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RESEARCH ARTICLE

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Complex system governance: Concept, utility, and challenges

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Abstract

Complex system governance (CSG) is an emerging field focused on design, execution, and evolution of (meta)system functions that produce control, communications, coordination, and integration of a complex system. Ultimately, CSG explains system performance, prospects for continued system viability (existence), and future system sustainability. This paper explores three primary perspectives for CSG. First, following a brief introduction, a CSG overview is provided. Three underlying fields (systems theory, management cybernetics, and system governance), the derived model for CSG, and essential distinctions of CSG are developed. Second, the role and nature of *CSG pathologies* as aberrations from normal or healthy system conditions are developed. Pathologies are grounded in systems theory, and requisite variety is used to explain pathologies in complex system design, execution, or development impacting system performance. Third, challenges for balanced evolution of the CSG field are suggested. The paper concludes with suggestion for simultaneous development of science, engineering, and practice for CSG.

KEYWORDS

complex system governance, management cybernetics, systems theory, complexity, requisite variety

1 | INTRODUCTION

Dealing with increasingly complex systems and their constituent problems continues to be problematic. Irrespective of sector, nation, or political persuasion, society continues to face what appears to be an intractable problem domain for systems essential to societal well-being (e.g., health, food, transportation, energy, and security). The conditions and circumstances that mark this might be captured by several dominant characteristics. Following previous articulations of this domain (Jaradat & Keating, 2016; Keating, Katina, & Bradley, 2015; Keating, 2014; Keating & Katina, 2011; Keating, Katina, Jaradat, Bradley, & Gheorghe, 2017, Keating, Bradley, Katina, & Jaradat, 2017), Table 1 summarizes these characteristics.

Complex system governance (CSG) is developing as a systems-based approach to this somewhat bleak appearing future for systems practitioners. Systems-based approaches have been successful in addressing different aspects of complex systems. As Jackson (2019) has clearly demonstrated, there are effective systems-based approaches to address a myriad of complex system issues, including technical, process, structure, organizational, and coercion (power). However, there is no systems-based approach that offers universal applicability, easy deployment, or guaranteed successful results. CSG is no exception, as it simply cannot and will not be a panacea that will solve all complex system ills. However, CSG is evolving with several important distinctions in the sea of systems-based approaches, including the following:

TABLE 1 Domain of complex systems

Characteristics	Nature
Complexity	• Exponentially increasing amount, availability, veracity, and accessibility of information coupled with the increasingly large number of richly interconnected elements. • Incomplete, fallible, and dynamically evolving system knowledge. • High levels of uncertainty beyond current capabilities to structure, order, and reasonably couple decisions, actions, and consequences. • Emergence of behavior, performance, and consequences that cannot be known or predicted in advance of their occurrence.
Contextual dominance	• Unique circumstances, factors, patterns, and conditions within which a system is embedded—influencing the system, influenced by the system, and constraining/enabling to system performance. • Impacting decisions, actions, and interpretations made with respect to the system. • Multiple stakeholders with different worldviews (convergent/divergent), objectives, and influence patterns.
Ambiguity	• Instabilities in understanding system structure, behavior, or performance. • Potential lack of clarity in system identity/purpose, boundary conditions, delineation of system constituents, or understanding of a system within its context.
Holistic nature	• In addition to technical/technology aspects of a system, consideration for the entire influencing spectrum of human/social, organizational/managerial, policy, political, and information aspects central to a more complete (holistic) view of a system. • Behavior, properties, and performance as a function of interactions in the system—not reducible or revealed by understanding individual constituents.

1. Deep and explicit grounding in the underlying systems theory upon which it has been developed.
2. Qualification and acceptance that the level of "systems thinking capacity" held by individuals/organizations are critical to proper deployment of CSG.
3. Permits tailoring of the approach and tempering of expectations based on the unique context, system in focus, implementing entity, and support infrastructure for deployment.
4. Holistic system examination across the spectrum of technical, organizational, managerial, human, social, policy, and political dimensions of complex systems and problems.
5. Emphasis on discovery, classification, and engagement of "deep system issues" (pathologies) that limit system performance.
6. Purposeful system development that prioritizes and simultaneously targets individual, system, organizational, and support infrastructure for improvement.
7. Focus on functions already being performed by all systems and the pathologies being experienced in the design, execution, or development of those functions.

To present CSG, this paper is organized in four primary sections. First, the conceptual foundations for CSG are established. These foundations include management cybernetics, systems theory, and system governance. Second, a CSG reference model is presented. This model serves to establish the metasystem functions that must be performed by any complex system. Third, the nature of pathologies (aberrations from normal/healthy system conditions) that impact system performance is explored. A particular relationship of pathologies to requisite variety is suggested. Fourth, we examine some CSG development challenges as the field evolves. The paper closes with developmental directions and utility for the CSG field.

2 | CONCEPTUAL FOUNDATIONS OF CSG

> *CSG lies at the intersection of three fields, including* systems theory, management cybernetics, *and* governance *(Figure 1). In broad terms, systems theory provides the set of propositions (laws, principles, and concepts) that serve to explain the behavior and performance of all complex systems(Whitney et al., 2015). For CSG, systems theory is relied upon to guide integration and coordination necessary to maintain system viability and support future system sustainability. Management cybernetics has been described as the science of effective system organization (Beer, 1979). This complements systems theory by identifying the essential functions for control and communications, which must be performed by all complex systems to remain viable (continue to exist). Governance is broadly concerned with providing direction,*

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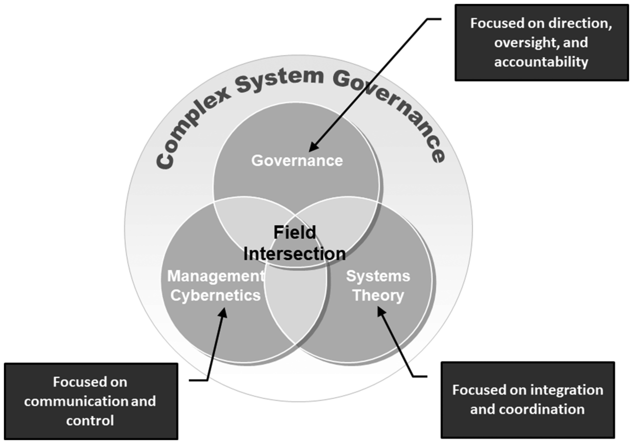

FIGURE 1 CSG stemming from the intersection of three associated fields

oversight, and accountability for systems (Calida, Jaradat, Abutabenjeh, & Keating, 2016; Calida & Keating, 2014). Governance supports a more global and evolutionary perspective sought by CSG. Each of these fields is discussed in more detail for their unique contributions to the conceptual foundations for CSG.

2.1 | Contributions of systems theory to CSG

Systems theory cannot be captured by a common definition that is universally accepted by scholars and practitioners. From the earliest beginnings of mankind, the struggle with increasingly complex and troublesome systems has endured. Even the central philosophical tenet of systems, holism, *can be traced back to the writings of Aristotle, who suggested that "the whole is more than the sum of its parts." The more recent depictions of systems theory are frequently attributed to Anatol Rapoport, Norbert Weiner, Karl Ludwig von Bertalanffy, and Ross Ashby (Klir, 1972; Laszlo & Krippner, 1998), having emerged in the 1940s in response to the inabilities of "reductionist" approaches to adequately account for behavior of more complex systems.* Reductionism *depicts a particular intellectual stance rooted in the assertions that knowledge is objective and understandable from the behavior of the parts, relationships that can be precisely and repeatably defined, and a close coupling to the tenets of the scientific method (Hammond, 2002; von Bertalanffy, 1968). In contrast,* holism, *emerged as the driving foundation of systems theory suggesting that knowledge is subjective and observer dependent, understanding of behavior is found in the relationships among parts, and that behavior in (complex) systems is not necessarily capable of being completely understood or repeatable (von Bertalanffy, 1972). The Aristotelian dictum of the whole being greater than the sun of its parts continued to be captured in such distinct fields as biology, psychology, sociology, and physics (Laszlo, 1996; von Bertalanffy, 1968). Thus, systems theory sets in motion a different level of thinking, based in understanding systems behavior/performance not being explained from traditional reductionist thinking.*

The genesis of systems theory is thus found in pursuit of the goal to find a common platform of understanding the behavior/performance for all systems and thus provide a basis for a common frame of reference for universally applicable models, principles, and laws that help explain "system" phenomena (Heylighen & Joslyn, 1992; Laszlo, 1996; Laszlo & Krippner, 1998; von Bertalanffy, 1950). Thus, systems theory has always been targeted to discovery and understanding of "universally" applicable propositions that govern the behavior, function, and performance of all systems, be they natural or manmade.

