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Exapt, Adapt, Disrupt: A Conceptual Framework for Systemic Innovation

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Abstract

How do breakthroughs emerge in unpredictable environments? This paper develops a unified framework for systemic innovation by integrating eight key concepts: exaptation, serendipity, emergence, co-optation, bricolage, affordances, recombinant innovation, and effectuation. By synthesizing insights from complexity science, sociology, and entrepreneurship, we reveal how creativity flourishes when innovators repurpose existing elements, harness uncertainty, and leverage unexpected affordances. Unlike conventional models that emphasize structured problem-solving, this framework captures the nonlinear, adaptive, and systemic nature of creativity in innovation ecosystems. We illustrate its applicability across diverse cases—from the exaptation of mRNA vaccines to the recombinant innovation of AI-driven drug discovery, the co-optation of gig work by tech giants, and the emergence of decentralized finance. Our findings suggest that transformative creativity is not a solitary act, but an emergent systems-level process shaped by adaptive recombination and strategic improvisation. By shifting the focus from predictive planning to creative adaptation, this study provides a novel roadmap for navigating uncertainty and fostering systemic change. It offers both scholars and practitioners an actionable lens to harness creativity, unlock latent affordances, and scale innovation in complex environments.

Keywords: Creativity, systemic innovation, exaptation, emergence, bricolage, effectuation, recombinant innovation, adaptive systems

1. Introduction

Innovation and adaptation are central to understanding how biological, social, technological, and organizational systems respond to dynamic challenges. This paper examines transformative processes that repurpose or recombine existing elements to generate novelty, integrating eight core concepts: exaptation, serendipity, emergence, co-optation, bricolage, affordances, recombinant innovation, and effectuation. These processes do not rely solely on deliberate problem-solving but also on the emergence of creativity through the recombination of existing resources and affordances within complex systems (Glăveanu, 2014). By exploring the nature of these constructs - and their interplay - this study deepens theoretical understanding while offering practical insights for navigating uncertainty and fostering innovation.

Exaptation, introduced by Gould and Vrba (1982), explains how traits evolved for one function can be repurposed for another. Beyond evolutionary biology, this principle applies to technology and design, where latent features are reimagined for new uses (Arthur, 2009; Wagner, 2014). For example, mRNA vaccine technology, initially developed for cancer research, was repurposed to combat the COVID-19 pandemic, exemplifying how scientific advancements can find new, transformative applications (Pardi et al., 2018; Kupferschmidt & Cohen, 2020).

Serendipity, coined by Horace Walpole (1754) and later developed by Merton and Barber (2004), highlights the role of chance in discovery and the necessity of what Pasteur calls a "prepared mind" (Merton & Barber, 2004) in recognizing and leveraging unexpected opportunities. A recent example is AI-driven drug discovery, where deep learning algorithms inadvertently identified Halicin, a powerful antibiotic, while screening existing drug libraries for different purposes (Stokes et al., 2020).

Emergence refers to the spontaneous formation of new properties from interactions within a system (Holland, 1998; Sawyer, 2005). In contemporary innovation, decentralized finance (DeFi) has emerged from blockchain networks, demonstrating how financial services can develop organically without centralized institutions, reshaping global economic systems (Schär, 2021) llm.

Co-optation, as articulated by Selznick (1949), describes the strategic incorporation of external elements into systems. A modern example includes the gig economy's co-optation by major corporations like Microsoft and Google, which integrated freelance workforce platforms such as Upwork and Fiverr into traditional employment structures, blending flexibility with corporate control.

Theories of **bricolage** (Lévi-Strauss, 1966) emphasize resourceful recombination to address challenges (Baker & Nelson, 2005). The COVID-19 pandemic saw a surge in bricolage through the development of DIY ventilators, where engineers and healthcare workers repurposed readily available materials to address critical shortages (Abdelrahman et al., 2020).

Affordances (Gibson, 1979; Norman, 1999) explore how context shapes the functional interpretation of objects and environments. TikTok's recommendation algorithm, initially designed for entertainment, has been exapted for political mobilization, with activists leveraging its affordances to drive social change (Zeng & Schäfer, 2021).

Effectuation (Sarasvathy, 2001) aligns with this perspective, emphasizing the use of available means and partnerships to navigate uncertainty. The Clubhouse app's rapid growth during the pandemic exemplifies effectual reasoning, as its founders scaled the platform through iterative invitations and emergent user demand rather than traditional business planning.

Recombinant innovation (Schumpeter, 1934; Weitzman, 1998) further extends this logic, demonstrating how novel solutions emerge from the synthesis of existing components. DeepMind's AlphaFold combined artificial intelligence with protein structure prediction, solving a long-standing challenge in molecular biology and revolutionizing drug discovery (Jumper et al., 2021).

This paper pursues three interrelated goals:

1. **Conceptual Analysis and Comparative Examination:** We systematically dissect and compare eight key constructs—exaptation, serendipity, emergence, co-optation, bricolage, affordances, recombinant innovation, and effectuation—clarifying their theoretical foundations and their role in transformative adaptation. By integrating insights from complexity science, design theory, and entrepreneurship, we delineate their distinctions and synergies, refining their applicability across disciplines.

2. **Development of a Unified Framework:** Building on this comparative analysis, we synthesize these constructs into a cohesive, multidimensional framework that articulates the principles and mechanisms underpinning transformative adaptation. This framework systematically captures how innovation emerges, evolves, and scales within complex systems, bridging micro-level agency with macro-level systemic dynamics.

3. **Actionable Application in Theory and Practice:** Beyond theorization, we operationalize the framework into a structured roadmap, equipping scholars and practitioners with concrete methodologies for navigating uncertainty, fostering creativity, and driving systemic innovation. The paper demonstrates its real-world utility through diverse empirical cases, including the exaptation of mRNA vaccines for the COVID-19 response, AI-driven drug discovery such as Halicin, the rise of decentralized finance, and the emergent user-driven adoption of TikTok for activism. The framework is further translated into structured implementation guides, offering a clear methodology for applying these constructs in innovation processes.

This study thus advances the literature by clarifying innovation constructs, mapping their interconnections, and synthesizing them into a single, actionable framework. Theoretically, it integrates perspectives from biology (Gould & Vrba, 1982), complexity theory (Kauffman, 1993), and innovation studies (Arthur, 2009; Sarasvathy, 2001), while also incorporating recent advancements in emergent AI capabilities (Bubeck et al., 2023), adaptive innovation networks (Pievani, 2024), and digital platform scaling dynamics (Schär, 2021). Practically, it provides a rigorous yet adaptable methodology for innovation practitioners, policymakers, and organizational leaders seeking to leverage emergent opportunities and strategically recombine resources in rapidly evolving environments (Stokes et al., 2020; Jumper et al., 2021). By grounding its propositions in both seminal theories and contemporary empirical applications, this paper bridges abstract theorization with structured, implementable strategies, offering a powerful resource for researchers and decision-makers alike.

2. Theoretical Underpinning of the Principal Constructs

Understanding transformative processes requires a thorough exploration of the theoretical constructs that explain how systems repurpose, recombine, and innovate. This chapter delves into the eight principal constructs—exaptation, serendipity, emergence, co-optation, bricolage, affordances, recombinant innovation, and effectuation—drawing on seminal works and integrating insights from multiple disciplines. These constructs provide a comprehensive lens for understanding how innovation, novelty and adaptation occur across dynamic systems.

2.1 Exaptation

Exaptation, introduced by Gould and Vrba (1982), describes how traits originally evolved for one function can be co-opted for entirely different purposes. This challenges the traditional adaptationist paradigm, which assumes traits persist solely due to direct selection. Instead, exaptation highlights how biological and technological features may emerge as byproducts or structural constraints before acquiring new utility. Gould and Vrba's (1982) seminal distinction between adaptation and exaptation builds on earlier critiques of strict adaptationism (Lewontin & Gould, 1979) and has since shaped research across multiple domains. Dennett (1995) expanded on its philosophical implications, emphasizing exaptation as a critical mechanism in the evolution of complexity.

In biological systems, exaptation manifests through the repurposing of biochemical pathways and genetic structures. Wagner (2014) demonstrated how metabolic networks exhibit exaptive properties, with preexisting biochemical pathways later serving novel functions. Empirical studies further validate this: Blount, Borland, and Lenski (2008) showed how genetic mutations in *Escherichia coli* were repurposed under selective pressures, giving rise to new metabolic capabilities. Brosius and Gould (1992) extended this insight to genomics, arguing that non-coding DNA, once dismissed as "junk," has acquired regulatory significance through exaptation. Recent advances in synthetic biology reinforce this view, as researchers increasingly exploit latent genetic potential to engineer novel biological functions (Arber, 2019).

Exaptation's explanatory power extends beyond biology to cognitive science, technology, and social systems. In evolutionary linguistics, Chomsky (1986) and Pinker and Jackendoff (2005) argued that human language arose through exaptation, where pre-existing cognitive faculties—initially evolved for general problem-solving—were later repurposed for linguistic communication. This view finds empirical support in recent neuroscience studies, which reveal that brain regions associated with tool use and spatial reasoning also activate during language processing, suggesting deep functional overlap (Stout & Chaminade, 2012).

Innovation research has also embraced exaptation as a framework for understanding technological and scientific breakthroughs. Andriani and Cattani (2016) explored how exaptation fosters creativity in organizations, demonstrating that radical innovations often emerge when existing technologies are repurposed for unintended applications. A recent case in point is the development of mRNA vaccine technology, initially designed for oncology applications but later exapted to combat COVID-19 (Pardi et al., 2018; Felgner, 2021). Similarly, DeepMind's AlphaFold repurposed AI models developed for language processing to predict protein structures, solving a long-standing challenge in molecular biology (Jumper et al., 2021).

