perturbations may have different implications from internal perturbations to build system robustness—external perturbations can reshape system effectiveness. Therefore, external perturbation may require new system inputs to the same system outputs, the same system inputs to new system outputs, or even both system inputs and system outputs can be re-positioned. Though many combinations, one thing is sure—the new calculative path is mostly different from the previous path. While systems may also configure alternative path for internal perturbation, the reconfiguration for external perturbation is much more complex and uncertain, as the new scenario may have less similarity from the old scenario.

In terms of the nature of perturbations, perturbations can be categorized as *structured* or *unstructured* (Marion & Bacon, 1999). With structured perturbations, the deviations of a set of system factors are logical, sequential, predictable, and analyzable. These deviations can be traced back to one original deviation, which is caused by some certain reasons. To overcome structured perturbations, systems mostly need to adopt top-down strategies to reconfigure system components to cope with perturbation, as these components are required to be coordinated and adjusted in a structured manner. Also, structured perturbations are relatively easy to predict. A top-down approach can assist systems to establish a clear overview of the existing environment. Then, it can facilitate consensus regarding the current system state and target solutions. Therefore, taking a top-down approach in making strategies can let systems better foresee perturbations and systematically plan/prepare for these perturbations (Bakonyi, 2018).

Unstructured perturbation, on the contrary, defines a set of random deviations. These deviations may not be related to each other, or their interdependencies are hard to vision and analyze. Unstructured perturbation could vary from minor random disruptions to very complex system-level chaos (De Meyer et al., 2002). For unstructured perturbations, systems can be benefited from adopting bottom-up strategies (Grote, 2004). In a bottom-up approach, at first, the specific characteristics of the perturbation and microattributes are analyzed in detail. These analyses, then, enable identifying opportunities for system-level solutions. Since unstructured perturbations are random, the nature of disruption in individual components of a system can differ. It is hard and, more importantly, not effective to make strategies in a top-down and centralized manner. To restore the normal state of a system, local knowledge and agile response can be more effective. Later, top-down coordination may or may not be needed depending on whether a structured problem emerges in the collective response to the unstructured perturbations.

We map three specific types of perturbations mentioned in the existing literature into our conception framework (see Figure 3). The first type among the three is *system uncertainty*. System uncertainty refers to the internal disruption of system functions, such as the configuration of system components and governance mechanisms (e.g., genetic mutation; Fares, 2015). System uncertainty can affect system functions at the fundamental level in terms of system resources and system process, thus affecting system effectiveness. One example of system uncertainty is organizational disruptions (e.g., logistical breakdowns). Organizational disruptions can change the configuration of organizational resources, which may further influence the functions of organizations (Pajunen, 2006).

The second type is *environmental disturbance*. Environmental disturbance refers to the disruptions of external factors influencing system functions (Lengnick-Hall & Beck, 2005). Specifically, environmental disturbance suggests the inconsistency in the exchange of information, energy, or material between a system and its environment. For example, for a closed system, the variation of environmental energy can be one type of environmental disturbance. Taking business models

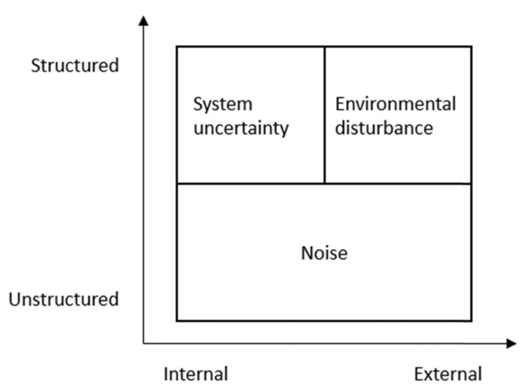

FIGURE 3 Three types of perturbation

as an instance, environmental energy for this closed system can be market settings. It is likely that business models can be effective in one market setting but not effective in the others. For instance, all famous western Internet companies such as Google, Facebook and Amazon failed to survive in China (Li, 2019). Therefore, the variation of environmental energy can affect system effectiveness.

The third type is called *noise*. Unlike system uncertainties and environmental disturbance which are structured perturbations, noise refers to the stochastic fluctuations of both internal and external factors of a system's functions, and it is unstructured (e.g., Paul et al., 2006; Tanizawa et al., 2005). Notably, the notion of noise does not suggest a low scale of perturbation. Instead, it refers to any disruption or a set of disruptions that generate from random processes in the environment. Majority of real-world systems are nondeterministic (Gursky et al., 2012). They often involve random pathways to generate system outputs from system inputs. Any stochastic fluctuation in these random pathways may affect system functions. For instance, strategy-making in organizations can involve random processes. It has been argued that organizations are facing a collection of choices looking for problems and that organization's decision-makers can randomly choose solutions to answer these problems (Cohen et al., 1972).

3.3 | Environment

As discussed above, system environment can be either static or dynamic. This distinction is made based on whether system environment remain stable after perturbation occurs. In a static environment, to build system robustness, systems only need to overcome one fixed perturbation, which is determined by the static environment. Maintaining system functions tends to be linear and foreseeable because perturbations can be predicted, defined, analyzed, and addressed. Systems, therefore, can rely on their memories to adjust their functions, based on past experiences (Cheng et al., 2008). However, in a dynamic environment, achieving robustness can be a completely different, also a more complex, story. First, as perturbations are configured by environment, the changes of environment can lead to further revisions of perturbations, which, at a bottom-level, re-define the system inputs and system outputs in the robustness task (Jain et al., 2020). In other words, systems need to overcome multiple perturbations to constantly maintain system functions in a period of time. More importantly, perturbations can change at any time, before or after the systems achieve stableness against one individual perturbation. Robust systems, thus, should have the capability to not only deal with individual perturbations but also sense signals, foresee potential changes of perturbations, prepare for, and agilely adapt to revised missions. Second, the change of environment may shift the 'environment paradigm'. As a result, previous calculative logic may become different in a new context. With the same system configuration and same system inputs, systems may generate different system outputs. For instance, SARS and COVID-19 redefined bio operations and reshaped the structure of airline companies (e.g., redefining the responsibility of frontline staffs and services provided at airport and airplanes) (Gradek, 2020; Nunes, 2020). This adds another level of complexity for systems to build robustness in a dynamic environment. Third, systems may intentionally utilize the dynamics of environment to achieve robustness (Nan & Tanriverdi, 2017). Systems may generate innovations that lead to a planned new 'environment paradigm.' In such a context, systems' scheduled change of configurations can strengthen their capabilities to build robustness.

3.4 | Robustness

Robustness is an emerging system level property, and it is often not a simple sum of the robustness of subsystems (Kitano, 2004). In most situations, robustness of subsystems in a system can contribute to the robustness of the system in a complicated and nonlinear way. For example, robustness of each component of a rocket does not necessarily lead to the robustness of the rocket, though pretesting of each rocket component can greatly reduce the failure rate of the rocket.