Systems theory provides a strong theoretical grounding for CSG. One depiction of systems theory identifies a set of axioms and associated propositions (principles) that seek to describe the behavior of systems, either natural or manmade (Adams, Hester, Bradley, Meyers, & Keating, 2014; Skyttner, 2005; Whitney, Bradley, Baugh, & Chesterman, 2015). A full development of systems theory and constituent laws, principles, and concepts is beyond the scope of this paper. However, following the development of Whitney et al. (2015) and adapted from the earlier work of Keating (2014), the nature of systems theory in relationship to CSG is captured in the set of seven systems axioms. These axioms serve to organize systems theory concepts, laws, and principles. For the corresponding detailed *constituent principles, laws, and concepts, readers are referred to Whitney et al. (2015). Axioms include the following:*

1. *Centrality Axiom*—Central to all systems are emergence and hierarchy and communication and control. This implies that there should be consideration for flexibility in design for uncertainty, minimal constraint on constituents within a system, and the flow of information by design.
2. *Contextual Axiom*—Meaning in systems is derived from the circumstances and factors that surround them. This implies the necessity to account for influence of system context and the holistic consideration of the range of socio-technical-political aspects of the domain within which a system is embedded.
3. *Goal Axiom*—Systems achieve specific goals through purposeful behavior using pathways and means. This implies that there must be clarity in system purpose as well as the pathways, strategies, and resources necessary to achieve those purposes.
4. *Operational Axiom*—Systems must be addressed in situ, where the system is exhibiting purposeful behavior. This implies that system performance must be monitored and balanced to alleviate variability and provide for integration of constituent elements.
5. *Viability Axiom*—Key parameters in a system must be controlled to ensure continued existence. This implies that external perturbations and internal flux must be managed to maintain viability consistent with the continuing identity of the system.
6. *Design Axiom*—Purposeful imbalance of resources and relationships. This implies that there must be responsive system reconfiguration through trade-offs consistent with the identity of the system and, also, that there is a rebalancing of constituent autonomy with system level integration considerations.
7. *Information Axiom*—Systems create, process, transfer, and modify information. This implies that information necessary to support consistency in decision, action, and interpretation on behalf of the system must be by purposeful design. Also, sufficient redundancy in information must be available to ensure continuity of the system.

In effect, systems theory provides a theoretical grounding for CSG such that integration and coordination necessary to ensure viability of a system can be maintained.

2.2 | Contributions of the governance field to CSG

Governance provides a critical set of grounding insights for CSG. There is an abundance of perspectives on governance stemming from the literature. However, tailoring this work for CSG, the following developments based in the work of Calida (2013) and subsequently Calida and Keating (2014) elucidate the multitude of perspectives that permeates the governance field. We offer three different perspectives that are influential in providing a governance perspective for CSG:

1. *Process-centric*—Collective decision-making processes that are based in formal, consensus seeking, and deliberative execution. The aim is to provide effective processes that enable the act(s) of governance to be performed.
2. *Structure-centric*—Emphasis on the formulation and execution of structures that preserve order/continuity and steer the system in desired directions. The aim is to install sufficient structure that provides and maintains trajectory of a system towards desired ends.
3. *Policy-centric*—Emphasis on the formulation of policies that act to inculcate the principles, norms, rules, and behaviours that produce sufficient regularity in performance. The aim is to invoke policies with sufficient capacity to direct/control aspects essential to achieve/maintain system performance.

In addition, it is important in the development of CSG to make a distinction between "governance" and "management" perspectives. Based on the work of Keating (2014), Table 2 identifies the management–governance critical distinctions.

A critical distinction of "governance" for CSG is the view of governance from a cybernetic perspective. From this perspective, governance is concerned with the design for "regulatory capacity" to provide appropriate controls capable of maintaining system balance. Thus, governance acts in the cybernetic sense of "steering" a system by invoking sufficient controls (regulatory capacity) to permit continued viability. Closely coupled is the systems principle of "minimal critical specification" (Cherns, 1976, 1987), which suggests that only the bare essential controls (regulation) should be invoked in a system.

TABLE 2 Differences between management and governance

Characteristic	Management	Governance	Implications for CSG
Emphasis	Outputs (tangible, objective, short term)	Outcomes (less tangible, subjective, long term)	Determination of governance "goodness" is not simple or straightforward.
Central questions of concern	What? And How?	Why?	Governance exists at a higher logical level of performance—emphasizing purpose.
Focus	Near term demonstrable results, efficiency, near-term viability	Long term future focused trajectory, effectiveness, long-term sustainability	The focus of governance is expansive, entertaining long view questions of strategic rather than operational significance.
Determinants of success	Easily defined, measured, and tracked	Difficult to define and measure	Although governance measures might be developed, they necessarily lack precision.
Time horizon	Short term	Long term	The nature of governance invokes a much longer time horizon.
Action-response proximity	Close separation between action and system response	Tenuous separation and relationship between action and response	Instabilities in understanding, knowledge, and magnitude create separation between action-response certainties.
Uncertainty	Local uncertainty concerns	Global uncertainty concerns	Governance has a more global level of uncertainty and its resolution.
Stability and emergence	Local proximity stability, local level emergence	Global proximity stability, global level emergence	Global focus of governance questions assumptions of long range or time stabilities.

Anything beyond this is wasteful of resources, unnecessarily restricts autonomy, and degrades system performance.

On the basis of this spectrum of governance perspectives suggested by Calida (2013), we can draw several important themes, which serve to inform a systems perspective of governance from the literature. For CSG, we suggest that governance supports continuous achievement of the following: (a) *direction* (sustaining a coherent identity and vision that supports consistent decision, action, interpretation, and strategic priorities), (b) *oversight design* (providing control and integration of the system and corresponding initiatives), and (c) *accountability* (ensuring efficient resource utilization, performance monitoring, and exploration of aberrant conditions). Second, taking the "cybernetic" perspective of governance as "control through regulatory capacity" shifts governance to the systems domain. This is opposed to more restrictive viewpoints of governance as "government" or strictly "law making" or "policy" perspectives.

2.3 | Contributions of management cybernetics to CSG

Management cybernetics has been described by its founder as the science of effective organization (Beer, 1979; Clemson, 1984). This field provides a critical contribution to the emerging CSG paradigm. Beer's (1979, 1981, 1985) work in management cybernetics introduced the concept of the "metasystem" as a set of functions and corresponding communication channels that must be performed by any viable (continuing to exist) system. The metasystem acts to provide the communication and control necessary to ensure that a system continues to produce the products or services that allow it to meet performance levels necessary to continue to operate (exist). Failure of any of the metasystem functions would jeopardize the overall system. Beer's formulation of the metasystem provides five essential functions for continued system viability. These functions are summarized below:

- *Coordination function (S2 System 2)* provides for system stability by preventing unnecessary oscillations within the set of systems being integrated by the metasystem, promotes operational system performance by ensuring sufficient integration within the system, and acts to harmonize the system such that the system acts in unison. Without the co-ordination function, the system would be subject to unnecessary turbulence, decreasing both efficiency as well as effectiveness.
- *Operational Control function (S3 System 3)* maintains operational performance on a day-to-day basis and provides for the execution of policy, distribution of resources, and accountability within the system. Governance must provide a focus that allows near-term achievement to be balanced with longer term system shifts necessary to maintain viability.
- *Audit and Accountability (S3* System 3 Star)* provides monitoring of the system to identify aberrations and

invoke necessary explorations to determine the source of the aberrant behavior or unexpected variance. Essential to understand the nature of variance and focus actions to resolve variance.