Exaptation is particularly relevant in times of crisis. The COVID-19 pandemic saw numerous instances where existing technologies were repurposed to meet urgent needs. Sedita, Blasi, and Ganzaroli (2022) examined how manufacturing systems originally designed for automotive and aerospace production were rapidly adapted to produce ventilators and personal protective equipment. The architectural and urban planning fields have also applied exaptation principles to create adaptive and resilient spaces, with Melis and Pievani (2022) advocating for design approaches that repurpose existing infrastructure to accommodate shifting environmental and social needs.

Network theory further underscores exaptation's role in innovation. Barve and Wagner (2013) identified latent capacities for evolutionary innovation within metabolic systems, emphasizing that exaptive dynamics facilitate adaptive problem-solving across biological and technological networks. Ferreira et al. (2020) quantified exaptation in the evolution of scientific ideas, showing that breakthroughs often arise from concepts initially developed in unrelated fields.

Distinguishing exaptation from adaptation remains essential for analytical clarity. Adaptation describes traits that evolve directly in response to selection pressures, enhancing fitness in a given environment (Gould & Vrba, 1982). In contrast, exaptation involves the opportunistic reuse of existing traits, often in response to unanticipated circumstances (Andriani & Cattani, 2016). While adaptation follows a primarily functional optimization trajectory, exaptation enables latent affordances to emerge, fueling serendipitous or strategic innovation. Recognizing this distinction prevents conceptual oversimplification and enhances our understanding of how novelty arises in complex systems.

By synthesizing insights from evolutionary biology, cognitive science, organizational theory, and technological innovation, exaptation emerges as a powerful cross-disciplinary framework. Whether in nature, science, or industry, it provides a robust explanation for how features and systems evolve, adapt, and transform beyond their original intent. Recent empirical studies continue to reaffirm its relevance, demonstrating that exaptation remains a cornerstone of both evolutionary theory and contemporary innovation research.

2.2 Serendipity

Serendipity refers to the fortuitous discovery of something valuable while pursuing an unrelated goal. Coined by Horace Walpole in 1754, the term originated from *The Three Princes of Serendip*, a Persian tale in which protagonists consistently stumbled upon unexpected but beneficial findings. While chance is central to serendipity, Merton and Barber (2004) emphasized the role of the *prepared mind*—the ability to recognize and act upon unexpected opportunities. This perspective frames serendipity as an interplay between randomness and cognitive readiness, distinguishing it from mere luck.

Classic examples of serendipity include Alexander Fleming's accidental discovery of penicillin and the development of Post-it Notes, where a weak adhesive, initially considered a failure, became the basis for an innovative product (Roberts, 1989). These cases underscore how scientific progress often hinges on recognizing the latent value in unexpected results. However, as Christian Busch (2024) argues in his work on "smart luck," serendipity is not entirely passive—it can be cultivated through strategic openness, curiosity, and networked collaboration.

The psychological mechanisms underpinning serendipity have been explored across multiple disciplines. Simonton (1999) linked serendipitous discovery to creativity, arguing that individuals and organizations with high absorptive capacity (Cohen & Levinthal, 1990) are better positioned to integrate external knowledge. Csikszentmihalyi (1996) further connected serendipity to the *flow state*, where deep engagement enhances the likelihood of unexpected insights. Lane, Koka, and Pathak (2006) expanded on this by describing absorptive capacity as a dynamic capability, enabling firms to recognize, assimilate, and exploit serendipitous discoveries for strategic advantage.

From an epistemological perspective, serendipity plays a critical role in scientific breakthroughs. Van Andel (1994) categorized different types of serendipitous findings, highlighting how unexpected results are systematically integrated into existing knowledge frameworks. Recent contributions by Ross (2023) and Copeland (2019) emphasize how interdisciplinary collaboration fosters serendipitous insights. They argue that environments rich in diverse perspectives increase the probability of valuable unexpected discoveries, reinforcing the view that serendipity thrives in intellectually heterogeneous settings (Copeland & Ross, 2024).

In contemporary science and technology, AI-driven discovery has emerged as a new frontier for serendipity. The identification of Halicin, an antibiotic discovered through deep learning models, exemplifies this phenomenon. Initially designed for drug repurposing, AI algorithms unexpectedly revealed a compound with potent antibacterial properties (Stokes et al., 2020). This case highlights how computational methods can augment traditional scientific serendipity, accelerating the pace of unexpected discoveries.

Serendipity also plays a pivotal role in innovation ecosystems. The emergence of graphene applications, initially discovered when physicists Novoselov and Geim (2004) isolated the material using adhesive tape, underscores how accidental breakthroughs can redefine entire industries. Similarly, CRISPR gene-editing technology was identified when researchers studying bacterial immune responses stumbled upon a programmable genetic defense mechanism (Jinek et al., 2012). These discoveries demonstrate how serendipity often intersects with exaptation, as novel applications emerge from initially unrelated findings (Gould & Vrba, 1982).

Beyond science, serendipity has profound implications for disaster response and crisis management. Ross (2023) examined how trauma research frequently benefits from unexpected insights, leading to novel therapeutic approaches. During the COVID-19 pandemic, serendipitous repurposing of existing drugs accelerated treatment strategies, as researchers identified unexpected antiviral properties in compounds originally designed for other diseases (Kupferschmidt & Cohen, 2020).

Serendipity's role in shaping research trajectories and scholarly inquiry has also been widely recognized. Pievani (2024) explores how uncertainty fuels scientific progress, arguing that fostering an openness to surprise is intrinsic to innovation. Goggin and Goggin (2022) similarly highlight how unexpected intellectual encounters shape academic discourse, demonstrating serendipity's pervasive influence in shaping new paradigms across disciplines.

By synthesizing insights from sociology, psychology, cognitive science, and technological innovation, this section underscores serendipity's enduring relevance. While chance discoveries remain unpredictable, cultivating environments that promote intellectual diversity, exploratory risk-taking, and openness to novelty significantly enhances the likelihood of serendipitous breakthroughs. In an era increasingly defined by AI-driven research, networked collaboration, and interdisciplinary convergence, serendipity is poised to remain a cornerstone of discovery, creativity, and systemic innovation.

2.3 Emergence

Emergence describes the arising of new properties, structures, or behaviors from interactions within a system that cannot be predicted from its individual components. Holland (1998) defines emergence as a hallmark of complexity science, particularly in adaptive systems where decentralized interactions generate systemic order. Goldstein (1999) emphasizes its role in innovation, where bottom-up interactions lead to spontaneous, often unpredictable developments. In social contexts, Sawyer (2005) explores how collective interactions give rise to emergent innovations, while Barabási (2002) highlights how network effects drive self-organizing behaviors. The interplay between emergence and exaptation is particularly salient, as emergent opportunities often create fertile ground for exaptive transformations (Arthur, 2009; Kauffman, 1993).

Historically, the concept of emergence was explored in philosophy and natural science. Early thinkers observed that certain properties could not be deduced from their constituent parts (Mill, 1843). This distinction between predictable outcomes and novel emergent properties was further articulated by Lewes (1875) and Broad (1925), who argued that higher-order behaviors—such as life and consciousness—arise through complex interactions irreducible to their components. Anderson (1972) captured this principle in his assertion that "more is different," demonstrating how collective interactions yield properties greater than the sum of their parts.

In biological systems, emergence is evident in self-organization and complexity theory. Kauffman (1993) demonstrated how intricate structures and behaviors develop spontaneously from simple rules without external guidance, providing a foundation for understanding the evolution of complexity in nature. Neuroscientific studies further illustrate emergence in consciousness, where mental properties arise from neural interactions yet also influence lower-level processes, a phenomenon described as downward causation (Sperry, 1969). Recent work in cognitive neuroscience suggests that self-awareness may emerge from recursive and self-referential structures, providing new insights into the dynamics of emergent cognition (Dehaene, 2020).

Technological and social systems similarly exhibit emergent properties. Johnson (2001) explores how emergent behaviors shape technological and social landscapes, while Barabási (2002) demonstrates how decentralized networks produce self-organizing phenomena. A contemporary example is the rise of decentralized finance (DeFi), where blockchain-based financial instruments evolved from distributed interactions rather than centralized control (Schär, 2021). Similarly, the rapid scaling of large language models (LLMs), such as OpenAI's GPT, illustrates emergence in artificial intelligence, where advanced capabilities arise from simple predictive algorithms trained at scale (Bubeck et al., 2023).

The philosophical implications of emergence remain a topic of debate. While some argue that emergent properties possess genuine causal powers, others question whether they violate the causal closure of physical systems (Kim, 1999). Polanyi (1966) emphasized the autonomy of emergent systems, arguing against reductionist paradigms. Chalmers (2006) distinguished between weak emergence, where higher-level phenomena are theoretically reducible, and strong emergence, where they are not. These discussions continue to shape perspectives on complex system dynamics, particularly in fields like artificial intelligence, consciousness studies, and evolutionary biology.

The integration of emergence into innovation studies has provided further theoretical and empirical insights. Arthur (2009) highlights how technological evolution follows emergent patterns, where innovations arise unpredictably from the interaction of existing knowledge and capabilities. A recent case is the development of AlphaFold, which repurposed AI models originally designed for natural language processing to solve protein structure prediction—an emergent breakthrough in computational biology (Jumper et al., 2021). Similarly, AI-driven drug discovery demonstrates emergence in biomedical research, where machine learning models unexpectedly identify novel chemical interactions (Stokes et al., 2020).

By bridging reductionist and holistic approaches, emergence provides a critical framework for understanding complexity across disciplines. It challenges linear models of causation, emphasizing the novel and often unpredictable outcomes of intricate interactions. Whether in biological evolution, neural systems, technological innovation, or economic structures, emergence remains a foundational concept for explaining how complex systems adapt and self-organize in dynamic environments.

2.4 Co-optation

Co-optation refers to the process by which external individuals, groups, or ideas are assimilated into an organization's leadership or decision-making structures, often to mitigate threats, stabilize systems, or maintain control. Selznick (1949) introduced the concept in organizational theory, illustrating how institutions neutralize opposition by incorporating external stakeholders. Unlike exaptation, which arises organically, co-optation is typically a strategic process involving power dynamics and institutional negotiation (Hardy & Phillips, 1998; Lawrence & Suddaby, 2006).