Existing literature implicitly has two perspectives to examine robustness, regarding the system type (Bradley, 1978; Durach et al., 2015; Kitano, 2004; Woodward, 2006). When examining robustness of a closed system (e.g., Xu & Mannor, 2012), previous scholars have focused on the reliability of the system. A robust system is proposed to achieve stable system outputs, given disturbed system inputs. The robustness of a closed system can be intuitively understood as the stability of system functions facing uncertainties. For instance, in simulation studies, the objective of robustness analysis is to ensure that simulation models produce similar outputs given varied model inputs, thus suggesting robustness of the model calculative logic (e.g., Nan & Tanriverdi, 2017). In other words, a simulation model that passes robustness analysis shall be reliable to use in various contexts. This perspective is mostly adopted by scholars in engineering, statistics, economics and other disciplines.

Closed systems suggest limited interactions between systems and environment. The change of external factors may less affect system functions. Therefore, when examining robustness of closed systems, focused perturbations are mostly internal, and dynamics of environment tend to have few implications. In most scenarios, robustness of closed systems tells how and why systems are immune from internal noises. However, in some situations, robustness of closed systems is also about against system uncertainty, such as recovery program of an operating system during system crashes. In both kinds of context, robustness analysis can suggest the stability of system functions. Consider a business model that emphasizes holistic approach on how organizations 'do business' (Zott et al., 2011). For example, the business model of eBay is related to providing connections between individual suppliers and individual consumers using Internet technologies. Such a business pattern focuses on its internal business logic, which less depends on environmental factors. Therefore, this kind of business models can be viewed as closed systems. In such a circumstance, organizational robustness focuses on the consistency and stability of the business processes (i.e., system functions) prescribed by these business models.

In comparison, when examining the robustness of an open system, existing studies instead look at the stability of a system in relation to its environment as a whole (e.g., Kitano, 2004). As discussed above, robustness of an open system is a broader concept covering the robustness of a closed system. Therefore, robustness of an open system describes how system can be immune from internal noise and system uncertainties, assuming a static environment. In addition, it depicts how system overcomes environmental disturbance and external noises in a static environment, and more importantly, how systems achieve effectiveness in a dynamic environment.

The robustness of reactive systems and open systems have different foci. Robustness of reactive systems focuses on system complexity. Reactive systems are in a static environment, where the regulations of environment on reactive systems remain consistent. Therefore, the system tasks to achieve stability are easy to envision, design and execute. In such a context, a reactive system with high robustness tends to have higher complexity, as system complexity can facilitate reactive systems to have nuanced coordination of system components to execute these system tasks (Carlson & Doyle, 2002). By contrast, robustness of proactive systems may focus on system agility instead of system complexity. As the environment of a proactive system is dynamic, it is unlikely that a set of system functions can enable system robustness forever. Therefore, systems need to frequently adjust their operations to address the change of environment and remain stable. In other words, a robust system is supposed to be agile in foreseeing and perceiving the dynamics of environment as well as reacting to environmental changes promptly (Jain et al., 2020).

It is worthwhile to understand the relationship between system complexity and system agility, to understand robustness of two types of open systems. Increase in system complexity, to some degree, suggests the increase of system components and their interactions, thus enabling stronger system capabilities such as information processing and coordination. Systems can then have stronger capabilities to plan and execute changes and can thereby have higher system agility (e.g., Gallagher & Worrell, 2008). However, when system complexity is high, the complex structural design may instead become the hurdle for systems to change quickly, limiting system agility (Arteta & Giachetti, 2004). For example, enterprise resource plannings limit the ability of dynamic organizational change as they are quite cumbersome (Desouza, 2006). It hence suggests that robustness of reactive systems and proactive systems can be overlapped when they are in a low degree but can be contradictory at a high degree.

3.4.1 | Organizational robustness

Organizations are entities within a market (ecosystem). Each organization operates largely independently in the market, aiming to maximize its objectives (e.g., performance) instead of seeking to globally optimize the overall market. In addition, organizations can independently change their structures based on their own utility maximization functions. However, the operations of each organization greatly depend on various inputs from the market (i.e., system environment). Therefore, organizations within a market can be open systems with a high-level configuration of feedback loops and feedforward loops.

When taking the open system perspective into account to examine organizational robustness, the majority of existing literature focuses on reactive systems, assuming a static system environment (e.g., Kantur & Iseri-Say, 2012; Vogus & Sutcliffe, 2007). For example, most prior studies investigate how organizations react to uncertainties by exploring and exploiting the functions of feedback loops (e.g., Kantur & Iseri-Say, 2012). They assume perturbations are fixed, and organizational robustness can be achieved through one mission to reach a clear goal. Such assumptions ignore the dynamic nature of business environment and less reflects the effects of feedforward loops in organizations. Making these assumptions, existing research findings can be limited in different ways.

First, dynamic environments can change perturbations frequently and require a series of different methods and approaches (e.g., trial-and-errors) to configure desired system functions (Jain et al., 2020). The understanding of robustness of reactive systems can only explain one of these methods to successfully overcome one temporal perturbation. However, these series of methods and approaches may be interrelated, and organizations may not finish one before the change of the temporal perturbation. Thus, these research findings cannot fully explain how organizations can achieve organizational robustness.

Second, proactive systems can intentionally utilize the dynamics of environment to achieve robustness, which is not captured by reactive systems. For example, Alibaba launched a new business platform named 'Fresh Hema' in 2016, bringing Alibaba's newly defined concept 'new retail' into reality (Ding et al., 2018). The new business platform 'Fresh Hema' allow customers to place orders online and then decide whether they would like to take the fresh food home, or have it cooked and eat in-store. The delivery time is typically within 30 min, much quicker than traditional retailing method, leading to an absolute success of this business platform and a revolution in the retailing sector (Deloitte, 2020). Alibaba intentionally introduced this game changing business platform so they can take advantage of their strong infrastructure (e.g., Alipay) and advanced technology (e.g., artificial intelligence) (Barbaschow, 2018), thus better surviving in the new business environment. Adopting the reactive system perspective cannot effectively explain how Alibaba has built robustness via introducing environment dynamics with the 'Fresh Hema' new business initiative.

Third, robustness of reactive systems focuses on system complexity while robustness of proactive systems focuses on system agility. When discussing low degree of system complexity, the findings of the robustness of reactive systems can be beneficial to understand the robustness of proactive systems. However, the findings may give false instructions for proactive systems when complexity is high. Supporting this argument, prior literature has

TABLE 2 Typology of robustness

	Instrumental robustness	Structural robustness	Cognitive robustness
System perspective	Closed system	Reactive system	Proactive system
System effectiveness	System function stability and system reliability	System stability and system complexity	System stability and system agility
Focused perturbations	Internal (mostly unstructured) perturbation	All types of perturbation	All types of perturbation
Assumption on environment	Static or Dynamic	Static	Dynamic
Example	Robustness of business models	Robustness of electricity providers	Robustness of carriers

evidenced that less complex organizations are easier to change and thus more agile (Arteta & Giachetti, 2004; Irfan et al., 2020; Sherehiy et al., 2007).

3.5 | Typology of robustness

To summarize our conceptualization of robustness, we provide a typology of robustness as demonstrated Table 2.

Instrumental robustness is the robustness of a closed system. A closed system is normally used as an instrument, such as a mathematical model or an engineering system. The objective of robustness analysis is to ensure that an instrument can be applied to different contexts (e.g., Sussman, 2007). Therefore, instrumental robustness can be roughly perceived as reliability or external validity of an instrument. This type of robustness analysis is more prevalent in engineering and the physical sciences.