- *Development function (S4 System 4)* scans and captures information from the environment and assesses that information for strategic implications and system level impacts and models the future and strategic evolution of the system. Critical to governance because the early indicators of strategic system threat are identified and interpreted.
- *Policy function (S5 System 5)* provides for the strategic decisions and direction that maintain the identity of the system and monitors and maintains a balance between the inherent tension between the long-term external focus and the short-term internal focus of the system. For governance, this function is essential to ensure that the system maintains itself on a trajectory consistent with the desirable future.

In the development of CSG, management cybernetics brings three important contributions. First, the extensive grounding in cybernetics provides a strong theoretical foundation for CSG. Cybernetics, at a most basic level, is concerned with communication and control—in effect deriving from the Greek notion of "steering." This is consistent with the function of governance as providing the direction and monitoring the movement of the system along that trajectory. With respect to control, taking a cybernetic viewpoint allows inclusion of the more expansive perspective of control consistent with providing the highest degree of autonomy within a system, while preserving system performance. Second, the work of Beer (1979, 1985) provides a model (Viable System Model [VSM]) that includes functions (metasystem) consistent with achievement of governance for a system. This reference model, identified by the functions above, provides CSG with an established frame of reference upon which to build. The management cybernetics foundation provides a strong systemic/cybernetic set of underpinnings, is logically consistent with CSG articulation from a systems perspective, and grounds CSG in a field that has withstood several decades of scrutiny. Third, the essence of the VSM in relationship to Ashby's Law of Requisite Variety (Ashby, 1958) provides an important opportunity to enhance the basis of CSG. Specifically, extension and amplification of requisite variety for CSG are central to the development of the field. Since its development in the 1970s, management cybernetics has been successfully applied for over four decades. It has maintained a sustainable footing, even with the arrival and departure of a multitude of other approaches that have ceased to exist in any formidable fashion.

However, we have offered several amplifications of the VSM for CSG development. First, there is a focus on the metasystem for system development. This does not minimize the System 1 (productive function) importance accorded by the VSM but only suggests metasystem development as primary for CSG. Second, the S2 coordination function of the VSM has been elaborated to encompass "information and communications" in CSG. This extends the nature and role of communication/information as development since the original instantiation of the VSM was established. Exploding information and the increasing reliance of systems on information flows suggested a more central role for communications. In addition, the elaborated model included three additional communication channels from the original VSM formulation. Third, although the VSM has always been grounded in the underlying foundations of cybernetics and systems theory, care has been taken to make the grounding more explicit for CSG (see Adams et al., 2014; Whitney et al., 2015). Fourth, an additional (sub)function has been established to more explicitly recognize the need for a strategic developmental emphasis on system "learning and transformation." Arguably, this has always been included in the VSM System 4 function but was selected to be specifically emphasized for CSG. Fifth, an additional function has been included as "system context" to recognize the importance of articulating, understanding, and developing the system context within which a complex system is embedded. Sixth, although Beer (1979, 1985) recognizes the general existence of pathologies in the execution of VSM functions (e.g., inappropriate balance between present and future system focus), CSG has significantly expanded pathologies in their specific relationship to system functions and grounding as violations of underlying systems theoretic propositions. Although these elaborations of the VSM can certainly be "questioned," they serve the present purposes of the emerging CSG field in theoretical grounding as well as practice implications.

3 | CSG

There is a growing body of knowledge related to CSG (Keating, Katina, & Bradley, 2014; Keating & Bradley, 2015, Keating, Bradley, & Katina, 2016). The essence of CSG lies in the current state of the definition captured as the "Design, execution, and evolution of the [nine] metasystem functions necessary to provide control, communication, coordination, and integration of a complex system." (Keating et al., 2015). There are several points of emphasis for this depiction of CSG. First, "design accentuates the purposeful and proactive engagement in creation of the governance system." Although this seems as though it should be a taken for granted proposition, we suggest that truly purposeful, holistic, and comprehensive design of governing systems represents the exceptional case rather than the norm. Although we might argue the merits of this conclusion, at this point, it suffices to say that based on the current level of societal systems performance of our complex systems suggests otherwise. Based on issues propagating all manner and form of our "manmade" complex systems, the anecdotal evidence suggests that our systems are not sufficiently serving the needs or expectations intended to enhance societal well-being. In addition, irrespective of purposeful/purposeless design, *execution* embodies the notion that a design without effective deployment offers little more than good intention. Execution is where a design meets the harsh realities of the "real world," which is fraught with complexity and emergent conditions that are sure to test our most thoughtful system designs. We should note that the need to adjust a system during execution is not indicative of poor design, but rather recognition that all designs are flawed. They must be flawed because they are abstractions of real-world complexity that can be neither totally captured nor completely understood. The third leg of CSG, *evolution*, recognizes that systems, as well as their environments, are in constant flux. Therefore, governance must also be able to flex (evolve) in response to internal and external changes impacting the system over time. Evolution by its very nature suggests that the developmental emphasis is on long-term sustainability, irrespective of the need to operate a system in real time. In effect, governance must be capable of absorbing, processing, and responding to external turbulence and internal system flux. This can ensure the system remains viable (continues to exist) in both the short-term operational sense that delineates current system existence and the long-term evolutionary sense that positions the system for the future.

The second aspect of the CSG definition lies in the articulation of the metasystem as the set of nine interrelated functions that produce governance for a complex system. We have provided Figure 2 to succinctly identify the nine interrelated functions and associated communication channels that serve to capture CSG (Keating et al., 2014, Keating & Bradley, 2015, Keating et al., 2016). These functions find their basis in and offer an extension of Beer's metasystem concept in the VSM (1979, 1981, 1985) as well as three additional communication channels following the work of Keating and Morin (2001).

The metasystem for CSG is the set of nine interrelated functions that act to provide governance for a complex system. These functions include the following:

- *Metasystem Five (M5)—Policy and Identity*—focused on overall steering and trajectory for the system and maintains identity and balance between current and future focus.
- *Metasystem Five Star (M5*)—System Context*—focused on the specific context within which the metasystem is embedded. Context is the set of circumstances, factors, conditions, or patterns that enable or constrain execution of the system.
- *Metasystem Five Prime (M5′)—Strategic System Monitoring*—focused on oversight of the system performance indicators at a strategic level, identifying performance that exceeds or fails to meet established expectations.

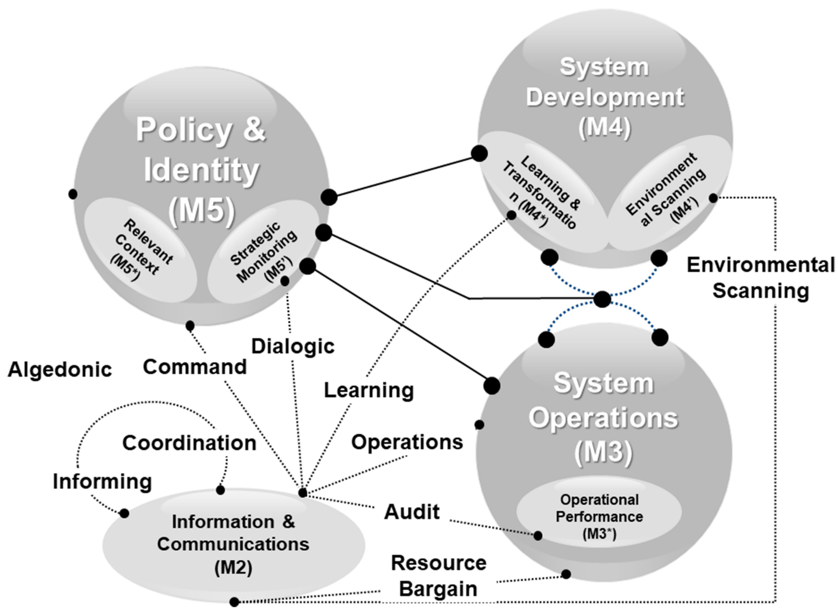

FIGURE 2 CSG Model with functions and corresponding communication channels [Colour figure can be viewed at wileyonlinelibrary.com]