Initially examined in the context of the Tennessee Valley Authority, co-optation was shown to serve as a mechanism for integrating external actors into leadership positions to align interests and diffuse dissent (Selznick, 1949). Gamson (1968) extended this analysis to social movements, highlighting how co-optation can dilute radical agendas by incorporating movement leaders into dominant institutions, thereby reducing the capacity for systemic change. In political science, Linz (1970) explored how authoritarian regimes employ co-optation to integrate opposition figures, limiting dissent while projecting an image of inclusivity.

Co-optation also plays a significant role in corporate and technological innovation. Stinchcombe (1965) argued that incumbent firms strategically absorb disruptive technologies to sustain competitive advantage. A contemporary example is how Big Tech firms co-opted the gig economy**:** initially positioned as an alternative to traditional employment, platforms like Upwork and Fiverr have been integrated into corporate hiring models, transforming freelancing into a structured, managed labor force (Scholz, 2017). This process demonstrates how co-optation extends beyond political and organizational spheres into economic and technological domains.

In organizational change, co-optation has been framed as a tactic to preempt resistance. Kotter and Schlesinger (1979) described how involving potential resistors in decision-making can secure compliance while maintaining institutional control. This aligns with Hardy and Phillips' (1998) analysis of co-optation as a tool for managing external dependencies, ensuring that disruptive actors are absorbed into existing power structures rather than challenging them outright.

Cultural co-optation has been widely examined in studies of subcultures and authenticity. Coy and Hedeen (2005) explored how commercial absorption of subcultural practices often leads to a loss of authenticity, as mainstream appropriation alters the original meaning and purpose of those practices. A contemporary example is the co-optation of environmental activism by corporate sustainability initiatives: while brands increasingly adopt eco-conscious messaging, scholars argue that many such efforts constitute greenwashing, diluting the movement's original intent while preserving corporate interests (White et al., 2019).

Co-optation also functions in digital ecosystems, where dominant platforms integrate features pioneered by smaller competitors. The absorption of ephemeral content by major social media companies exemplifies this trend: Snapchat's core feature of disappearing messages was rapidly co-opted by Instagram, Facebook, and WhatsApp, allowing incumbents to retain market dominance while neutralizing potential threats (Zeng, 2021). This highlights how co-optation operates as a competitive strategy in technology-driven markets.

While co-optation can foster stability and facilitate innovation, it also carries risks. By integrating external elements, dominant actors can reshape or weaken the objectives of those being co-opted, leading to the dilution of movements, the erosion of alternative models, or the reinforcement of existing power structures. This dual nature makes co-optation a critical concept in understanding organizational adaptation, institutional legitimacy, and strategic governance across political, corporate, and social domains.

2.5 Bricolage

Bricolage, originally conceptualized by Lévi-Strauss (1966), refers to the creative recombination of available resources to address challenges. In organizational studies, Baker and Nelson (2005) applied bricolage to entrepreneurship, defining it as "making do by applying combinations of the resources at hand to new problems and opportunities." Their research demonstrated how entrepreneurs in resource-constrained environments use bricolage to overcome limitations and generate innovation. This process illustrates how creativity can emerge not from unconstrained ideation but from the constraints and affordances that shape adaptive problem-solving (Baker & Nelson 2005). Duymedjian and Rüling (2010) further explored bricolage in organizational theory, emphasizing its role in fostering adaptability by enabling firms to respond flexibly to changing conditions.

In social entrepreneurship, bricolage facilitates the creation of social value. Di Domenico et al. (2010) analyzed how social enterprises leverage limited resources to develop impactful solutions. Garud and Karnøe (2003) introduced the concept of "distributed agency" to explain how innovation arises collectively through bricolage, where multiple actors recombine existing elements in novel ways. In strategic management, Senyard et al. (2014) found that firms employing bricolage gain competitive advantages in uncertain environments by creatively utilizing existing assets.

Bricolage is closely linked to frugal innovation, particularly in emerging markets. Sarkar (2018) examined how grassroots entrepreneurs use bricolage to develop affordable, sustainable solutions, highlighting its significance in resource-limited settings. During the COVID-19 pandemic, bricolage was evident in the rapid development of makeshift ventilators, where engineers repurposed existing components to address critical shortages (Abdelrahman et al., 2020). This aligns with Weick's (1993) work on bricolage and crisis response, which emphasizes how improvisation and resource recombination help navigate uncertainty.

The relationship between bricolage and effectuation has also been explored to understand entrepreneurial decision-making. Fisher (2012) compared these approaches, noting that while both emphasize flexibility, bricolage focuses on resource utilization, whereas effectuation centers on leveraging stakeholder commitments. Bricolage further intersects with exaptation, as both constructs involve repurposing existing resources to generate innovation (Gould & Vrba, 1982; Wagner, 2014). Recent studies in technological innovation show how bricolage underpins the development of emerging technologies, such as early computing systems, where engineers combined off-the-shelf components to create novel functionalities (Mazzucato, 2018).

By emphasizing improvisation, resourcefulness, and adaptability, bricolage remains a critical concept in entrepreneurship and innovation studies. It provides a theoretical framework for understanding how novel solutions emerge in resource-constrained environments, whether in social enterprises, crisis response, or technological development. Its role in fostering creativity and resilience continues to shape contemporary research on organizational adaptability and problem-solving.

2.6 Affordances

Affordances describe the potential actions enabled by an object or environment. Introduced by Gibson (1979) in ecological psychology, the concept emphasizes the relationship between perception and actionable possibilities. Norman (1988) later extended affordance theory to design, distinguishing between real affordances, which exist independently of perception, and perceived affordances, which depend on user interpretation. For example, a chair affords sitting, but its design may also suggest stacking or repurposing. Affordances have since become central in psychology, design, and human-computer interaction.

Gaver (1991) categorized affordances as perceptible or hidden, highlighting how design and context shape their interpretation. In cognitive science, Kirsh (1995) connected affordances to problem-solving and decision-making, while Greeno (1994) emphasized their role in situated cognition, where perception and action are co-determined by an agent's abilities and environmental opportunities. More recently, Heras-Escribano (2019) explored the ontological status of affordances, discussing their implications for philosophy of mind and cognitive science.

The interplay between affordances and exaptation is particularly evident in technological and social systems. Originally designed for personal communication, social media platforms have been exapted for activism and political mobilization, illustrating how users leverage affordances beyond their original intent (Zeng & Schäfer, 2021). Similarly, TikTok's recommendation algorithm, intended for entertainment, has facilitated social and political movements, demonstrating how algorithmic affordances shape emergent uses (Cotter, 2022).

In design and ergonomics, affordance theory informs user-centered design principles by ensuring that products signal their functionality effectively (Norman, 1999). Research on digital affordances has expanded this framework, analyzing how interface design influences user behavior (Leonardi, 2013). For instance, ephemeral messaging—initially introduced for casual social interactions—has been co-opted for privacy-conscious communication in business and political contexts, reflecting how affordances evolve with user needs (Bucher & Helmond, 2018).

Social affordances, referring to possibilities for interaction shaped by cultural norms, have also been widely examined (Scarantino, 2003). Recent studies highlight how affordances in digital environments influence collective action, as seen in the co-optation of social media by grassroots movements and misinformation campaigns alike (Van Dijck et al., 2018). These developments underscore how affordances extend beyond individual perception, shaping large-scale sociotechnical dynamics.

By bridging perception and action, affordances provide a powerful framework for understanding how individuals and systems interact with their environment. Their interdisciplinary relevance continues to shape research in design, cognitive science, and digital media, demonstrating the ongoing impact of affordance theory in contemporary discourse.

2.7 Effectuation

Effectuation describes an approach to decision-making in uncertain environments where entrepreneurs rely on existing resources, partnerships, and iterative learning rather than predictive planning. Sarasvathy (2001) introduced effectuation as an alternative to traditional causal reasoning, arguing that entrepreneurs navigate uncertainty by leveraging what they have rather than trying to predict future outcomes. This perspective has reshaped research in entrepreneurship, strategic management, and innovation studies.

Effectuation theory comprises five key principles: the bird-in-hand principle (starting with available means), the affordable loss principle (prioritizing actions that minimize risk), the crazy quilt principle (forming partnerships to expand resources), the lemonade principle (embracing contingencies), and the pilot-in-the-plane principle (focusing on control rather than prediction) (Sarasvathy, 2008). These principles challenge conventional business planning models, emphasizing adaptability over rigid forecasting.

Empirical studies have validated effectuation's relevance in entrepreneurial practice. Fisher (2012) compared effectuation with bricolage, noting that while both emphasize flexibility, bricolage focuses on resource recombination, whereas effectuation centers on leveraging stakeholder commitments. Arend, Sarooghi, and Burkemper (2015) examined its impact on firm performance, finding that effectual decision-making enhances resilience in volatile markets. More recently, Read et al. (2021) explored how effectuation supports rapid scaling in digital startups, particularly in sectors where uncertainty is high.

The rise of digital entrepreneurship has further highlighted the applicability of effectuation. Clubhouse, a social audio platform that grew rapidly during the COVID-19 pandemic, exemplifies this approach. Rather than following a predetermined business model, its founders iteratively adapted the platform based on user engagement, relying on network effects and exclusivity rather than structured market forecasts (Chen et al., 2022). Similarly, digital-first businesses like Shopify and Substack have thrived by embracing effectual logic, leveraging pre-existing infrastructure and community-driven adoption rather than traditional growth strategies (Nambisan, 2020).

Effectuation also intersects with crisis entrepreneurship. Research on responses to the COVID-19 pandemic found that many small businesses survived by adopting effectual strategies, shifting operations, forming ad hoc partnerships, and repurposing existing resources to navigate disruptions (Kuckertz et al., 2020). These findings align with earlier work on how effectuation fosters resilience in resource-scarce environments (Dew et al., 2009).