Structural robustness is the robustness of a reactive system. As one specific type of an open system, a reactive system has a significant level of interactions with an environment, thus being an essential and inseparable component within the environment. The analysis of a reactive system focuses on the autonomy of this environmental component in a dynamic relationship with other environmental components (e.g., Kitano, 2004). Hence, robustness analysis of a reactive system focuses on the stability of a system as a whole in a larger context, instead of the stability of individual system components separately. Robustness analysis of a reactive system thus further examines the structural configuration of a system and elevates stability concerns from system functions to an emerging system property. Robustness of reactive systems suggests system complexity so that systems can absorb the impacts of perturbations, thus immune from perturbations, and can easily reconfigure system components to arrive at stability.

Cognitive robustness is the robustness of a proactive system. Proactive systems and reactive systems are both open systems, but they differ in the environment assumption. Robustness analysis of proactive systems focuses on the system stability as well. However, as environment of proactive systems is dynamic instead of static, system tasks of proactive systems to achieve system effectiveness against perturbations can be changed. On the one hand, environmental changes can change perturbations, thus re-defining these system tasks. On the other hand, environmental changes can also reshape the contextual factors influencing system tasks. Proactive systems may thus frequently change system tasks and adjust system operations accordingly to cope with perturbations. Hence, robustness of proactive systems places more focus on system's cognitive capability to plan, perceive, react to and even learn from perturbations in an agile manner (e.g., Jain et al., 2020).

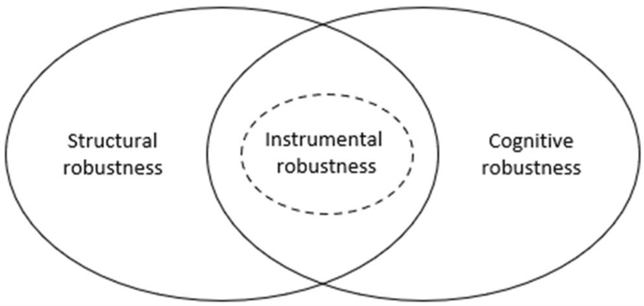

FIGURE 4 The relationship between three kinds of robustness

In short, instrumental robustness focuses on the stability of system functions and system reliability. It can contribute to both structural robustness and cognitive robustness. Structural robustness and cognitive robustness share many similarities such as the focus of system autonomy and system stability. However, structural robustness and cognitive robustness are distinctive in terms of how they respond to perturbations and their desired system capabilities. The relationship of the three types of robustness is illustrated in Figure 4.

4 | UNDERSTANDING ROBUSTNESS MECHANISMS

To further demonstrate our conceptualization of robustness, we now discuss how robustness is affected by its antecedents (noted as robustness mechanism hereafter). Based on our typology of robustness and the existing literature on robustness (e.g., Kitano, 2004; Krakauer, 2006; Wagner, 2013), we define robustness mechanisms in three layers: strategic mechanisms, functional mechanisms and infrastructure mechanisms (see Figure 5). There are several other related concepts in the existing literature to explain the mechanisms

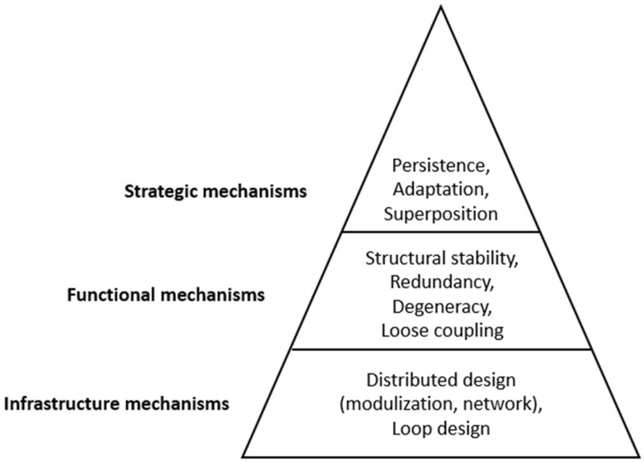

FIGURE 5 Layered view of robustness mechanisms

of robustness. Table A1, in the appendix, maps these concepts onto our layered view of robustness.

4.1 | Strategic mechanisms

At the highest layer, we define three strategic mechanisms for robustness as persistence, adaptation and superposition. *Persistence* suggests that systems can counter perturbations and maintain system functions without changing system operations (Barkai & Shilo, 2007; Félix & Wagner, 2008; Kitano, 2004, 2007; Masel & Siegal, 2009). As a result, perturbations can be 'absorbed'. Persistence is relevant to system complexity. To be persistent towards perturbations, systems should have nuanced design of system functions so that perturbations cannot distort the main calculative logic of system functions. Thus, perturbation remain a minor factor for the system, and system functions are unaffected by perturbations. Suppose an organization faces a blackout perturbation. If the organization can immediately switch to the backup powerline, its operations are hardly affected by the power disruption. In this case, the organization does not change its operations to survive the perturbation; it thus adopts the persistence strategy to achieve organizational robustness.

Adaptation suggests that systems can reactively adjust to perturbations and maintain system functions through arbitrarily changing system operations (Félix & Wagner, 2008; Kitano, 2004, 2007). Adaptation indicates a supervised search process to build system robustness, in which systems constantly adjust their operations to fit a new goal defined by the environment. In such a process, system moves from one balanced system state to another system state. Adaptation requires a high degree of feedback loops, which enables systems to evaluate and adjust system processes based on the anchors in the environment. In the above example, suppose the organization does not have a backup powerline. The organization may outsource to maintain its core functions of production. In this scenario, organizational robustness is achieved by revising organization's operations, that is, adaptation.

Beyond these two strategical mechanisms of robustness, both of which that have received extensive coverage in the literature (e.g., Kitano, 2004, 2007), we define a third strategical mechanism of robustness as *superposition*. Superposition suggests that systems can proactively adapt to perturbations and maintain system functions through agilely changing system operations in a dynamic environment (e.g., Jain et al., 2020). Superposition differs from adaptation for considering the hyper turbulence of robustness missions. In a fast-changing dynamic environment, robustness missions of a system are hyperturbulent. Systems do not know whether the current robustness mission will change nor when it will change. Given this extreme complexity and uncertainty, systems need to sharpen its capabilities to sense signals, plan fast and reconfigure swiftly. This feature distinguishes superposition from adaptation. Whereas adaptation suggests an individual well-planned, structured and goal-seeking iterative process, superposition suggests a series of flexible, explorative, learning and adaptive processes. The state of a robust system can be highly uncertain, until it is observed after fixing environment. Therefore, the state of a robust system in this context can be in a superposition. Suppose an organization is constantly facing a series of unpredictable blackout disruptions in the above example. To achieve organizational robustness, the organization needs to act in an agile manner to adjust its outsourcing strategy to survive different degrees of blackout disruptions. Given that the outsourcing strategy may change frequently, the operations of the organization are highly uncertain; thus, the organization takes a superposition strategy to achieve organizational robustness. Figure 6 illustrates the difference between the three strategical mechanisms of robustness.