- *Metasystem Four (M4)—System Development*—maintains the models of the current and future system, concentrating on the long-range development of the system to ensure future viability.
- *Metasystem Four Star (M4*)—Learning and Transformation*—focused on facilitation of learning based on correction of design errors in the metasystem functions and planning for transformation of the metasystem.
- *Metasystem Four Prime (M4′)—Environmental Scanning*—designs, deploys, and monitors sensing of the environment for trends, patterns, or events with implications for both present and future system viability.
- *Metasystem Three (M3)—System Operations*—focused on the day to day execution of the metasystem to ensure that the overall system maintains established performance levels.
- *Metasystem Three Star (M3*)—Operational Performance*—monitors system performance to identify and assess aberrant conditions, exceeded thresholds, or anomalies.
- *Metasystem Two (M2)—Information and Communications*—designs, establishes, and maintains the flow of information and consistent interpretation of exchanges (communication channels) necessary to execute metasystem functions.

A third primary aspect of the metasystem construct is found in the communication channels that provide for the flow of information between system entities as they perform functions. These channels support the flow of information for decision and action as well as produce consistency in interpretation for exchanges within the metasystem and between the metasystem and external entities. The 10 communication channels are adapted from the work of Beer (1979, 1984, 1985) and extensions of Keating and Morin (2001). Table 3 below (adapted from earlier works of Keating and Bradley (2015) provides a concise listing of the communication channels, their primary metasystem function responsibility, and the particular role they play in metasystem execution.

The final part of the definition of CSG is focused on the elements of control, communication, coordination, and integration as determinants of system performance. These terms and their basis emanate from management cybernetics (communication and control) and systems theory (coordination and integration). Here are the extended perspectives for each of these elements as they relate to inform CSG:

- *Control* (constraints that provide regulation necessary to ensure consistent performance and future system trajectory). In our formulation of control, we look to a more informed system view for guidance. This view suggests that control is not a pejorative term, to be scorned as a form of domination over a particular venue, activity, or entity. On the contrary, from our systems view, we suggest that control is essential to ensure that the system stays on a trajectory that will provide future viability in response to changing conditions and circumstances. This is achieved by providing the greatest degree of autonomy (freedom and independence of decision, action, and interpretation) possible while still maintaining the system at desired levels of performance and behavior. In effect, this suggests that overconstraint of a system waste resources (constraint is not free), limits system initiative/creativity/innovation, and unnecessarily diverts important metasystem resources to lower levels of the system (inefficiency).
- *Communication* (flow and processing of information necessary to support consistent decision, action, and interpretation across the system). Communication is essential to governance and operation of the metasystem. Communications include not only the exchange of information but also the interpretative schemas that permeate the system. These interpretative schemas are necessary to provide coherence in making, understanding, and interpreting the myriad of exchanges in a system. Communications may range from formal to informal, explicit to tacit, and patterned to emergent. There is not an optimal configuration for communication in a system, and the arrangements are certainly subject to shifts over time and emergent conditions. However, from a CSG perspective, communications are something that would be better off not left to chance self-organization. Instead, purposeful design and evolution of communications within a system is more likely to produce and support desirable results.
- *Coordination* (providing for effective interaction among different entities within the system, and external to the system, to prevent unnecessary oscillations). Certainly, coordination is an essential aspect to ensure that a system provides sufficient interaction among different elements to maintain consistency. Quite possibly the most important aspect of coordination is the damping of unnecessary fluctuations as the system operates. In effect, this implies that there must be sufficient standardization to provide routine interface as well as a sufficiently robust design to absorb emergent conditions that could not have been known in advance. Although original work in management cybernetics focused on coordination as an internal function, we should also consider the necessity for coordination external to the system.

TABLE 3 Communication channels in CSG

Communications channel and responsibility	CSG Metasystem role
Command (Metasystem 5)	• Provides nonnegotiable direction to the metasystem and governed systems • Primarily flows from the Metasystem 5 and disseminated throughout the system
Resource bargain/Accountability (Metasystem 3)	• Determines and allocates the resources (manpower, material, money, methods, time, information, and support) to governed systems • Defines performance levels (productivity), responsibilities, and accountability for governed systems • Primarily an interface between Metasystem 3 to the governed systems
Operations (Metasystem 3)	• Provides for the routine interface concerned with near term operational focus • Concentrated on providing direction for system production of value (products, services, processes, and information) consumed external to the system • Primarily an interface between Metasystem 3 and governed systems
Coordination (Metasystem 2)	• Provides for metasystem and governed systems balance and stability • Ensures design and achievement (through execution) of design: (a) sharing of information within the system necessary to coordinate activities and (2) ensuring of decisions and actions necessary to prevent disturbances are that shared within the Metasystem and governed systems • Primarily a channel designed and executed by Metasystem 2
Audit (Metasystem 3^*)	• Provides routine and sporadic feedback concerning operational performance • Investigation and reporting on problematic performance issues within the system • Primarily a Metasystem 3^* channel for communicating between Metasystem 3, the governed systems, and the metasystem concerning performance issues
Algedonic (Metasystem 5)	• Provides a “bypass” of all channels when the integrity of the system is threatened • Compels instant alert to crisis or potentially catastrophic situations for the system • Directed to Metasystem 5 from anywhere in the metasystem or governed systems
Environmental Scanning (Metasystem 4′)	• Provides design for sensing to monitor critical aspects of the external environment • Identifies environmental patterns, activities, or events with system implications • Provided for access throughout the metasystem as well as governed systemsby Metasystem 4′
Dialogue (Metasystem 5′)	• Provides for examination of system decisions, actions, and interpretations for consistency with system purpose and identity • Directed to Metasystem 5′ from anywhere in the metasystem or governed systems
Learning (Metasystem 4*)	• Provides detection and correction of error within the metasystem as well as governed systems, focused on system design issues as opposed to execution issues • Directed to Metasystem 4^* from anywhere in the metasystem or governed systems
Informing (Metasystem 2)	• Provides for flow and access to routine information within the metasystem or between the metasystem and governed systems • Access provided to entire metasystem and governed systems • Primarily designed by Metasystem 2 for utilization by all metasystem functions as well as governed systems

- *Integration* (design for system unity with common goals, accountability, and balance between individual autonomy and system level interests). The primary focus of integration is to insure that the system achieves desirable levels of performance while (a) providing the maximum level of autonomy to constituents, (b) invoking the minimal constraint necessary for the system to function as a unity in achieving the intended purpose, and (c) strategically shifting the balance point between autonomy and integration based on changes in contextual factors, environmental shifts, and system performance levels. Integration is not achieved through serendipity but rather by active design and continuous purposeful evolution.

Having provided the conceptual underpinnings for CSG, we now turn our attention examine pathologies to explain deficiencies in the design, execution, or development of a system.

4 | CSG PATHOLOGIES

For grounding our present exploration, we introduce three key points related to the nature and role of pathologies in CSG: first, examination of the nature of pathologies; second, the relationship of pathologies to errors in design, execution, or development (pathologies) of CSG functions; and third, an elaboration of pathologies with underlying theoretical foundations provided by Ashby's Law of Requisite Variety (Ashby, 1958).

4.1 | Nature of pathologies in complex systems

Certainly, understanding of system performance involves discovery of conditions that might act to limit that performance. Previous research related to systems theory and systems theory-based methodologies offers insights that provide explanation for aberrant conditions affecting performance (Keating & Katina, 2012). These aberrant conditions have been labelled as pathologies, defined as "A circumstance, condition, factor, or pattern that acts to limit system performance, or lessen system viability <existence>, such that the likelihood of a system achieving performance expectations is reduced." (Keating & Katina, 2012, p. 214). Pathologies have a rich development and have been anchored in systems theory and management cybernetics.