Despite its strengths, effectuation has been critiqued for lacking boundary conditions. Arend et al. (2015) questioned whether it is universally beneficial, arguing that some industries require predictive strategies. Others have noted the challenges of scaling effectual ventures, as iterative learning and reliance on partnerships may become inefficient in larger firms (Wiltbank et al., 2006). Nevertheless, effectuation remains a critical framework for understanding entrepreneurship under uncertainty, particularly in fast-evolving, technology-driven environments.

By emphasizing action over prediction, effectuation provides a robust alternative to deterministic planning models. Its interdisciplinary relevance continues to grow, shaping discussions in strategy, innovation, and digital transformation. As uncertain environments become the norm, effectuation's insights remain pivotal for both researchers and practitioners navigating complex, unpredictable markets.

2.8 Recombinant Innovation

Recombinant innovation refers to the creation of novelty by combining existing elements in new ways. Schumpeter (1934) introduced the concept of creative destruction, where established systems are dismantled to make way for innovation. Weitzman (1998) extended this idea, likening recombinant innovation to genetic recombination, where diverse inputs generate unique outputs. Arthur (2009) further elaborated by describing technology as a system of evolving components, emphasizing that technological development occurs through recursive recombination. This iterative synthesis is a fundamental driver of creativity, demonstrating how novelty often emerges through structured recombination rather than isolated ideation (Fleming & Sorenson, 2001). Fleming (2001) provided empirical evidence supporting this perspective, showing that inventions resulting from novel recombinations tend to have greater impact, as measured by patent citations.

Organizational research has examined how firms leverage recombinant innovation by acting as knowledge brokers. Hargadon and Sutton (1997) studied how firms facilitate the transfer and recombination of knowledge across industries, fostering innovation. Carnabuci and Operti (2013) explored the origins of firms' recombinant capabilities, finding that internal knowledge diversity and collaboration networks significantly influence a firm's ability to innovate. Similarly, Fleming and Waguespack (2007) analyzed open-source software development, showing that diverse collaboration networks enhance the potential for novel recombinations. Griffith et al. (2016) examined the impact of market frictions on recombinant innovation, demonstrating that barriers to knowledge transfer between firms can limit the efficiency of recombination processes.

The economic implications of recombinant innovation have been widely discussed. Jones (2009) argued that as the stock of knowledge expands, the potential for recombinant innovation grows, driving sustained economic development. This aligns with Kogut and Zander's (1992) view that firms exist because they are more efficient than markets at transferring and recombining knowledge, making them key agents of innovation. Recombinant innovation has also played a crucial role in environmental sustainability. Popp (2006) examined how existing technologies are recombined to develop solutions for environmental challenges, underscoring its significance in sustainable development and green technology.

Recent technological advancements illustrate the power of recombinant innovation. The CRISPR gene-editing tool exemplifies this process, transforming a bacterial defense mechanism into a revolutionary biotechnological application (Jinek et al., 2012; Wagner, 2014). Similarly, the fusion of artificial intelligence with molecular biology in AlphaFold represents a breakthrough in protein structure prediction, demonstrating how cross-disciplinary recombination accelerates scientific progress (Jumper et al., 2021). The rise of blockchain applications beyond cryptocurrency, such as decentralized finance (DeFi) and smart contracts, further highlights how existing technologies can be recombined to create novel functionalities (Schär, 2021).

Recombinant innovation is often associated with modularity, but these concepts are distinct. Modularity refers to the structural organization of components that allows for flexible reconfiguration, whereas not all recombinant processes rely on predefined interfaces (Baldwin & Clark, 2000). Some innovations emerge from the fusion of disparate elements, leading to novel, sometimes unpredictable breakthroughs (Fleming, 2001). Recognizing this distinction prevents conflation between structural modularity and the broader mechanisms of recombination.

By emphasizing the cumulative and evolutionary nature of innovation, recombinant innovation provides a framework for understanding technological progress, organizational learning, and economic development. It highlights how new ideas emerge not in isolation but through the creative synthesis of existing knowledge, reinforcing the interconnected nature of discovery and invention across disciplines.

This chapter has examined the eight theoretical constructs—exaptation, serendipity, emergence, co-optation, bricolage, affordances, effectuation, and recombinant innovation—providing a foundation for understanding how novelty arises in complex systems. In the next chapter, we explore the interplay between these constructs, analyzing how they interact dynamically to drive transformative processes across various domains.

3. Synthesis of Theoretical Constructs

This chapter provides a comprehensive examination of eight theoretical constructs—exaptation, serendipity, emergence, co-optation, bricolage, affordances, recombinant innovation, and effectuation—to elucidate their individual characteristics, interrelationships, and collective contributions to understanding adaptive and innovative processes within complex systems.

3.1 Introduction to Constructs

Understanding the mechanisms that drive adaptation and innovation in complex systems necessitates a detailed analysis of various theoretical constructs. Each construct offers a unique lens through which to view the emergence of novelty and the processes underpinning systemic change. By dissecting these constructs and exploring their intersections, we can develop a more nuanced comprehension of how innovative phenomena manifest across different contexts.

- **Exaptation:** The process by which traits, ideas, or technologies initially developed for one purpose are repurposedfor a different function, often in response to new opportunities (Gould & Vrba, 1982).
- **Serendipity:** The unexpected discovery of something valuable or functional, often as a byproduct of unrelated efforts (Roberts, 1989; Merton & Barber, 2004).
- **Emergence:** The spontaneous formation of complex structures, behaviors, or properties from simple interactions, yielding higher-order patterns not reducible to individual components (Holland, 1998; Arthur, 2009).
- **Bricolage:** The resourceful recombination of available materials, knowledge, or processes to solve problems or create value without predefined structures (Lévi-Strauss, 1966; Baker & Nelson, 2005).
- **Effectuation:** A mode of entrepreneurial action that prioritizes existing means and iterative adaptation over predictive, goal-driven strategies, enabling navigation of uncertain environments (Sarasvathy, 2001).
- **Affordances:** The action possibilities presented by an environment, shaped by an actor's perception and ability to interact with it (Gibson, 1979; Norman, 1988).
- **Co-optation:** The strategic incorporation of external individuals, groups, or ideas into an organization or system to mitigate threats or align incentives (Selznick, 1949).
- **Recombinant Innovation**: The generation of novelty through the reconfiguration and combination of existing knowledge components, technologies, or concepts (Schumpeter, 1934; Weitzman, 1998).

3.2 Comparisons and Distinctions of Constructs

3.2.1 Exaptation vs. Serendipity

Both exaptation and serendipity involve elements of the unforeseen in the innovation process. Exaptation refers to the process by which features acquire functions for which they were not originally adapted or selected (Gould & Vrba, 1982). In contrast, serendipity pertains to the accidental discovery of something valuable, often while searching for something else (Roberts, 1989). The critical distinction lies in intentionality: exaptation involves the recognition and subsequent utilization of a new function for an existing trait, whereas serendipity emphasizes the role of chance in making a beneficial discovery.

Example: Alexander Fleming's discovery of penicillin is often cited as serendipity: the mold's antibacterial properties were noticed by chance during unrelated research. However, when scientists later recognized its clinical potential and began mass-producing it for therapeutic use, this constituted exaptation — a repurposing of a previously overlooked phenomenon for a radically new function.

3.2.2 Exaptation vs. Emergence

Emergence refers to the process by which complex systems and patterns arise out of relatively simple interactions (Holland, 1998). While exaptation involves the repurposing of existing traits for new functions, emergence focuses on how novel properties or behaviors arise from the interactions among system components. Thus, exaptation is a mechanism that can occur within emergent systems, but emergence itself pertains to the broader phenomenon of new patterns arising without deliberate intent.

Examples: The internet's infrastructure emerged from the interconnectedness of computer networks. The use of this infrastructure for social media platforms represents exaptation, where existing technology was repurposed for new social functions. The rise of YouTube influencers illustrates both constructs. The emergent behavior — user-generated video culture — arose spontaneously from decentralized user interactions. The exaptation occurred when companies began using these platforms for influencer marketing, repurposing personal content channels as advertising vectors, a use not originally intended in the platform's design.

3.2.3 Exaptation vs. Bricolage

While both *exaptation* and *bricolage* involve creative reuse, they differ in mechanism, intention, and temporal orientation. *Exaptation* refers to the functional repurposing of existing traits, technologies, or ideas for new uses, typically in a different context than originally intended (Gould & Vrba, 1982). It is often recognized in hindsight and involves a shift in use rather than active recombination. In contrast, *bricolage* is an improvisational, agent-driven process in which actors recombine available resources to address immediate problems or opportunities in real time (Lévi-Strauss, 1966; Baker & Nelson, 2005).

Duymedjian and Rüling (2010) clarify that bricolage is best understood as a *practice*—a situated and often constrained form of problem-solving—whereas exaptation functions more as an *explanatory concept*, used to describe how features acquire new purposes retrospectively. Similarly, Andriani and Cattani (2016) emphasize that exaptation involves a *shift in interpretive frame*, revealing new value in an existing trait, whereas bricolage is embedded in the process of assembling novelty from whatever is at hand.

Example: The development of early personal computers involved bricolage, as hobbyists cobbled together parts from calculators, radios, and surplus hardware. The later use of these machines for gaming, graphic design, and word processing—far beyond their original intended function—illustrates exaptation: new purposes emerged not from design, but from the evolving socio-technical context and reinterpretation of capabilities.

3.2.4 Exaptation, Serendipity, and Effectuation

These constructs together illustrate a dynamic interplay of chance, strategy, and repurposing. Serendipity provides unplanned discoveries, effectuation offers the strategic framework to leverage them, and exaptation executes the repurposing (Sarasvathy, 2001; Merton & Barber, 2004).