Different types of robustness tend to be enabled with different categories of strategic mechanisms. Instrumental robustness and structured robustness are mostly built through persistence and adaptation mechanisms. These two types of robustness incorporate only one robustness mission to build robustness. Systems can remain stable for one perturbation with high system complexity or can systematically explore alternatives to overcome this perturbation. However, cognitive robustness is enabled in a different approach. As there is no one solution for all, it is nearly possible for systems to remain unchanged and stand stable with a diversity of perturbations. Further, systems are unable to devise and deploy long-term strategies to overcome hyperturbulent perturbations. Thus, cognitive robustness can only be enabled by the superposition mechanism.

4.2 | Functional mechanisms

There are three functional mechanisms supporting strategical mechanisms: structural stability, redundancy and degeneracy. *Structural stability* is a key enabler of persistence. With structural stability, systems can have a complex structural design that allows systems to be insensitive to perturbations (Krakauer, 2006). One example of structural stability is the capability of providing buffering (Barkai & Shilo, 2007; Kitano, 2004). The buffering capability can separate the

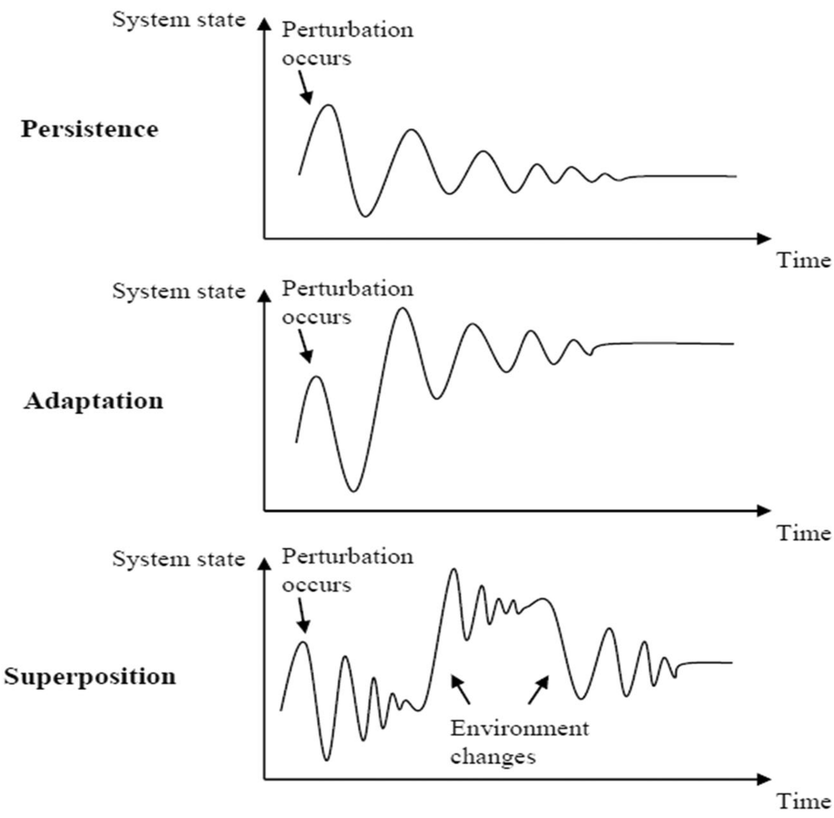

FIGURE 6 Illustration of three different strategical mechanisms of robustness

system functions from affecting factors with buffers. Perturbations cannot directly affect system functions, and thus the impact of perturbations of system functions can be tremendously minimized. An example of structural stability is the design of damper (e.g., Vakilinejad et al., 2020). A damper in the system can convert one perturbation into other kinds of perturbations which systems can handle or delay/smooth the impact perturbations, thus minimizing the impact of perturbations. For instance, organizations can mix products, technologies, markets, operations and supply chains to covert risks and reduce risk level to a manageable level.

Redundancy suggests that systems have redundant pathways in transforming system inputs into system outputs (Kitano, 2004). It is another key enabler of persistence. This is probably the most popular mechanism examined in the existing literature (Félix & Barkoulas, 2015; Félix & Wagner, 2008; Kitano, 2004, 2007; Masel & Trotter, 2010). If a system has multiple same pathways from system inputs to system outputs, when one pathway is blocked due to perturbations, systems may immediately switch to an alternative backup pathway. As a result, the normal system operation is not affected. Such systems can thus demonstrate high persistence.

The third functional mechanism *degeneracy*. It suggests that systems have multiple heterogeneous pathways in transforming system inputs into system outputs (Sussman, 2007). Although these pathways may be essentially different, they can still enable a viable connection from system inputs and system output (Félix & Wagner, 2008; Kitano, 2004).

The last functional mechanism is *loose coupling*. Loose coupling suggests a weak tie between independent system components. These system components are standardized so they can be quickly assembled and replaced. Systems can easily reconfigure the existing pathways to another viable pathway from system inputs to system outputs, thus maintaining system functions (Okoh & Haugen, 2015; Sanchez & Mahoney, 1996). Loose coupling can be a key enabler for innovations and adaptability, thus supporting adaptation and superposition (Pancs, 2017).

4.3 | Infrastructure mechanisms

At the bottom layer, two infrastructure mechanisms are distributed design and loop design. *Distributed design* can include modularization design and network design. Modularization means disintegrating system resources, tasks and autonomy into functionally separate components, that is, modules (Kitano, 2004; Sanchez & Mahoney, 1996). Network design, or architectural framework, is a hierarchical design of connecting individual modules (Kitano, 2004).

Individually, modulization design can enable redundancy if systems have backup modules. These backup modules can be replaced with the original modules enabling the same pathway from system inputs and system outputs. Also, network design is directly related to the functional mechanism of loose coupling, in terms of whether system components are tightly connected or loosely connected. Together, modularization design and network design can ensure structural stability and degeneracy. Structural stability can be easily achieved through adding noncore modules to system functions with complicated connections, thus enabling extra functionalities. In addition, modules can be connected to enable diverse heterogeneous pathways transforming system inputs into system outputs. When one pathway is blocked due to perturbations, systems can switch to other distinct pathways in a complex network design. Hence, degeneracy is ensured.

Essentially, distributed design bring complexity to system structure (Carlson & Doyle, 2002; Kitano, 2004). Without distributed design, how systems transform system inputs into system outputs is mostly linear. A change of system inputs is very likely to change system outputs in a single direction. Therefore, systems tend to be sensitive to system inputs, being less stable and robust. However, when systems have both a modularization design and a network design, system operations can become complex. How systems inputs are transformed into system outputs can become increasingly nonlinear. How system inputs affect system outputs will become more unpredictable. The change of system inputs is thus less likely to have a significant impact, resulting in systematic changes of system outputs. For example, most robust organizations have separate departments which have different business responsibilities. Each department is further split into several independent teams. Further, departments and teams have complex interplays. The delivery of organizational projects may need the collaboration of multiple teams from different departments; and, for different organizational projects, the collaboration pattern can be completely different.