Previous research in general systems theory (GST) produced over 80 system theory-based pathologies (Katina, 2015b; Keating et al., 2017). This set of pathologies emerged from contrasting the meaning of concepts of GST as they relate to problem formulation. Using a thesis that failure to adhere to principles of GST decreases likelihood of achieving expected system performance, Katina (2015a, 2015b, 2016a, 2016b) used Grounded Theory Method and QSR International's NVivo®10 software package to analyse systems theory text "data" for "significant word or phrase" (Saldana, 2013, p. 42) and then thinking critically about the meaning as it relates to phenomena at hand (Mason, 2002). A detailed account of these systems theory-based pathologies is found elsewhere (Katina, 2015b, 2016a, 2016b). Certainly, there is no accepted guide or one "correct" way to group pathologies. In fact, Troncale's (1977) research recognizes that his hierarchical tree of concepts stemming from GST was only meant as one of "many [possible] alternative hierarchies among P.S.C.'s [Principal Systems Concepts that] could be logically supported and empirically demonstrated for real systems" (p. 36). After using phases of the Grounded Theory Method to create a model for discovering pathologies in principles of GST, eight categories emerged that appear to provide an umbrella covering the entire set of systems theory-based pathologies. These metasystem pathologies were clustered and are specified in Figure 3.

This brief overview of systems pathologies serves to briefly acquaint and orient readers to the broad-based dimensions and nature of thinking in terms of metasystem pathologies. However, although this higher level organization of pathologies offers an important step forward, additional specificity is necessary to make the pathologies "actionable" for CSG. Actionable entails sufficient granularity such that assessment of design,

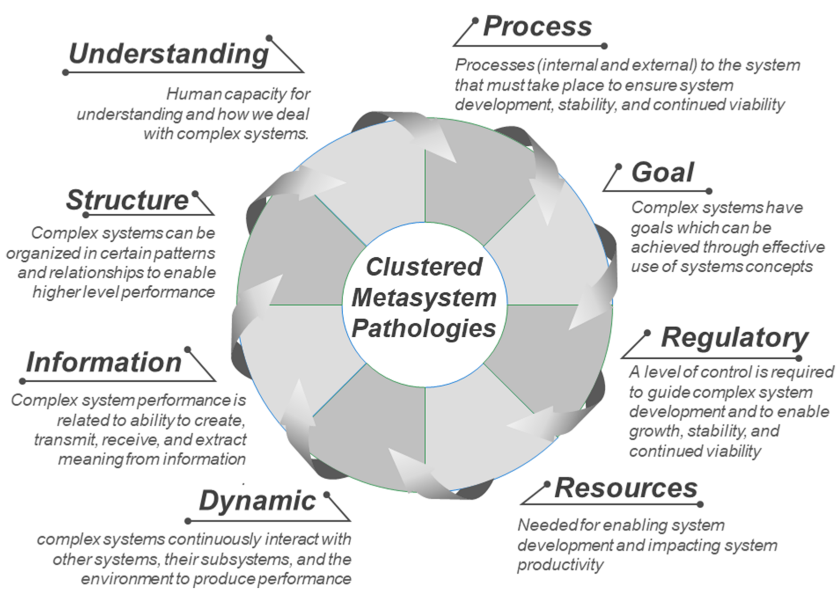

FIGURE 3 Clustered metasystem pathologies stemming from the work of Katina (2015b, 2016a, 2016b) [Colour figure can be viewed at wileyonlinelibrary.com]

execution, and development deficiencies are sufficiently identified to permit detailed analysis and response.

4.2 | Pathologies specific to CSG metasystem functions

For grounding our present exploration, we introduce two key points related to the nature and role of pathologies in complex systems—pathologies and their more specific relationship to systems theory. First, pathologies have been extensively developed for application to the design, execution, and development (governance) of complex systems (Keating & Katina, 2012; Katina, 2015). CSG functions and communication channels provide a set of "coordinates" to locate the existence of a pathology. This location is linked to the nine different metasystem functions essential to continued viability of a complex system.

However, following the recent work of Katina (2016c) and earlier work of Keating and Katina (2012), a set of 53 specific pathologies have been develop in relationship to the CSG metasystem functions provided earlier. These pathologies are organized around the nine metasystem functions and serve to identify aberrations to normal (healthy) functioning of a complex system (Table 4).

A second essential and fundamental grounding for development of pathologies is their linkage to systems theory-based propositions (laws, principles, and concepts). For our present purposes, the nature of pathologies in complex systems can be captured in the following critical points and their suggested relevance to system practitioners and system development:

1. *All systems are subject to the propositions (laws, principles, and concepts) of systems*. Just as there are laws governing the nature of matter and energy (e.g., physics law of gravity), so too are our systems subject to propositions. These system propositions are always there, always on, nonnegotiable, nonbiased, and explain system performance. System practitioners must ask, "do we understand systems propositions and their impact on our system(s) design and performance?"
2. *All systems perform essential system functions that determine system performance*. These functions are performed by all systems, regardless of sector, size, or purpose. These functions define "what" must be achieved for maintaining viability of a system. Every system invokes a set of unique implementing mechanisms (means of achieving system functions) that determine "how" system functions are accomplished. Mechanisms can be formal–informal, tacit–explicit, routine–sporadic, or limited–comprehensive in nature. These functions, through their implementing mechanisms, serve to produce system performance. System practitioners must ask, "do we understand how our system performs essential system functions to produce performance, maintain viability, and support sustainability?"
3. *Violations of systems propositions in design, execution, or development of a system are "pathologies" and carry consequences*. Irrespective of noble intentions, ignorance, or wilful disregard, violation of system propositions generates pathologies and carries real consequences for system performance. In the best case, violations degrade performance. In the worst case, violations can escalate to cause catastrophic consequences or even eventual system collapse. System practitioners must ask, "do we understand problematic system performance in terms of violations of fundamental system propositions?"
4. *System performance can be enhanced through development of essential system functions*. When system performance fails to meet expectations, deficiencies in governance functions (experienced as pathologies) can offer novel insights into the deeper sources of failure. Performance issues can be traced to governance function issues as well as violations of underlying system propositions. Thus, system development can proceed in a more informed and purposeful manner. System practitioners must ask, "how might the roots of problematic performance be found in deeper system issues and violations of system propositions, suggesting different development directions?"

4.3 | CSG, pathologies, and a relationship to requisite variety

Requisite variety was developed by Ashby (1956; 1991) to explain that a system must have sufficient regulatory capacity to match or exceed the variety being generated by the environment. Other statements of variety include (a) the number of different states of a system (Beer, 1979); (b) "if a system is to be stable, the number of states of its control mechanism must be greater than or equal to the number of states in the system being controlled (Ashby, 1956, p. 10); (c) the larger the variety of actions available to a control system, the larger the variety of perturbations it is able to compensate (Heylighen, 1992); (d) "the greater the variety within a system, the greater its ability to reduce variety in its environment through regulation" (Principia Cybernetica Website, 2019); and (e) "for appropriate regulation the variety in the regulator must be equal to or greater than the variety in the system being regulated"