Examples: The founding of Airbnb involved serendipity (recognizing the opportunity to rent out air mattresses), exaptation (repurposing living spaces for temporary lodging), and effectuation (utilizing available resources to build a platform connecting hosts and guests). The invention of the microwave oven stemmed from a serendipitous moment when Percy Spencer noticed a candy bar melted in his pocket near a magnetron. This chance observation led to the exaptation of radar technology for cooking food. Effectuation came into play as companies iteratively developed and marketed the microwave using existing resources (magnetrons, culinary needs, home appliances) without a clear market plan in advance.

3.2.5 Emergence, Affordances, and Co-optation

Affordances refer to the possibilities for action that objects or environments offer to an individual (Gibson, 1979). Co-optation involves the assimilation of new elements into an existing system, often to neutralize threats or exploit new opportunities (Selznick, 1949). Emergent properties can reveal new affordances, which organizations may co-opt to enhance their adaptability.

Examples: The emergence of social media platforms revealed affordances for mass communication, which political organizations co-opted to engage with constituents and mobilize support. The emergence of Reddit as a decentralized discussion forum created new affordances for mass participation and discourse. These affordances were later co-opted by brands and political actors to engage in meme-based marketing or influence public opinion. The affordance for upvoting and anonymity, originally intended to democratize conversation, was strategically absorbed into institutional campaigns.

3.2.6 Bricolage vs. Recombinant Innovation

Recombinant innovation involves creating new ideas or products by combining existing ones in novel ways (Weitzman, 1998). While bricolage emphasizes improvisation with available resources, recombinant innovation focuses on systematic recombination to generate novelty.

Examples: The smartphone represents recombinant innovation, integrating functionalities of a phone, camera, and computer. In contrast, bricolage is exemplified by entrepreneurs in resource-constrained environments who improvise solutions using whatever materials are at hand. Also, in the aftermath of natural disasters, grassroots engineers often engage in bricolage by creating makeshift water filtration systems using charcoal, sand, and plastic bottles — immediate, improvisational solutions. In contrast, recombinant innovation is seen in the development of desalination systems that combine nanotechnology, solar power, and data analytics to systematically create scalable, high-efficiency water purification solutions.

3.3 Categorizing Constructs: Distinctions and Theoretical Overlaps

To clarify the nuances among these constructs, we categorize them based on focus, role of context, temporal dynamics, and level of analysis. This classification draws on theoretical perspectives from complexity science, organizational theory, and innovation studies, ensuring that the constructs are framed in a way that reflects both their theoretical significance and practical implications.

The first dimension, focus, distinguishes constructs by their primary contribution to adaptation and innovation. Some constructs center on resource reconfiguration (such as bricolage and exaptation), emphasizing how existing elements are repurposed to create novel solutions. Others emphasize decision-making under uncertainty (such as effectuation and co-optation), focusing on strategies for navigating ambiguity and constraints. A third category highlights systemic emergence (such as affordances and emergence), where novel properties arise from interactions within broader environments. This classification aligns with research on innovation typologies (Schumpeter, 1934; Weick, 1995) and cognitive approaches to problem-solving, which distinguish between deliberate, agent-driven innovation and emergent, systemic change (Gavetti & Levinthal, 2000).

The second dimension, role of context, examines how constructs depend on external conditions or systemic structures. Some constructs, such as serendipity and emergence, are highly context-dependent, meaning their effects are contingent on broader environmental conditions rather than direct strategic intervention. Others, such as recombinant innovation and bricolage, involve agency-driven recombination, where actors deliberately reconfigure available resources within given constraints. This distinction builds on structuration theory (Giddens, 1984), which examines the reciprocal relationship between agency and systemic structures, and complexity science, which explores how adaptation arises from interactions between actors and environments (Holland, 1998; Kauffman, 1993).

The third dimension, temporal dynamics, differentiates between constructs that unfold through gradual, iterative processes and those that emerge unpredictably. For example, co-optation and effectuation involve longer-term adaptation, where relationships and strategic decisions evolve over time, while serendipity and emergence can trigger sudden transformations that shift innovation trajectories. Bricolage and recombinant innovation represent iterative processes, where experimentation and feedback loops drive progressive refinements. This classification is informed by research on path dependence and cumulative change (Arthur, 2009) and scholarship on organizational evolution and temporal perspectives in innovation (Garud & Karnøe, 2001).

The final dimension, level of analysis, differentiates constructs by whether they operate at the level of individual decision-making, organizational strategy, or broader systemic adaptation. Some constructs, such as effectuation and bricolage, are most relevant to entrepreneurs, designers, and decision-makers, emphasizing how individuals navigate uncertainty and resource constraints. Others, such as emergence and scalability, function at the network or ecosystem level, explaining how innovations diffuse and take root in larger systems. This classification aligns with research on multi-level innovation systems (Geels, 2002) and network science approaches to systemic change (Barabási, 2002), which highlight the importance of scale in understanding innovation dynamics.

By structuring the constructs along these four dimensions, this framework moves beyond merely listing them as discrete elements, positioning them within a coherent analytical structure. The classification is grounded in established theoretical foundations, ensuring alignment with both conceptual underpinnings and real-world applications. This approach enhances clarity and utility, enabling a deeper understanding of how these constructs interact to shape adaptation and innovation processes.

3.3.1 Focus

- Problem-Solving Constructs: Bricolage and effectuation are primarily concerned with addressing immediate challenges through resourcefulness and iterative strategies.
- Discovery-Oriented Constructs: Serendipity and exaptation involve uncovering new functions or opportunities, often unexpectedly.
- Systemic Constructs: Emergence and recombinant innovation pertain to the development of novel patterns or products through interactions within a system.

3.3.2 Role of Context

- Context-Dependent Constructs: Affordances and co-optation are heavily influenced by environmental factors, as they depend on the possibilities offered by the context and the strategic incorporation of external elements, respectively.
- Context-Independent Constructs: Bricolage, serendipity, and exaptation can occur regardless of specific environmental constraints, as they rely more on individual or organizational agency.

3.3.3 Temporal Dynamics

- Gradual Processes: Effectuation and recombinant innovation often unfold through iterative experimentation and recombination over time.
- Sudden Processes: Serendipity and exaptation typically emerge through unexpected discoveries or shifts in function.

3.3.4 Level of Analysis

- Individual-Level Constructs: Serendipity, effectuation, and bricolage are entrepreneurial or agent-drivenprocesses.
- System-Level Constructs: Emergence, co-optation, and recombinant innovation describe broader systemic transformations.

3.4 Construct Synergies in Innovation Systems

Innovative processes rarely operate through a single construct in isolation. Instead, multiple mechanisms—such as emergence, bricolage, effectuation, and serendipity—converge dynamically. These synergies create complex adaptive systems where novel solutions emerge from iterative experimentation, recombination, and strategic adaptation.

Example: Open-source platforms like Linux showcase this interaction: emergent contributions (Sawyer, 2005), bricolage in code development (Weick, 1993), effectual strategies by developers (Sarasvathy, 2001), and serendipitous breakthroughs combine to create a continuously evolving ecosystem.

This chapter thus provides a structured analysis of the constructs, reinforcing their comparative distinctions while highlighting the interdependencies that drive innovation. Table 1 provides a structured synthesis of the eight constructs analyzed in this chapter, categorizing them by their application, conceptual similarities, key distinctions, and systemic interactions. This comparative overview clarifies both the unique contributions of each construct and the synergies that emerge when they operate together. The next chapter will build on this framework, integrating these insights into actionable implications for theory and practice.

Table 1. Innovation Constructs, their Applications, Similarities and Distinctions

	Constructs	Application	Similarities	Distinctions	Combinations	References
1	Exaptation	Used in evolutionary biology, technology repurposing, and innovation to explain functional shifts in existing elements.	Resembles bricolage in its emphasis on creative reuse; linked to serendipity through unexpected opportunities.	Focuses on functional shifts rather than resource recombination or systemic properties.	Often paired with serendipity, bricolage, and emergence to enable transformative reuse.	Gould & Vrba (1982); Arthur (2009); Baker & Nelson (2005).
2	Serendipity	Commonly applied in scientific discoveries, innovation processes, and unexpected breakthroughs.	Shares commonality with exaptation in leveraging the unexpected; overlaps with effectuation in embracing unpredictability.	Centers on chance discoveries, unlike exaptation's emphasis on purposeful reuse or bricolage's creativity.	Commonly combined with exaptation and effectuation to leverage chance in strategic contexts.	Roberts (1989); Merton & Barber (2004); Sarasvathy (2001).
3	Emergence	Relevant in systems theory, complexity science, and organizational behavior to study systemic transformations.	Similar to exaptation and bricolage in focusing on systemic changes that enable novel uses.	Highlights higher-order properties arising from interactions, unlike bricolage or effectuation's agent-centric focus.	Frequently intersects with exaptation and affordances to provide contexts for novel transformations.	Holland (1998); Arthur (2009); Sawyer (2005).
4	Bricolage	Widely used in entrepreneurship, grassroots innovation, and resource-scarce environments.	Aligns with exaptation in repurposing; shares innovation aspects with recombinant innovation.	Emphasizes immediate resource creativity rather than systemic or functional transformations.	Works well with recombinant innovation and exaptation to develop modular, innovative solutions.	Lévi-Strauss (1966); Baker & Nelson (2005); Weick (1993).
5	Effectuation	Focused on entrepreneurship, strategic decision-making under uncertainty, and new venture creation.	Overlaps with bricolage in resource adaptability and with serendipity in leveraging surprises.	Stresses strategic action and stakeholder commitment under uncertainty, unlike bricolage's improvisation.	Combines effectively with serendipity and bricolage to adaptively exploit unexpected opportunities.	Sarasvathy (2001); Dew et al. (2009); Perry et al. (2012).
6	Affordances	Applied in design, human-computer interaction, and environmental psychology to explore actionable	Relates to emergence in revealing new opportunities; overlaps with exaptation in highlighting latent possibilities.	Examines actionable opportunities in the environment, unlike the systemic focus of emergence or strategic focus of effectuation.	Often paired with emergence and co-optation in design and organizational innovation.	Gibson (1979); Norman (1988); Greeno (1994).
7	Co-optation	Found in organizational theory, political science, and social movement studies for aligning external elements with internal goals.	Similar to effectuation in aligning stakeholders and bricolage in creatively integrating external elements.	Focuses on neutralizing threats by incorporating external elements, unlike bricolage or emergence.	Intersects with emergence and bricolage in aligning external resources for systemic stability.	Selznick (1949); Linz (1970); Coy & Hedeen (2005).
8	Recombinant Innovation	Used in technological innovation, economic growth, and cross-disciplinary knowledge recombination.	Shares commonality with bricolage in resource recombination and with emergence in systemic innovation.	Centers on structured recombination of knowledge, differing from bricolage's improvisation or exaptation's repurposing.	Works closely with bricolage and emergence to create breakthrough innovations.	Schumpeter (1934); Weitzman (1998); Hargadon & Sutton (1997).