Another core infrastructure mechanism is *loop design*. Loop design includes both feedback loop design and feedforward loop design. Loop design is related to all functional mechanisms as well. It acts as a control circuit that enables a system to change its distributed design, based on past operations (Kitano, 2004; Stelling et al., 2004). Loop design can revise the modularization design through so-called decoupling and coupling (Kitano, 2004). Decoupling suggests decomposing existing modules into granular resources and coupling suggests encapsulating granular resources into new modules. This approach can enhance redundancy if the newly generated modules are identical to existing ones, and degeneracy, if the newly generated modules enable new heterogeneous pathways from system inputs to system outputs. Loop design can also revise the network design (Kitano, 2004). Revising network design means revising the protocols in guiding the hierarchy of modules. Loop design can enable systems to reconfigure its module connections, thus strengthening existing system paths or implementing new system paths. In other words, loop design can also facilitate redundancy and degeneracy from the perspective of network design.

System agility lies on loop design. System agility suggests that system can renew itself, adapt, change quickly and succeed in a rapidly changing, ambiguous, turbulent environment. System agility thus requires strong cognitive capabilities such as signal sensing, signal processing and event reaction (Sheppard & Young, 2006). For example, agile organizations need to recognize the abundance of opportunities and resources, implement self-regulation teams and promote local quick responses, and enable rapid decisions and learning cycles (Aghina et al., 2018). Such cognitive capabilities fundamentally are enabled by the system capabilities to provide feedback on system operations, coordinate system components and design/execute system changes, which can be mostly implemented through loop design.

5 | DISCUSSIONS

5.1 | Advances of the GST and robustness conceptualization

Throughout our extension of systems theory (Kast & Rosenzweig, 1972), we provide a clear description of closed systems and open systems concepts. Prior studies such as (Coetzee et al., 2016; Harney, 2019) explored organizations as adaptive systems embedded in different environmental contexts. We contribute to the general system theory by extending its application to organizational robustness. We define how open and closed systems boundary and their interactions with environment can define organizational capabilities, and explain the turbulence and nuances in constantly evolving and dynamic ecosystems with frequent and dramatic changes, such as economic crisis, climate change, technology innovation and pandemic, examining dynamics of environment. We also extend the concept of open systems (Chick & Dow, 2005) and propose two types of open systems as reactive systems and proactive systems by considering dynamics of environment. This contributes to address the emerging, essential and critical needs of understanding the typologies of robustness to deal with natural and social fluctuations.

Another major contribution of this study lies on the advances of robustness conceptualization (e.g., Kitano, 2004; Tang, 2006). Although robustness is an old concept and has been studied widely, there still lacks a harmonized view on its conceptualization, especially from an organizational and strategic perspective. Building on previous studies (Carlson & Doyle, 2002; Masel & Siegal, 2009; Miroudot, 2020), we definite fundamental concepts in organizational robustness including its four elements system, effectiveness, perturbation and environment, and we provide a typology of organizational robustness. Further, although different disciplines provide various definition of robustness (e.g., Alippi, 2014; Durach et al., 2015; El Baz & Ruel, 2021; Fuchs et al., 2008), extant literature does not capture the mechanisms to achieve organizational robustness. We define three layers of mechanisms through which organizations can respond to crises and achieve robustness. We particularly advance existing understandings by proposing a new type of robustness (i.e., cognitive robustness) and defining a new strategical mechanism of robustness (i.e., superposition strategy). We, therefore, contribute to the current knowledge of robustness, which we hope can initialize a novel promising research stream to study robustness.

5.1.1 | The dark side of organizational robustness

While our conceptualization highlighted the importance of organizational robustness, we also indicate that improving organizational robustness can bring several issues to organizations.

Building organizational robustness can increase organizational fragility (Mahdiani & Ungar, 2021). According to our conceptualization, robustness is bounded to specific perturbations and environment. If organizations go too far with one specific kind of robustness, they may become fragile to other perturbations in other environments. For example, to be robust against the increase of online demands, organizations may implement a higher degree of digitalization (e.g., configure more IT resources). As a result, organizations can be more fragile towards a blackout perturbation. Also, when organizations strengthen structured and nuanced processes to analyze perturbations, plan for change and coordinate executions for perturbations. They may not be flexible enough to adapt to new perturbations when environment changes.

To mitigate the risks of becoming fragile, organizations need to be more strategic to balance their objectives in terms of building structural robustness or cognitive robustness. Structural robustness brings system complexity. It does not often require dramatic shift in organizational resources and processes in coping with perturbations; hence, little investment and efforts can be demanded. However, focusing structural robustness can increase organizational fragility. Organizations need to better plan for potential perturbations and strategically set objects of structural robustness and cognitive robustness.

Further, the relationship between organizational robustness and organizational performance can be complex (Kitano, 2004). We refer to organizational performance as the overall efficiency of organizational operations, such as resource utilization and business process performance. When organizational robustness is low, the increase of organizational robustness can help organizations optimize its structural design, build its operation strength and better configure its resources. Therefore, robustness can promote organizational performance. However, when organizational robustness is high, organizations need to deploy many resources to strength their loop design. Consequently, few resources are deployed to promote organizational performance. In addition, as organizations have a high level of looping activities, organizational processes can be potentially slowed, which can also significantly hinder organizational performance.

Organizations can be more strategic in deploying infrastructure mechanisms of robustness. The key infrastructure mechanisms to build robustness are distributed design (modularization and network) and loop design. They need to carefully consider the marginal gains regarding building robustness before investing on infrastructural mechanisms, thus achieving a desired balance between organization robustness and organizational performance.

5.1.2 | Future research directions

We synthesize the existing understanding of robustness from different fields and provided a cohesive grounding for organizational robustness. Following our conceptualization, future studies can explore various approaches to build organizational robustness. In Table 3, we suggest some potential research questions to provide a clearer direction for future research. However, we do not claim that we provide a comprehensive list of questions, and future studies should not be limited only to our specified research questions. We categorize our research questions in more general questions based on our conceptualization and based on specific aspects of robustness such as the use of IS and superposition strategical mechanism. We briefly discuss these specific aspects in the following paragraphs.

The emerging challenges that have arisen because of more frequent and unpredictable crises such as trade tensions, COVID-19 pandemic, or the closure of the Suez channel, have called for studies to examine organizational capabilities in adapting and continuing their operations (Rai, 2020; Verma & Gustafsson, 2020). For instance, a recent study indicates that 43% out of 5,800 small businesses had closed due to COVID-19 and it was even more catastrophic for the 'Mid-Atlantic region, where 54% of firms were closed and employment was down by 47%' (Bartik et al., 2020). COVID-19 has dramatically re-shaped existing business patterns and has greatly increased public awareness on uncertainties, consequently motivating senior executives to move from defensive risk management to strategic planning (Natale et al., 2022). Coping with these emerging crises, organizations

TABLE 3 Research questions for future research studying organizational robustness

Specialization	Research questions
General	• What are the lessons from COVID-19 in building organizational robustness? • How to design metrics to measure and benchmark organizational robustness? • What level of modulization in coupling organizational resources and assets can best enable organizational robustness? • How do the counteracting effects of attractive-coupling and repulsive-coupling erode organizational robustness? • What are the relationships between staff robustness, organizational robustness and supply chain/industry robustness?
Information systems	• How can emerging IS enable organizational robustness? • What are the dark sides of IS on organizational robustness? • What is the best approach to implement IS to achieve organizational robustness?
Superposition	• What are the key organizational processes to enable superposition? • How can organizations adjust their organizational structures and resources to enable superposition? • How to balance strategical focuses on adaptation and superposition in building organizational robustness?

have to operate in highly ambiguous environments in an agile manner. A pertinent example of this shift in workplace arrangements is seen in the rapid transition of universities to online provision and use of digital pedagogies (Watermeyer et al., 2021) or the UK ventilator challenge (https://www.ventilatorchallengeuk.com/) where agile and diverse team of suppliers worked together to make more ventilators in one day than they used to make in ten months. Future studies can adopt our robustness conceptual framework as a theoretical lens to generate operational insights on how organizations can prepare and overcome unpredictable crises in a more turbulent future business ecosystem.