TABLE 4 Pathologies corresponding to metasystem functions

Metasystem function	Corresponding set of pathologies
Metasystem five (M5): Policy and identity	M5.1. Identity of system is ambiguous and does not effectively generate consistency system decision, action, and interpretation. M5.2. System vision, purpose, mission, or values remain unarticulated, or articulated but not embedded in the execution of the system. M5.3. Balance between short term operational focus and long term strategic focus is unexplored. M5.4. Strategic focus lacks sufficient clarity to direct consistent system development. M5.5. System identity is not routinely assessed, maintained, or questioned for continuing ability to guide consistency in system decision and action. M5.6. External system projection is not effectively performed.
Metasystem Five Star (M5*): System context	$M5^*$.1. Incompatible metasystem context constraining system performance. $M5^*$.2. Lack of articulation and representation of metasystem context. $M5^*$.3. Lack of consideration of context in metasystem decisions and actions.
Metasystem Five Prime (M5′): Strategic system monitoring	M5′.1. Lack of strategic system monitoring. M5′.2. Inadequate processing of strategic monitoring results. M5′.3. Lack of strategic system performance indicators.
Metasystem Four (M4): System development	M4.1. Lack of forums to foster system development and transformation. M4.2. Inadequate interpretation and processing of results of environmental scanning—nonexistent, sporadic, limited. M4.3. Ineffective processing and dissemination of environmental scanning results. M4.4. Long-range strategic development is sacrificed for management of day-to-day operations—limited time devoted to strategic analysis. M4.5. Strategic planning/thinking focuses on operational level planning and improvement.
Metasystem Four Star (M4*): Learning and transformation	$M4^*$.1. Limited learning achieved related to environmental shifts. $M4^*$.2. Integrated strategic transformation not conducted, limited, or ineffective. $M4^*$.3. Lack of design for system learning—informal, nonexistent, or ineffective. $M4^*$.4. Absence of system representative models—present and future.
Metasystem Four Prime (M4′): Environmental scanning	M4′.1. Lack of effective scanning mechanisms. M4′.2. Inappropriate targeting/undirected environmental scanning. M4′.3. Scanning frequency not appropriate for rate of environmental shifts. M4′.4. System lacks enough control over variety generated by the environment. M4′.5. Lack of current model of system environment.
Metasystem Three (M3): System operations	M3.1. Imbalance between autonomy of productive elements and integration of whole system. M3.2. Shifts in resources without corresponding shifts in accountability/shifts in accountability without corresponding shifts in resources. M3.3. Mismatch between resource and productivity expectations. M3.4. Lack of clarity for responsibility, expectations, and accountability for performance. M3.5. Operational planning frequently pre-empted by emergent crises. M3.6. Inappropriate balance between short term operational versus long term strategic focus. M3.7. Lack of clarity of operational direction for productive entities (i.e., subsystems). M3.8. Difficulty in managing integration of system productive entities (i.e., subsystems). M3.9. Slow to anticipate, identify, and respond to environmental shifts.
Metasystem Three Star ($M3^*$): Operational performance	$M3^*$.1. Limited accessibility to data necessary to monitor performance. $M3^*$.2. System-level operational performance indicators are absent, limited, or ineffective. $M3^*$.3. Absence of monitoring for system and subsystem level performance. $M3^*$.4. Lack of analysis for performance variability or emergent deviations from expected performance levels—the meaning of deviations. $M3^*$.5. Performance auditing is nonexistent, limited in nature, or restricted mainly to troubleshooting emergent issues. $M3^*$.6. Periodic examination of system performance largely unorganized and informal in nature. $M3^*$.7. Limited system learning based on performance assessments.
Metasystem Two (M2): Information and communications	M2.1. Unresolved coordination issues within the system.

(Continues)

TABLE 4 (Continued)

Metasystem function	Corresponding set of pathologies
	M2.2. Excess redundancies in system resulting in inconsistency and inefficient utilization of resources—including information. M2.3. System integration issues stemming from excessive entity isolation or fragmentation. M2.4. System conflict stemming from unilateral decisions and actions. M2.5. Excessive level of emergent crises—associated with information transmission, communication, and coordination within the system. M2.6. Weak or ineffective communications systems among system entities (i.e., subsystems). M2.7. Lack of standardized methods (i.e., procedures, tools, and techniques) for routine system level activities. M2.8. Overutilization of standardized methods (i.e., procedures, tools, and techniques) where they should be customized. M2.9. Overly ad hoc system coordination versus purposeful design. M2.10. Difficulty in accomplishing cross-system functions requiring integration or standardization. M2.11. Introduction of uncoordinated system changes resulting in excessive oscillation.

(Principia Cybernetica Website, 2019). The suggestion for "variety" is that essential variables must be kept with limits if survival is to be maintained—this is achieved by a "regulator" and invoking sufficient regulatory capacity. Lacking this variety match would result in a system not being able to effectively respond to perturbations stemming from external turbulence or internal flux. Thus, regulatory capacity is a function of system capability to mount an effective response(s) to disturbances such that essential variables necessary for sustained system performance are maintained within desirable limits.

In developing CSG relationship to requisite variety, regulatory capacity, and pathologies, the following formulation is provided:

> *The regulatory capacity of a system is the degree to which response to disturbances can maintain essential system performance parameters within acceptable limits. Regulatory capacity is achieved through the interaction of system design, execution of that design, and system development (redesign). Insufficient regulatory capacity produces pathologies that degrade system performance.*

The key elements of this perspective include the following:

1. *Regulatory Capacity*—This involves the capacity of the system to provide sufficient variety such that performance is maintained. Regulatory capacity for a system is not static and may be invoked by *self-organization* (permitting the structural patterns of the system to "take their own course" to absorb variety without invoking external design/execution constraints), *accretion* (adding piecemeal ad hoc elements to absorb variety in a system), or *purposeful* (actively engaging in the holistic design/execution of the system to absorb inevitable emergent variety).
2. *System Design*—The structure of elements (entities and mechanisms) and relationships of a system that provides the ability to absorb variety stemming from external perturbations and internal flux. This provides *resilience* (ability to absorb variety and re-establish performance parameters following external disturbances), *robustness* (the range over which a system can be resilient to anticipated and unanticipated perturbations), and *fragility* (the degree to which a system is vulnerable to external fluctuation [perturbations] and at risk of performance degradation or collapse). System design generates a capacity to absorb variety being generated external/internal to a system. The degree to which a system design is incapable of absorbing variety presents the system with residual, or "unabsorbed" variety. Residual unabsorbed design variety (a) creates a level of uncertainty in a system, (b) results in pathologies stemming from inadequacies in the system design capability to "absorb" variety through regulatory capacity, and (c) left unresolved will result in system degradation, or ultimately collapse should it pass a limiting threshold.
3. *Execution*—This provides the capacity to deal with unabsorbed variety (not matched by the system design regulatory capacity). Unabsorbed variety is representative of "system design slop," accentuating inadequacies of the design in relationship to demands of the environment. Execution provides a continual damping (matching) of variety unabsorbed by design and permits the system to maintain performance (dynamic equilibrium) under conditions of varying

unabsorbed variety stemming from internal or external perturbations. If execution is not capable of sufficiently matching unabsorbed variety stemming from the system design, the best case is system degradation and the worst case is eventual system collapse.

4. *System Development*—This represents the continual modification of the system design to more effectively absorb variety stemming from pathologies (unabsorbed variety stemming from design or execution). The degree to which system redesign maintains residual (unabsorbed) variety below a “threshold” level ensures continued system viability (continued existence) and is the primary determinant of system performance improvement in response to continual environmental shifts. This occurs through the continuing maintenance of congruence between the regulatory capacity of the system (variety absorbing) in response to variety generated external (or internal) to the system (perturbations that manifest as pathologies representative of unabsorbed (by system design or execution) residual variety.
5. *Pathologies*—Recognizable as aberrations from normal or healthy system conditions. The existence of pathologies represents inadequacies in design, execution, or development for a complex system. Pathologies result from unabsorbed variety and act to degrade system performance or, in the worst case, cause the system to experience disabling conditions.

Figure 4 shows “variety” relationships in system design, execution, and development for CSG. It is important to note that CSG is an approach that is focused on purposefully dealing with variety. CSG fosters improvement in design and execution through the purposeful pursuit of identification of pathologies (residual unabsorbed variety) and their resolution.