4. Toward A Unified Framework for Transformative Adaptation

This chapter develops a comprehensive framework that integrates the eight constructs—exaptation, serendipity, emergence, co-optation, bricolage, affordances, recombinant innovation, and effectuation—to explain how systems adapt, innovate, and thrive in dynamic environments. By synthesizing insights from these constructs, the framework offers a multidimensional perspective on transformative adaptation. It bridges academic theory with actionable strategies, providing both scholars and practitioners with tools to navigate uncertainty and drive innovation. The framework's utility is illustrated through real-world applications across fields, including technology, design, entrepreneurship, and social systems.

4.1 Foundations of the Framework

The unified framework is built on three core principles that explain how transformative adaptation unfolds within complex systems. These principles draw from interdisciplinary research in innovation studies, complexity science, and social theory, offering both explanatory depth and practical applicability. By emphasizing repurposing, agency, and iterative collaboration, the framework provides a structured approach to understanding adaptive processes across diverse fields, including technology, design, entrepreneurship, and social transformation.

Each principle is supported by well-established theoretical constructs and real-world applications, underscoring the importance of flexibility, responsiveness, and creative problem-solving in navigating dynamic environments.

Repurposing and Recombination: Transformative adaptation leverages existing elements—structures, traits, or ideas—for new purposes through repurposing and recombination. These mechanisms involve:

- Identifying latent affordances—recognizing potential uses of existing structures (Gibson, 1979; Norman, 1999).

- Recombining elements creatively—integrating disparate components into novel configurations (Weitzman, 1998; Arthur, 2009).

This principle builds on exaptation (where functions evolve beyond their original purpose) and recombinant innovation (where existing knowledge is recombined in new ways).

Example: The CRISPR gene-editing tool exemplifies repurposing and recombination. Initially studied as a bacterial immune response, CRISPR was later exapted for genetic engineering, combining molecular biology techniques to revolutionize medicine (Doudna & Charpentier, 2014).

Interplay of Agency and Context: This principle emphasizes the dynamic interaction between individual agency and systemic context. Adaptation and innovation are shaped by both:

- Strategic agency—how individuals and organizations navigate uncertainty using effectual logic (Sarasvathy, 2001).

- Environmental affordances—how emergent conditions enable new opportunities (Holland, 1998; Merton & Barber, 2004).

Broader sociological theories such as structuration theory (Giddens, 1984) and projective agency (Emirbayer & Mische, 1998) provide further grounding for understanding how agents shape and are shaped by their environments.

Example: The rise of ride-sharing platforms (e.g., Uber, Lyft) illustrates this interplay.

Entrepreneurs leveraged existing infrastructures (GPS, mobile payments) while responding to emergent consumer behaviors (preference for on-demand mobility), combining agency-driven innovation with contextual opportunities.

Iterative and Collaborative Processes: Innovation emerges through experimentation, feedback, and collaboration, emphasizing:

- Iterative problem-solving—adapting strategies through continuous experimentation (Lévi-Strauss, 1966; Weitzman, 1998).
- Collective contributions—harnessing networked collaboration (Hargadon & Sutton, 1997; Chesbrough, 2003).

This principle aligns with open innovation ecosystems, where problem-solving is distributed across stakeholders.

Example: The development of Linux illustrates how open-source collaboration accelerates adaptation. Developers iteratively refine the codebase, recombining contributions from a decentralized community to create a continually evolving system (Sawyer, 2005; Raymond, 1999).

4.2 Dimensions of the Framework

The proposed framework is structured around four interconnected dimensions that collectively capture the process of transformative adaptation. Each dimension represents a critical phase in navigating complex environments and sustaining innovation. The process begins with exploration, where latent opportunities are uncovered through emergent properties and chance discoveries. These insights feed into recombination, where elements are synthesized in novel ways to generate innovative solutions. Next, the action phase ensures these opportunities are effectively leveraged through strategic implementation. Finally, scalability determines whether innovations become embedded within broader systems, achieving sustained impact. By structuring the adaptation process into these four dimensions, the framework provides a systematic yet flexible approach to understanding and harnessing innovation dynamics.

Exploration focuses on identifying latent possibilities within existing elements. It draws on constructs such as serendipity, emergence, and affordances, which reveal new opportunities either accidentally or through intentional inquiry. Serendipity enables unexpected discoveries of valuable innovations (Roberts, 1989; Merton & Barber, 2004). Emergence highlights how novel affordances arise from systemic interactions (Holland, 1998), while affordances define how environmental features create action possibilities (Gibson, 1979; Norman, 1999). Exploratory innovation processes (March, 1991) illustrate how organizations shift between searching for new opportunities and refining existing capabilities. The discovery of graphene as a highly conductive material through research on carbon structures exemplifies how exploratory research can lead to breakthrough applications in electronics and medicine (Novoselov et al., 2004).

Recombination builds on exploration by creatively integrating elements to form novel solutions. It relies on constructs such as exaptation, bricolage, and recombinant innovation, which facilitate the synthesis of disparate ideas, resources, and technologies. Exaptation enables elements to acquire new functions beyond their original purpose (Gould & Vrba, 1982). Bricolage allows innovators to repurpose available materials in novel ways (Lévi-Strauss, 1966; Baker & Nelson, 2005). Recombinant innovation generates novelty through structured recombination (Weitzman, 1998; Hargadon & Sutton, 1997). Empirical studies on technological recombination (Fleming, 2001) and technology brokering (Hargadon & Sutton, 1997) highlight how cross-domain knowledge transfer enhances innovation. The development of mRNA COVID-19 vaccines combined decades of virology research with lipid nanoparticle delivery systems, demonstrating rapid medical innovation (Pardi et al., 2018).

Action emphasizes the implementation of innovation strategies by leveraging agency and stakeholder alignment. Constructs such as effectuation and co-optation drive this phase by enabling organizations to act decisively under uncertainty. Effectuation prioritizes using available means to iteratively shape opportunities (Sarasvathy, 2001), while co-optation involves incorporating external actors and resources to stabilize or scale an innovation (Selznick, 1949). Entrepreneurial strategy theories (Mintzberg et al., 1998; Shane & Venkataraman, 2000) further elaborate on how firms execute innovation in dynamic environments. The rise of Tesla in the electric vehicle industry demonstrates action-oriented innovation, as it leveraged government incentives, infrastructure partnerships, and an iterative market strategy to establish a dominant position (Bohnsack et al., 2014).

Scalability addresses the amplification and diffusion of innovations within broader systems. Constructs such as emergence and recombinant innovation ensure that innovations become sustainable and widely adopted. Emergence facilitates network-driven expansion through self-organizing interactions (Holland, 1998), while recombinant innovation enables modular and scalable solutions through iterative improvements (Weitzman, 1998). Network effects (Barabási, 2002) and diffusion of innovations (Rogers, 2003) highlight mechanisms that enhance adoption and institutionalization of transformative changes. The growth of open-source software ecosystems, such as Linux and Android, illustrates how decentralized innovation benefits from emergent user contributions and network-driven scalability, fostering global impact (Raymond, 1999).

A figure presents the Framework for Transformative Adaptation, illustrating how systems navigate complex environments through four interconnected dimensions: Exploration, Recombination, Action, and Scalability. These dimensions structure the adaptive process by linking theoretical constructs that drive innovation, recombination, and expansion of novel solutions (Figure 1).

Exploration serves as the starting point, where affordances, serendipity, and emergence reveal latent possibilities within existing systems. These insights feed into Recombination, where mechanisms such as exaptation, bricolage, and recombinant innovation facilitate the synthesis of ideas and resources into viable innovations. In the Action phase, innovation is implemented and strategically expanded through effectuation and co-optation, ensuring alignment with real-world constraints and opportunities. Finally, Scalability determines whether innovations diffuse widely, driven by emergence and recombinant innovation, allowing systemic integration and widespread impact.

The diagram also depicts feedback loops that highlight the iterative nature of transformative adaptation. Successful innovations at the Scalability stage often alter systemic constraints and affordances, thereby influencing future Exploration cycles. This dynamic interplay ensures that adaptation remains continuous, responsive, and systemic. By structuring adaptation into these four interdependent phases, the framework provides a systematic yet flexible approach to understanding how complex systems evolve, innovate, and sustain long-term transformation.