Adoption of information systems (IS) can promote organizational modulization design, facilitate internal communications and sharpen organizational capabilities to sense and process information, thus strengthening robustness infrastructure mechanisms (e.g., Tiwana, 2015). IS can also enhance robustness functional mechanisms through adding complexity to organizational structure, facilitating backup operations and enabling innovative resource utilization (Swanson, 1994). However, IS may bring fragility to organizations. For example, the use of IS may lead users to develop a strong maladaptive psychological dependency on using a technology artifact, thus resulting in technology related 'addictions' (D'Arcy et al., 2014). The excessive reliance on IS may then make organizations more fragile to IT-related perturbations. Also, large IS increases inflexibility and organization's unwillingness to change. Further, many IS encode processes and rules that govern organization operations. As such, even if the organization wants to change direction or focus, it might be limited to how quickly they can get the IS to change to achieve robustness (Desouza, 2006). Therefore, one promising future direction can be uncovering the complex effect of IS on organizational robustness.

Future studies can especially focus on examining the superposition strategical mechanism. The current world is fundamentally shaped by more frequent catastrophic events such as digital revolution, climate change, stakeholder expectations and geopolitical risk. It demands organizations to shift from traditional persistence and adaptation strategies to the superposition strategy (Jain et al., 2020). Superposition strategy requires enterprise curiosity, flexible strategic planning, agile organizational culture and trusted resource coupling. Future studies can substantiate the effect of the turbulence in business ecosystems on organizational performance and explore how organizations can specifically deploy resources and processes to enable superposition strategy against the turbulence. Further, pursuing pure superposition strategy may be restrained due to limited resources, organizational politics and the nature of humans in seeking stability. Therefore, future studies can also explore the optimal balance in adopting combined strategies to build organizational robustness.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

REFERENCES

Aghina, W., Ahlback, K., Smet, A. D., Lackey, G., Lurie, M., Murarka, M., & Handscomb, C. (2018). *The five trademarks of agile organizations*. McKinsey & Company. Retrieved 8 July from https://www.mckinsey.com/business-functions/organization/our-insights/the-five-trademarks-of-agile-organizations

Alippi, C. (2014). *Intelligence for embedded systems*. Springer.

Arteta, B. M., & Giachetti, R. E. (2004). A measure of agility as the complexity of the enterprise system. *Robotics and Computer-Integrated Manufacturing*, *20*(6), 495–503.

Bakonyi, Z. (2018). Why do firms centralise their strategic decision-making during crisis? A qualitative study. *Journal of Organizational Change Management*, *31*(5), 1191–1205.

Barbaschow, A. (2018). Alibaba's Hema stores changing the supermarket experience. Retrieved 2 August from https://www.zdnet.com/article/alibabas-hema-stores-changing-the-supermarket-experience/

Barkai, N., & Shilo, B.-Z. (2007). Variability and robustness in biomolecular systems. *Molecular Cell*, *28*(5), 755–760.

Bartik, A. W., Bertrand, M., Cullen, Z., Glaeser, E. L., Luca, M., & Stanton, C. (2020). The impact of COVID-19 on small business outcomes and expectations. *Proceedings of the National Academy of Sciences of the United States of America*, *117*(30), 17656–17666.

El Baz, J., & Ruel, S. (2021). Can supply chain risk management practices mitigate the disruption impacts on supply chains' resilience and robustness? Evidence from an empirical survey in a COVID-19 outbreak era. *International Journal of Production Economics*, *233*, 107972.

Bieliaieva, N., Krushelnytskyi, M., Voliak, L., Usata, N., & Sova, O. (2020). From survival to business prosperity: The financial aspect of managing an organization in a crisis. *Independent Journal of Management & Production*, *11*(9), 2275–2290.

Boyne, G. A., & Meier, K. J. (2009). Environmental turbulence, organizational stability, and public service performance. *Administration & Society*, *40*(8), 799–824.

Bradley, J. V. (1978). Robustness? *British Journal of Mathematical and Statistical Psychology*, *31*(2), 144–152.

Carlson, J. M., & Doyle, J. (2002). Complexity and robustness. *Proceedings of the National Academy of Sciences of the United States of America*, *99*(Suppl 1), 2538–2545.

Cheng, Z., Liu, F., Zhang, X.-P., & Wang, W. (2008). Robustness analysis of cellular memory in an autoactivating positive feedback system. *FEBS Letters*, *582*(27), 3776–3782.

Chick, V., & Dow, S. (2005). The meaning of open systems. *Journal of Economic Methodology*, *12*(3), 363–381.

Coetzee, C., Van Niekerk, D., & Raju, E. (2016). Disaster resilience and complex adaptive systems theory: Finding common grounds for risk reduction. *Disaster Prevention and Management*, *25*, 196–211.

Cohen, M. D., March, J. G., & Olsen, J. P. (1972). A garbage can model of organizational choice. *Administrative Science Quarterly*, *17*(1), 1–25.

D'Arcy, J., Gupta, A., Tarafdar, M., & Turel, O. (2014). Reflecting on the "dark side" of information technology use. *Communications of the Association for Information Systems*, *35*(1), 5.

Deloitte. (2020). *The new retail operating model of the future*. https://www2.deloitte.com/content/dam/Deloitte/de/Documents/consumer-business/Study_Retail%20Operating%20Model%20of%20the%20Future.pdf

De Meyer, A. C. L., Loch, C. H., & Pich, M. T. (2002). Managing project uncertainty: From variation to chaos. *Mit Sloan Management Review*, *43*(2), 60–67.

Desouza, K. (2006). *Agile information systems*. Routledge.

Dias, P. (2020). *Radio? Are you sure? Fanancial mail*. Retrieved 8 July from https://www.businesslive.co.za/redzone/news-insights/2020-09-08-radio-are-you-sure/

Ding, J., Lannes, B., Zhu, L., Gao, H., Peng, L., Song, F., & Jiang, Z. (2018). *Embracing China's new retail*. Bain & Company. Retrieved 2 August from https://www.bain.com/insights/embracing-chinas-new-retail/

Durach, C. F., Wieland, A., & Machuca, J. A. (2015). Antecedents and dimensions of supply chain robustness: A systematic literature review. *International Journal of Physical Distribution & Logistics Management*, *45*(1/2), 118–137.

Fares, M. A. (2015). The origins of mutational robustness. *Trends in Genetics*, *31*(7), 373–381.