There are two significant points of note in this set of variety relationships. First, although simple calculations for variety (as number of states of a system and that which may be generated from the environment) approach infinity rapidly, the actual variety that is projected to the system design is a subset of this total variety. We suggest that this variety, which must be engaged by a system, is evident as emergent activities, events, conditions, or trends that occur in the environment of interest for a particular system. Second, the resolution of variety occurs in three system venues, including *design* (absorption of emergent environmental variety by the system design, resulting in residual unabsorbed variety for variety not deposed by the system design), *execution* (absorption of unabsorbed residual design variety, which beyond a capacity level, produces unabsorbed residual execution variety), and *system development* (dealing with unabsorbed execution residual variety by engaging in redesign of system design and execution). Pathologies related to variety absorbing capacity can range across design, execution, and development for a complex system.

For developmental purposes, we have suggested the following first generation equation to capture the variety relationships suggested for CSG:

$$T_{uv} = (SD_{uv} + SE_{uv}) - SR_{v}, \leq 0$$

where

T_{uv} is the total unabsorbed variety for a system of interest,

SD_{uv} is the residual unabsorbed variety from the system design,

SE_{uv} is the residual unabsorbed variety from system execution,

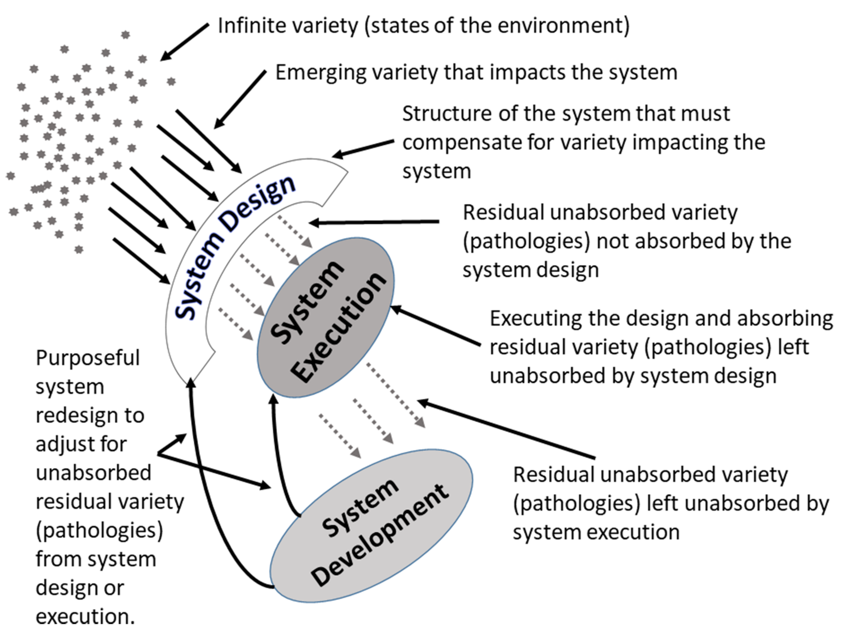

FIGURE 4 Variety in relationship to system design, execution, and development [Colour figure can be viewed at wileyonlinelibrary.com]

SR_v is the variety generated from system redesign or enhanced system execution,

UV is the unabsorbed variety, which is measured by the existence of pathologies in a system of interest, associated with residual variety in design, execution, or development (redesign) that is unabsorbed.

It is noteworthy that the total unabsorbed variety (T_{uv}) being less than or equal to zero would represent a system in perfect balance. That is, the system (design, execution, and development) would have the regulatory capacity to absorb all variety being "presented" to the system. The result would be a system free of pathologies. This is a noble goal but, in reality, most likely unattainable.

5 | CHALLENGES FOR CSG DEVELOPMENT

The challenges for CSG, or any emerging field, are legion. However, we have selected two primary challenges that must be faced as CSG continues to gain traction as a theoretically and conceptually grounded approach to improve the design, execution, and development of complex systems. Ultimately, emanating from a strong theoretical base, the intent of CSG is to improve system performance and thus enhance the prospects for human well-being. Two top challenges for further development and propagation of CSG include, *balanced field development* and *tempered application*. We examine each of these challenges.

5.1 | Balanced field development

Research in CSG is certainly not confined to a prescribed approach or privileged intellectual school of thought. In this section, we focus on providing two primary suggestions to further organize development of the CSG field. The first suggestion is the consideration of a framework for holistic field development that we have used in several different venues (Keating, 2005; 2014). The purpose of this framework is to suggest that the CSG field will be well served by a purposeful consideration and balanced development along several interrelated lines of inquiry. Although it would be "easy" to cast one line of inquiry as more important than others, each of the developmental areas is important to support holistic field development. Even though cogent arguments might be made for one development area having priority over another, what is absolute is that exclusion of any of the areas will not support holistic field development. Thus, in keeping with the one of the central tenets of systems theory, this framework provides a holistic developmental perspective for CSG. This framework is based on previous work for emerging knowledge (Keating, 2005, 2014; Keating & Katina, 2011; Keating et al., 2016) and has been crafted with respect to CSG (Figure 5).

Seven levels of interrelated elements for CSG field development include the following:

1. *Philosophical*—Development directed at establishing a theoretically consistent articulation of the paradigm(s) for CSG. The emerging system of values and beliefs providing grounding for theoretical development is the primary contribution of this area. A strong, coherent, and articulated philosophical grounding is essential to provide a foundation upon which other field developments can be consistently based.
2. *Theoretical*—Development focused on explaining phenomena related to system governance and development of explanatory models and testable conceptual frameworks. The range of theoretical

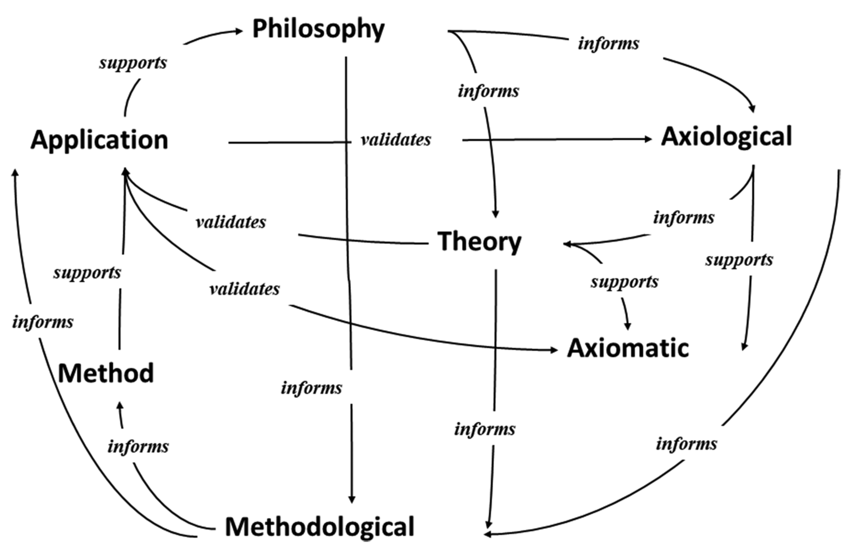

FIGURE 5 Areas of balanced development for CSG

developments advances understanding of the field and the phenomena of central concern. It is essential that the theoretical development of the field is actively pursued and not left to chance.

3. *Axiological*–Development that establishes the underlying value, value judgement frameworks, and belief propositions that are fundamental to understanding the variety of perspectives informing CSG. The absence of axiological considerations for development of the field fails to recognize the important value foundations upon which other development areas can utilize as a foundational reference point(s).
4. *Methodological*—Development undertaken to establish theoretically informed frameworks that provide high level guidance for design, analysis, deployment, and evolution of governance systems. Generalizable methodologies serve to provide transition from the conceptual foundations (philosophical, theoretical, and axiological) to applications that address CSG and the inherent issues in the domain of interest.
5. *Axiomatic*—Development of the existing and emerging principles, concepts, and laws that define the field and constitute the "taken for granted" knowledge upon which the field rests. This also includes integration of knowledge from other informing and related fields/disciplines. For CSG, the grounding in the axioms and supporting propositions of systems theory provides a strong starting point for further axiomatic development.
6. *Method*—Development focused on generating the specific models, technologies, standards, processes, and tools for CSG. In effect, this is the development of the supporting toolsets and capabilities for practitioners. Based on the strong conceptual foundations provided by other areas of field development, the methods should be compatible with the philosophical, methodological, axiomatic, and axiological predispositions for the field. This encourages consistency in development of methods.
7. *Application*—this emphasizes advancement of the practice of CSG through the deployment of conceptually sound technologies and methods. Applications that are not rooted in the conceptual foundations of the field are not likely to be either consistent or conceptually congruent with the deeper underpinnings upon which the field rests. As such, applications void of the philosophical, theoretical, and axiomatic foundations of the field are not likely to produce the intended utility for which they have been designed.