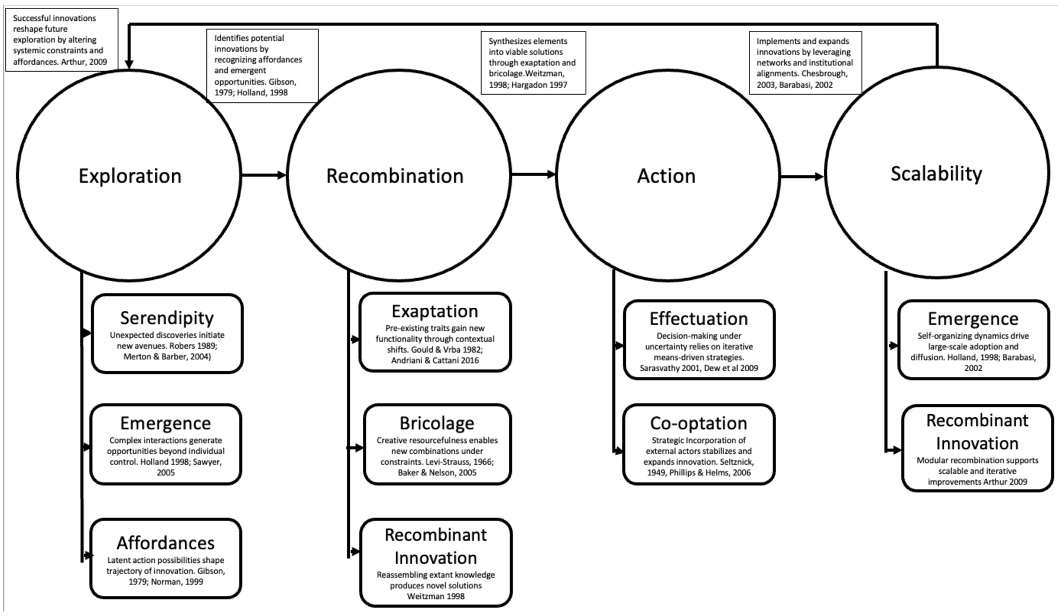

Figure 1. Framework for Transformative Adaption: Constructs, Dimensions and Process Flow

4.3 A Systemic View: Construct Interplay as Co-Evolution

4.3.1 A Systemic View — Innovation as a Co-Evolving Meshwork of Constructs

The previous figure (Figure 1) articulates the four core phases of the framework—Exploration, Recombination, Action, and Scalability—and aligns each with its corresponding set of constructs. It provides a structured, processual representation of how systemic innovation can unfold. However, innovation in complex environments rarely adheres to stable or sequential pathways. The reality is often more recursive, fluid, and contextually shaped by entangled relationships between constructs. This dynamic has been implicitly present throughout the paper—surfacing in the comparative examples, and subtly embedded in the feedback loops of the framework itself. Here, we make it explicit.

The visual that follows (Figure 2) offers a complementary lens: it presents the framework not as a modular sequence but as what Tim Ingold (2007) calls a meshwork—an evolving, entangled system of relational threads rather than fixed nodes. Unlike networks, which consist of static points connected by defined links, a meshwork is composed of lines in motion—lines of becoming. It foregrounds the emergent, unfolding, and reciprocal nature of the innovation process. In this light, the constructs in our framework are not isolated tools, nor are they chronologically locked; they are generative logics that continuously nourish, inform, and co-activate each other.

The arrows in Figure 2 are intentionally interpretive rather than deterministic. They suggest potential pathways of mutual resonance, catalytic amplification, or feedback loops, depending on situational and temporal factors. For instance, bricolage may surface affordances that enable exaptation, while serendipity might both emerge from and trigger effectuation. Constructs like co-optation may follow exaptation in one context and precede it in another. These interrelations, while unpredictable in their order, remain patterned and intelligible within the systemic logic of transformation.

Thus, the figure does more than symbolize fluidity; it affirms the ontological stance of the framework itself: that transformative innovation operates not through rigid modules, but through a co-evolving meshwork of constructs. This aligns with theoretical perspectives on innovation as a complex adaptive system (Capra & Luisi, 2014; Kauffman, 1993; Mitleton-Kelly, 2003), and with organizational theory that views change as a process of becoming rather than static change management (Tsoukas & Chia, 2002).

In reframing the constructs this way, we lay the conceptual groundwork for the next section. The practical tools and strategies that follow are not checklists to be deployed linearly, but invitations to engage dynamically with an unfolding system—one in which meaning, novelty, and action emerge through situated interaction.

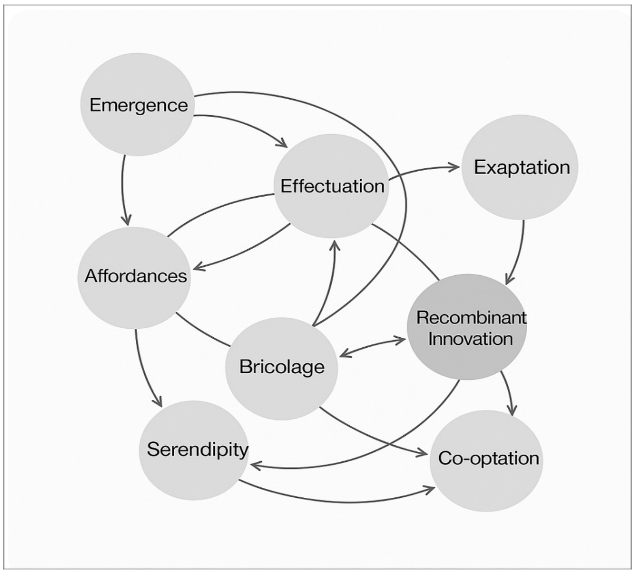

Figure 2. Innovation as a Co-evolving Meshwork of Constructs

5. Operationalizing the Framework in Practice

Operationalizing the unified framework requires translating its theoretical principles into structured, evidence-based applications. This involves identifying real-world contexts where the constructs can drive meaningful change, supported by validated methodologies and clear, actionable steps. By applying the framework across domains such as technology, design, entrepreneurship, and social systems, practitioners can leverage its multidimensional insights to foster innovation and adaptability.

To provide both an academic and practical perspective, we introduce two structured tables that serve as complementary guides for different audiences. Table 2 presents an advanced theoretical synthesis, mapping the framework's constructs within the broader academic discourse. It explores the epistemological foundations, theoretical mechanisms, and systemic implications of transformative adaptation. Table 3, in contrast, provides a hands-on roadmap for scholars and practitioners, translating these insights into a structured implementation guide for real-world innovation strategies.

5.1 Technology and Innovation

The rapid pace of technological change necessitates adaptive strategies that enable firms to remain competitive. The unified framework helps organizations systematically identify and repurpose latent opportunities, creatively recombine resources, and scale innovations effectively. Table 3 outlines how practitioners can apply this process through structured steps and decision-making tools.

Case Study: AI-Generated Drug Discovery

AI-driven drug discovery exemplifies the framework's adaptability. Language models originally developed for text processing were repurposed to predict molecular interactions, leading to breakthroughs in antibiotic and antiviral discovery (**exploration**) (Stokes et al., 2020). AI algorithms were then recombined with biomedical datasets, producing automated compound screening systems that drastically accelerated drug development (**recombination**). Startups iteratively tested these AI-derived drug candidates, bypassing conventional R&D bottlenecks through lean, data-driven experimentation (**action**). Pharmaceutical giants subsequently integrated AI-driven molecular design into their research pipelines, establishing it as a standard in biotech innovation (**scalability**) (Jumper et al., 2021).

Implementation Guide

1. Identify **dormant affordances** in existing technologies that could be repurposed.

2. Facilitate **interdisciplinary fusion**, breaking knowledge silos to accelerate recombination (Hargadon & Sutton, 1997).

3. Use **iterative prototyping**, validating hypotheses through rapid AI-driven experiments.

4. Deploy **networked scalability**, integrating open-source collaborations or modular architectures.

Practical Template: Applying the Framework to Technology Innovation

- What underutilized computational or material affordances exist?
- How can AI, automation, or modularity recombine elements in novel ways?
- What experimental validation processes minimize risk while maximizing learning?
- How can emergent ecosystems drive systemic transformation?

5.2 Design and Human-Centered Innovation

Design innovation emphasizes the importance of user-centered solutions and iterative prototyping, aligning closely with the principles of transformative adaptation. The framework provides a structured yet flexible approach to integrating diverse resources and insights into the design process.

Case Study: Smart Wearables for Continuous Health Monitoring

Smart health wearables illustrate adaptive design. Biometric sensors, initially developed for clinical diagnostics, were repurposed for real-time consumer health monitoring (**exploration**) (Bonato, 2020). These sensors were then recombined with AI-driven analytics and cloud connectivity, allowing for predictive diagnostics and early disease detection (**recombination**). Companies launched iterative product versions, refining their models based on user engagement and clinical feedback (**action**) (Steinhubl et al., 2017). Adoption surged as insurance companies and healthcare providers incorporated wearables into preventive care systems, reshaping the patient-provider dynamic (**scalability**).

Implementation Guide

1. Identify **hidden affordances** in materials, interfaces, or bio-integrated sensors.
2. Leverage **recombinant prototyping**, merging disparate fields (e.g., neurology, AI, and material science).
3. Implement **real-world validation**, refining based on longitudinal user behavior.
4. Cultivate **ecosystem adoption**, integrating with healthcare infrastructure and digital platforms.

Practical Template: Applying the Framework to Design

- What overlooked affordances in user interaction or material science can be exploited?
- How can cross-industry collaboration lead to disruptive recombinations?
- What iterative feedback loops ensure high adaptability?
- How can network effects drive adoption and long-term impact?

5.3 Entrepreneurship and Startups

Startups thrive on rapid iteration, leveraging scarce resources, and embedding innovation into scalable models. The framework equips them with structured tools to identify opportunities, recombine resources, and scale solutions effectively.

Case Study: The Creator Economy and Decentralized Work Platforms

Decentralized creator platforms demonstrate the power of recombinant entrepreneurship. The inefficiency of traditional publishing models and content monetization highlighted an overlooked affordance: direct creator-to-audience relationships (**exploration**) (Nambisan, 2020). Entrepreneurs recombined payment processing, subscription tiers, and community engagement mechanisms, enabling creators to monetize without intermediaries (**recombination**). Early-stage platforms operated iteratively, refining models through direct engagement with creators and audiences (**action**). These platforms scaled through emergent creator ecosystems, reinforcing network effects that reshaped independent media, journalism, and digital employment (**scalability**) (Zeng & Schäfer, 2021).

Implementation Guide

1. Identify **latent market inefficiencies**, recognizing underutilized assets (e.g., audience networks, peer-to-peer transactions).