Félix, M.-A., & Barkoulas, M. (2015). Pervasive robustness in biological systems. *Nature Reviews Genetics*, *16*(8), 483–496.

Félix, M.-A., & Wagner, A. (2008). Robustness and evolution: Concepts, insights and challenges from a developmental model system. *Heredity*, *100*(2), 132–140.

Frick, W. (2019). How to survive a recession and thrive afterward. *Harvard Business Review*, *97*(3), 98–105.

Fuchs, M., Girimonte, D., Izzo, D., & Neumaier, A. (2008). Robust and automated space system design. In A. Schuster (Ed.), *Robust intelligent systems* (pp. 251–271). Springer.

Gallagher, K. P., & Worrell, J. L. (2008). Organizing IT to promote agility. *Information Technology and Management*, *9*(1), 71–88.

Gradek, J. (2020). *How COVID-19 could impact travel for years to come*. The Conversation. Retrieved 11 August from https://theconversation.com/how-covid-19-could-impact-travel-for-years-to-come-142971

Grote, G. (2004). *Organizational measures for achieving loose coupling in high-risk systems: The importance of systematic rules management*. 2004 IEEE international conference on systems, man and cybernetics, The Hague, Netherlands.

Gursky, V. V., Surkova, S. Y., & Samsonova, M. G. (2012). Mechanisms of developmental robustness. *Biosystems*, *109*(3), 329–335.

Harney, B. (2019). Systems theory: Forgotten legacy and future prospects. In K. Cafferkey, K. Townsend, A. M. McDermott, & T. Dundon (Eds.), *Elgar introduction to theories of human resources and employment relations*. Edward Elgar Publishing.

Irfan, M., Wang, M., & Akhtar, N. (2020). Enabling supply chain agility through process integration and supply flexibility. *Asia Pacific Journal of Marketing and Logistics*, *32*(2), 519–547.

Jain, R., Nauck, F., Poppensieker, T., & White, O. (2020). *Meeting the future: Dynamic risk management for uncertain times*. McKinsey & Company. Retrieved 8 July from https://www.mckinsey.com/business-functions/risk/our-insights/meeting-the-future-dynamic-risk-management-for-uncertain-times

Kallon, E. (2020). Humanitarianresponse.info, *Nigeria: 2020 Humanitarian Response Plan*. Retrieved 30 March from https://www.humanitarianresponse.info/en/operations/nigeria/document/nigeria-2020-humanitarian-response-plan#:~:text=Together%2C%20in%202020%2C%20we%20will,all%20levels%20of%20humanitarian%20action

Kantur, D., & Iseri-Say, A. (2012). Organizational resilience: A conceptual integrative framework. *Journal of Management and Organization*, *18*(6), 762–773.

Kast, F. E., & Rosenzweig, J. E. (1972). General systems theory: Applications for organization and management. *Academy of Management Journal*, *15*(4), 447–465.

Kitano, H. (2004). Biological robustness. *Nature Reviews Genetics*, *5*(11), 826–837.

Kitano, H. (2007). Towards a theory of biological robustness. *Molecular Systems Biology*, *3*(1), 1–7.

Krakauer, D. C. (2006). Robustness in biological systems: A provisional taxonomy. In T. S. Deisboeck & J. Y. Kresh (Eds.), *Complex systems science in biomedicine* (pp. 183–205). Springer.

Lamberg, J. A., Tikkanen, H., Nokelainen, T., & Suur-Inkeroinen, H. (2009). Competitive dynamics, strategic consistency, and organizational survival. *Strategic Management Journal*, *30*(1), 45–60.

Leana, C. R., & Barry, B. (2000). Stability and change as simultaneous experiences in organizational life. *Academy of Management Review*, *25*(4), 753–759.

Lengnick-Hall, C. A., & Beck, T. E. (2005). Adaptive fit versus robust transformation: How organizations respond to environmental change. *Journal of Management*, *31*(5), 738–757.

Levin, S. A., & Lubchenco, J. (2008). Resilience, robustness, and marine ecosystem-based management. *Bioscience*, *58*(1), 27–32.

Li, F. (2019). Why have all Western Internet firms (WIFs) failed in China? A phenomenon-based study. *Academy of Management Discoveries*, *5*(1), 13–37.

Li, Y., Kim, Y. M., Mintarno, E., Gardner, D. S., & Mitra, S. (2009). Overcoming early-life failure and aging for robust systems. *IEEE Design & Test of Computers*, *26*(6), 28–39.

Lu, X., & White, H. (2014). Robustness checks and robustness tests in applied economics. *Journal of Econometrics*, *178*, 194–206.

Mahdiani, H., & Ungar, M. (2021). The dark side of resilience. *Adversity and Resilience Science*, *2*, 1–9.

March, J. G., & Simon, H. A. (1993). Organizations revisited. *Industrial and Corporate Change*, *2*(3), 299–316.

Marion, R., & Bacon, J. (1999). Organizational extinction and complex systems. *Emergence*, *1*(4), 71–96.

Masel, J., & Siegal, M. L. (2009). Robustness: Mechanisms and consequences. *Trends in Genetics*, *25*(9), 395–403.

Masel, J., & Trotter, M. V. (2010). Robustness and evolvability. *Trends in Genetics*, *26*(9), 406–414.

Maurer, F., & Schumacher, J. (2018). *Organizational robustness and resilience as catalyst to boost innovation in smart service factories of the future*. 2018 IEEE international conference on engineering, technology and innovation (ICE/ITMC), Stuttgart, Germany.

Miroudot, S. (2020). Resilience versus robustness in global value chains: Some policy implications. In R Baldwin & S. Evenett (Eds.), *COVID-19 and Trade Policy: Why Turning Inward won't Work* (pp. 117-130). CEPR Press.

Nan, N., & Tanriverdi, H. (2017, Sep). Unifying the role of IT in hyperturbulence and competitive advantage via a multilevel perspective of IS strategy. *MIS Quarterly*, *41*(3), 937–958.

Natale, A., Poppensieker, T., & Thun, M. (2022). *From risk management to strategic resilience*. McKinsey & Company. Retrieved 25 May from https://www.mckinsey.com/business-functions/risk-and-resilience/our-insights/from-risk-management-to-strategic-resilience

Neumayer, E., & Plümper, T. (2017). *Robustness tests for quantitative research*. Cambridge University Press.

Nijhout, H. F. (2002). The nature of robustness in development. *BioEssays*, *24*(6), 553–563.

Nunes, A. (2020). *How Covid-19 will change air travel as we know it*. BBC. Retrieved 11 August from https://www.bbc.com/future/article/20200709-how-covid-19-will-change-air-travel-as-we-know-it

Okoh, P., & Haugen, S. (2015). Improving the robustness and resilience properties of maintenance. *Process Safety and Environmental Protection*, *94*, 212–226.

Pajunen, K. (2006). Stakeholder influences in organizational survival. *Journal of Management Studies*, *43*(6), 1261–1288.

Pancs, R. (2017). Tight and loose coupling in organizations. *The BE Journal of Theoretical Economics*, *17*(1).

Paul, G., Sreenivasan, S., Havlin, S., & Stanley, H. E. (2006). Optimization of network robustness to random breakdowns. *Physica A: Statistical Mechanics and its Applications*, *370*(2), 854–862.