These interrelated components of research can be instructive as the CSG field continues to develop. Balanced field development demands that each of the components be developed.

5.2 | Tempered application

CSG has been developed from, and grounded in, a strong *systems* conceptual/theoretical foundation. As such, the proper deployment of CSG requires a congruent "worldview" capable of matching the level of "systemic sophistication" necessary for proper utilization. In many systems-based methodologies (e.g., see Checkland's [2019] work describing systems-based approaches), the necessary systemic orientation is either tacit, assumed, or omitted. For CSG, development for deployment requires that the level of "systems thinking capacity" (Jaradat & Keating, 2014; Jaradat et al., 2016, Jaradat et al., 2017) be accounted for prior to full engagement.

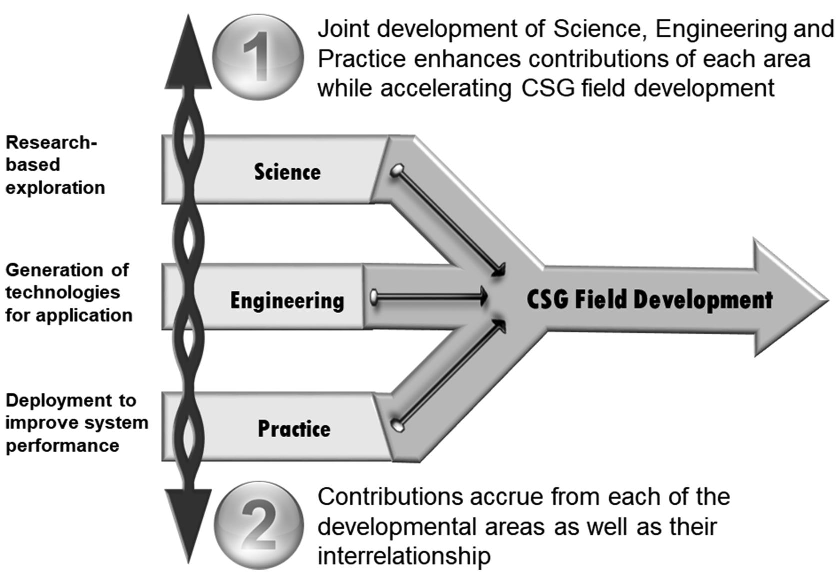

FIGURE 6 Simultaneous CSG evolution of science, engineering, and practice

We believe this to be the case with deployment of any systems-based methodology. That is, the systemic sophistication (holistic worldview) will enable greater realization of the intended utility of systems-based methodologies. Likewise, a more narrow "reductionist" worldview will constrain the ability to deploy systems-based methodologies, including CSG, as intended.

Recent work in worldviews (Rousseau, Billingham, & Calvo-Amodio, 2018) suggests the deep nature and implications of worldview formulation. A central challenge for CSG development will be assessing and matching systemic worldview with implementation design, initiative deployment, and expectations. It is unrealistic to believe that a "systemically incongruent" set of worldviews engaging CSG deployment will yield the expected or potential results. On the contrary, it is more likely that incongruent worldviews and inadequate "systemic thinking capacity" will fall short of expectations for CSG deployment and may do more harm than good for improving a system of interest. It is naïve to think that a methodology can be deployed independent of the worldviews driving design, execution, and interpretation of a systems-based initiative (including CSG). Thus, a critical challenge for CSG development rest with ensuring that the level of systemic thinking for engagement is made explicit and exists at a sufficient level to engage CSG and support the level of expectations for complex system improvement.

6 | CONCLUSION

In this paper, we have introduced the emerging field of CSG. CSG was presented at the intersection of systems theory (principles, laws, and concepts that explain the behaviour and performance of complex systems), management cybernetics (the science of effective system structural organization), and governance (provision of direction, oversight, and accountability for a system). Ultimately, CSG is developing as a field intended to improve our prospects for dealing more effectively with increasingly complex systems and problems confronting society.

As CSG is a new and novel development methodology, the current state is at once *incomplete*, *fallible*, and *emergent*. It is incomplete because it is continuing to evolve through new developments in technologies, methods, and tools to support CSG as they continue to evolve at a rapid pace. CSG development is fallible as it has not been deployed with sufficient frequency in field settings. CSG development is emergent because the field is rapidly advancing with new research and discoveries at a rate that currently exceeds their translation into instruments to support practice (Keating et al., 2016; Keating & Ireland, 2016). This pace of development is important to advance the field rapidly in the face of increasing challenges faced by practitioners in modern complex systems. However, care must be exercised to ensure that rapid development and deployment do not become an excuse for lack of rigour or "sloppiness" in purposefully advancing the field.

For CSG field development, there is a creative tension to be exploited between development and deployment. Although researchers want do develop and test, similarly, the practitioner is anxious to deploy and use. These perspectives must not be taken as mutually exclusive of one another. On the contrary, the CSG field will advance more rapidly and effectively by research informing practice and practice informing research. Researchers must not wait for absolute completeness prior to pushing new discoveries into the practice field. In a similar manner, practitioners must not expect "perfection" in knowledge products but rather must anticipate that field testing will require some skepticism and participatory engagement in advancing the next generation of "deployable discoveries."

Development and propagation of the CSG field ranges across science, engineering, and practice. Figure 6 captures this unique triad. *Science* is fundamentally concerned with exploration and understanding of underlying phenomena at the theoretical and conceptual levels. It is very easy to claim that application areas for CSG are practice-based professions that have neither the time nor interest in the theoretical musings rooted in scientific inquiry. This is a naïve position. First, we invest in fundamental exploration to advance understanding (e.g., system science) with the hope that it will provide for breakthroughs which will lead to better systems. Second, science-based foundations provide an anchoring stability for a field (e.g., CSG). Science-based inquiry exists at a much more fundamental level than simply providing a new tool, technology, or technique. However, the grounding of advanced science-based technologies, tools, and methods anchored in scientific foundations (e.g., systems theory) will have greater "staying power" than those absent a deep science-based conceptual grounding. Third, it is inappropriate to think that CSG science development requires "surrender" of "more important" pursuits of the practice community dealing with complex systems and their problems. It is short sighted to think that science-based inquiry for CSG is mutually exclusive of the world of application.

Engineering involves building of the science-based artifacts (tools, techniques, and methods) to support enhanced capabilities that promote improved CSG practices. Thus, engineering for CSG finds its basis in system science and bridges the world of system science to the world of application through engineering of technologies. *CSG technologies* are different from technologies that are produced as complex systems and solutions. In contrast, CSG technologies are those that serve to more effectively/efficiently guide the design, execution, and development of "systems that produce system solutions." Thus, the emphasis of CSG is on more effectively engaging systems responsible to bring about complex system solutions. Finally, *application* is focused on deployment of technology-based capabilities to enhance practice. In the case of CSG, this implies enabling practitioners with more sophisticated (system science-based) technologies to perform in their roles in execution of professional responsibilities. Figure 6 captures the uniquely interrelated triad of science, technology, and application for CSG.

In essence, moving CSG forward must be focused on science-based engineering of technologies to support applications that enhance practice. The CSG field faces a major challenge to pursue parallel integrated paths of development for the science, engineering, and practice of CSG for improving complex system performance. The easy, and more traditional, research is to separate the development of underlying science from corresponding engineering and eventual applications. However, there is much to be gained by permitting the triad (science, engineering, and practice) to constrain as well as enable one another. The CSG research path that emerges through the integration of science, engineering, and practice may be very different than had joint development not been considered.

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