Rai, A. (2020). Comments: The COVID-19 pandemic: Building resilience with IS research, *MIS Quarterly*, *44*(2), pp. iii–vii.

Rai, S. S., Rai, S., & Singh, N. K. (2021). Organizational resilience and social-economic sustainability: COVID-19 perspective. *Environment, Development and Sustainability*, *23*, 12006–12023.

Ruiz-Martin, C., López-Paredes, A., & Wainer, G. (2018). What we know and do not know about organizational resilience. *International Journal of Production Management and Engineering*, *6*(1), 11–28.

Sanchez, R., & Mahoney, J. T. (1996). Modularity, flexibility, and knowledge management in product and organization design. *Strategic Management Journal*, *17*(S2), 63–76.

Selznick, P. (1948). Foundations of the theory of organization. *American Sociological Review*, *13*(1), 25–35.

Sheppard, J. M., & Young, W. B. (2006). Agility literature review: Classifications, training and testing. *Journal of Sports Sciences*, *24*(9), 919–932.

Sherehiy, B., Karwowski, W., & Layer, J. K. (2007). A review of enterprise agility: Concepts, frameworks, and attributes. *International Journal of Industrial Ergonomics*, *37*(5), 445–460.

Skyttner, L. (1996). *General systems theory: An introduction*. Macmillan International Higher Education.

Srinivasan, A. (1985). Alternative measures of system effectiveness: Associations and implications. *MIS Quarterly*, *9*(3), 243–253.

Stelling, J., Sauer, U., Szallasi, Z., Doyle, III, F. J., & Doyle, J. (2004). Robustness of cellular functions. *Cell*, *118*(6), 675–685.

Suarez, F. F., & Montes, J. S. (2020). Building organizational resilience. *Harvard Business Review*, *98*(6), 47–52.

Sussman, G. J. (2007). *Building robust systems an essay*. Massachusetts Institute of Technology

Swanson, E. B. (1994). Information systems innovation among organizations. *Management Science*, *40*(9), 1069–1092.

Tang, C. S. (2006). Robust strategies for mitigating supply chain disruptions. *International Journal of Logistics: Research and Applications*, *9*(1), 33–45.

Tanizawa, T., Paul, G., Cohen, R., Havlin, S., & Stanley, H. E. (2005). Optimization of network robustness to waves of targeted and random attacks. *Physical Review E*, *71*(4), 047101.

Tiwana, A. (2015). Evolutionary competition in platform ecosystems. *Information Systems Research*, *26*(2), 266–281.

Vakilinejad, M., Grolet, A., & Thomas, O. (2020). A comparison of robustness and performance of linear and nonlinear Lanchester dampers. *Nonlinear Dynamics*, *200*, 269–287.

Verma, S., & Gustafsson, A. (2020). Investigating the emerging COVID-19 research trends in the field of business and management: A bibliometric analysis approach. *Journal of Business Research*, *118*, 253–261.

Vogus, T. J., & Sutcliffe, K. M. (2007). *Organizational resilience: Towards a theory and research agenda*. 2007 IEEE international conference on systems, man and cybernetics, Montreal, Quebec, Canada.

Wagner, A. (2005a). Distributed robustness versus redundancy as causes of mutational robustness. *BioEssays*, *27*(2), 176–188.

Wagner, A. (2005b). Robustness, evolvability, and neutrality. *FEBS Letters*, *579*(8), 1772–1778.

Wagner, A. (2013). *Robustness and evolvability in living systems* (24). Princeton University Press

Watermeyer, R., Crick, T., Knight, C., & Goodall, J. (2021). COVID-19 and digital disruption in UK universities: Afflictions and affordances of emergency online migration. *Higher Education*, *81*, 623–641.

Woodward, J. (2006). Some varieties of robustness. *Journal of Economic Methodology*, *13*(2), 219–240.

Xu, H., & Mannor, S. (2012). Robustness and generalization. *Machine Learning*, *86*(3), 391–423.

Zott, C., Amit, R., & Massa, L. (2011). The business model: Recent developments and future research. *Journal of Management*, *37*(4), 1019–1042.

How to cite this article: Xie, Y., Desouza, K. C., & Jabbari, M. (2022). On organizational robustness: A conceptual framework. *Journal of Contingencies and Crisis Management*, 1–16. https://doi.org/10.1111/1468-5973.12423

APPENDIX

See Table A1.

TABLE A1 A summary of related concepts on robustness and where they appear in our framework

Terms	Description & supporting references	M	C
Buffering	Systems have mechanisms to buffer perturbations; thus, system operations are less affected by perturbations (Kitano, 2004)	F	SS
Neutral space	Neutral space is a collection of equivalent solutions to the same biological problem (Wagner, 2013)	F	R&D
Purging	Purging amplifies the effects of perturbations, to ensure the purity of a population (Krakauer, 2006)	I	LD
Spatial compartmentalization	Spatial compartmentalization means a system design that is composed of a finite number of macroscopic subsystems called compartments, each of which is well mixed (Krakauer, 2006)	I	DD
Distributed processing	Distributed processing describes those cases in which an integrated set of functions are carried out by multiple, semiautonomous units (Krakauer, 2006)	I	DD& LD
Extended phenotypes	Extended phenotype refers to a means of emancipating the gene from the discrete vehicle (often taken to be the individual organism) (Krakauer, 2006)	F	D
Diversity/heterogeneity	Diversity and heterogeneity capture the adaptive capacity of a system, its ability to alter its composition in a changing environment (Levin & Lubchenco, 2008)	F	D
Canalization	Canalization is the extent to which phenotypes remain constant in the face of specified environmental and/or genetic perturbations (Masel & Trotter, 2010)	S	P
Developmental control circuits	Developmental control circuits are related to both operations of individual modules and a rich network of inter-module communications (Stelling et al., 2004)	I	DD
Exploratory behavior	Exploratory behavior suggests that systems can produce the desired outcome in a generate-and-test mechanism (Wagner, 2013).	I	LD
Compartments and localization	Systems are constructed in separate modules (Wagner, 2013).	F	LC
Defense, repair and regeneration	Systems have a dynamically reconfigurable structure made out of potentially universal interchangeable and reproducible parts: if a part is damaged, nearby cells can retarget to fill in the gap and take on the function of the damaged part (Wagner, 2013)	F	D&R
Composition	Large systems are composed of many smaller components, each of which contributes to the function of the whole either by directly providing a part of that function or by cooperating with other components by being interconnected in some pattern specified by the system architect to establish a required function (Wagner, 2013)	I	DD
Distributed Robustness	In distributed robustness, many parts of a system contribute to system function, but all of these parts have different roles. When one part fails or is changed through mutations, the system can compensate for this failure, but not because a 'back-up' redundant part takes over the failed part's role (Wagner, 2005a)	F	D

Note: Superposition is less examined in previous robustness literature.

Abbreviations: [C], concept; [D], degeneracy; [DD], distributed design; [F], functional; [I], infrastructure; [LC], loose coupling; [LD], loop design; [M], mechanisms; [P], persistence; [R], redundancy; [S], strategic; [SS], structural stability.