2. Use **resource recombination**, integrating financial, digital, and community-driven models.

3. Apply **effectuation**, prioritizing iterative experimentation and early customer engagement.

4. Design for **self-reinforcing growth**, embedding viral loops and participatory adoption mechanisms.

Practical Template: Applying the Framework to Startups

- What untapped assets (digital, physical, or social) could be leveraged for new business models?
- How can rapid prototyping validate new market solutions?
- How do partnerships mitigate early risk and accelerate market entry?
- How can community-driven network effects drive sustainable scalability?

5.4 Social Systems and Policy

Addressing complex social challenges requires systemic approaches that leverage emergent properties and network-driven innovations. The framework enables policymakers and social innovators to design interventions that are adaptive, scalable, and sustainable.

Case Study: Digital Public Infrastructure for Financial Inclusion

The emergence of digital public infrastructure illustrates systemic transformation. The widespread use of mobile networks in low-income economies revealed an affordance for financial inclusion (**exploration**) (Ghosh, 2022). Developers recombined mobile banking, biometrics, and secure digital ledgers, creating frictionless financial transactions (**recombination**). Governments and fintech firms piloted these systems, refining them based on real-world financial behaviors (**action**). Over time, mass adoption reshaped national financial landscapes, embedding real-time digital transactions into everyday economic life (**scalability**) (UNDP, 2023).

Implementation Guide

1. Identify **structural affordances** that can be repurposed for financial or civic innovation.

2. Facilitate **cross-sector recombination**, integrating private, public, and technological assets.

3. Use **policy experimentation**, iterating in real-world regulatory environments.

4. Design for **institutional scalability**, ensuring governance models sustain systemic transformation.

Practical Template: Applying the Framework to Policy Innovation

- What existing infrastructures (physical, digital, or regulatory) can be reconfigured for broader public benefit?
- How can multi-stakeholder collaboration accelerate adoption?
- What experimental governance models ensure adaptability?
- How can policy frameworks institutionalize systemic resilience?

5.5 Synergies Across Constructs

The unified framework demonstrates that transformative adaptation arises from the interplay of constructs rather than their isolated application. By synthesizing insights across multiple theoretical dimensions, the framework reveals how their combined use can drive systemic innovation. Rather than functioning independently, constructs interact dynamically, reinforcing innovation trajectories at different stages of adaptation.

To deepen this understanding, Table 2 provides a theoretical synthesis, categorizing the constructs based on their epistemological foundations, strategic mechanisms, and systemic implications. This academic perspective highlights how knowledge recombination, iterative adaptation, and institutional scaling operate within evolutionary innovation pathways.

The early stages of transformative adaptation involve identifying and recombining latent affordances. Constructs such as exaptation, serendipity, and bricolage illustrate how existing resources and ideas can be creatively reinterpreted and applied in new contexts. Table 2 provides a structured exploration of these constructs, emphasizing their theoretical significance and scholarly lineage.

Serendipitous discoveries often uncover hidden affordances, which are then exapted for novel functions and further refined through bricolage (Gould & Vrba, 1982; Roberts, 1989; Baker & Nelson, 2005). This interplay is evident in AI-driven drug discovery, where machine learning models developed for natural language processing were exapted for molecular prediction, unlocking new pharmaceutical pathways (Stokes et al., 2020; Jumper et al., 2021). Similarly, the adaptation of biometric sensors into consumer-grade health wearables exemplifies how latent affordances can be harnessed and iteratively refined for new applications (Bonato, 2020; Steinhubl et al., 2017).

The mid-stages of adaptation highlight how emergent opportunities are leveraged through decision-making strategies and systemic mechanisms. Constructs such as emergence, effectuation, and recombinant innovation explain how opportunities arise from self-organizing system properties and are translated into scalable innovations (Holland, 1998; Sarasvathy, 2001; Weitzman, 1998). Entrepreneurs and designers iteratively recombine knowledge elements, adapting to uncertainty through effectual reasoning and networked interactions. The creator economy provides a contemporary example, where digital platforms such as Patreon and Substack evolved from emergent user needs, recombining subscription models, direct audience engagement, and monetization tools into scalable ecosystems (Nambisan, 2020; Zeng & Schäfer, 2021). This interaction is also evident in blockchain-based decentralized finance (DeFi), where financial services were reconfigured using smart contracts, reducing reliance on traditional banking structures while enhancing systemic resilience (Schär, 2021).

The final stages of adaptation emphasize the strategic integration and scaling of innovations. Constructs such as co-optation and scalability illustrate how networks, institutional alignment, and systemic properties amplify the reach and sustainability of transformative solutions (Selznick, 1949; Barabási, 2002). Through co-optation, innovations align with existing organizational structures, industries, or regulatory frameworks, ensuring long-term viability. Digital public infrastructure, such as India's Unified Payments Interface (UPI), exemplifies this process, where mobile banking affordances were co-opted into national payment systems, integrating fintech startups, government institutions, and traditional banks into a single interoperable ecosystem (Ghosh, 2022; UNDP, 2023). Scalability is further reinforced through modularity and network effects, as seen in open-source ecosystems such as Linux and the continued expansion of AI-driven medical diagnostics (Raymond, 1999; Topol, 2019).

By integrating these constructs into a holistic framework, the study provides a robust lens for understanding and driving innovation across diverse contexts. Table 3 translates this conceptual synthesis into a structured roadmap for direct application, ensuring that both scholars and practitioners can leverage the framework effectively. The next chapter will build on this foundation by proposing specific pathways for applying this framework in dynamic and uncertain environments, offering concrete guidance for fostering transformative adaptation in both research and practice.

Table 2. Theoretical Framework for Transformational Adaptation

Theoretical Dimension	Conceptual Focus	Key Constructs	Theoretical Foundations	Analytical Framework	Case Studies	Recent References
Epistemology of Latent Potential	Understanding the conditions under which affordances emerge and are recognized as innovation catalysts.	Serendipity, Affordances, Emergence	Gibson (1979); March (1991); Norman (1999); Kauffman (1993)	• How do affordances become perceptible within a given epistemic framework? • What role does serendipity play in affordance recognition and innovation emergence? • How do systemic constraints shape the interpretation of latent possibilities?	AI-generated drug discovery: Analyzing affordance recognition in generative models and molecular design (Stokes et al., 2020).	Felin et al. (2023); Rezaee & Shafique (2022) – On affordances in AI and decision-making.
Mechanisms of Recombinant Innovation	Analyzing how knowledge recombination, exaptation, and bricolage enable the synthesis of novel constructs.	Exaptation, Bricolage, Recombinant Innovation	Gould & Vrba (1982); Weitzman (1998); Hargadon & Sutton (1997); Arthur (2009)	• How does exaptation enable recombination beyond conventional adaptation? • What role does bricolage play in assembling modular innovation components? • How do constraints and enabling conditions shape recombinant innovation pathways?	Fusion of AI and robotics: Tracing exaptive pathways in neural network-based automation (Arthur, 2009).	Andriani & Cattani (2021); Dobusch et al. (2020) – Exaptation and knowledge recombination in innovation.
Iterative Adaptation in Complex Systems	Exploring feedback loops, path dependence, and adaptation through evolutionary systems thinking.	Open Innovation, Effectuation, Path Dependency	Chesbrough (2003); Holland (1998); Sarasvathy (2001); Garud & Karnøe (2001)	• How do iterative feedback mechanisms refine adaptation strategies? • What role does open innovation play in fostering knowledge recombination? • How does effectuation facilitate strategic navigation of uncertainty in dynamic systems?	Open-source ecosystems: The role of iterative knowledge flows in open AI and decentralized innovation (Chesbrough, 2003).	Bogers et al. (2019); Yun et al. (2022) – Open innovation, adaptive ecosystems, and digital experimentation.
Strategic Navigation of Uncertainty	Examining the role of effectuation, emergence, and institutional co-optation in shaping strategic action.	Effectuation, Co-optation, Adaptive Strategy	Sarasvathy (2001); Mintzberg et al. (1998); Shane & Venkataraman (2000); Giddens (1984)	• How do actors navigate uncertainty using effectual logic versus predictive strategies? • What are the structural conditions for institutional co-optation in innovation ecosystems? • How do emergent processes shape adaptive strategic decision-making?	Effectual reasoning in digital transformation: Examining emergent strategies in the evolution of creator economy platforms (Nambisan, 2020).	Felin & Zenger (2020); Von Krogh et al. (2018) – Effectuation, emergent strategy, and uncertainty navigation.
Scaling Dynamics and Institutional Embedding	Mapping diffusion mechanisms, network effects, and modularity as systemic drivers of scalability.	Scalability, Network Effects, Institutional Coherence	Barabási (2002); Rogers (2003); Holland (1998); Geels (2002)	• What network structures facilitate innovation scaling? • How do modularity and systemic embeddedness interact in large-scale innovation diffusion? • What institutional mechanisms enable sustained adaptation and system-wide transformation?	Institutional integration of digital payment networks: Understanding systemic adoption of UPI and mobile banking (Geels, 2002).	Liu et al. (2021); Teece (2023) – Scaling dynamics, modularity, and institutional adoption.
Path Dependency and Evolutionary Trajectories	Investigating long-term institutionalization, regulatory adaptation, and the structuration of innovation.	Path Dependency, Evolutionary Economics, Structuration Theory	David (1985); Pierson (2000); Arthur (2009); Mahoney (2000)	• How do path-dependent constraints shape long-term innovation trajectories? • What are the implications of evolutionary economic models for institutional adaptation? • How do structuration processes embed innovation within regulatory and governance frameworks?	Path-dependent technological transitions: The role of regulatory co-evolution in AI governance and policy adaptation (Pierson, 2000).	Garud et al. (2019); Altman & Tushman (2022) – Path dependency, structuration, and regulatory co-evolution.

Table 3. Implementation Roadmap for Practitioners

Application Phase	Key Strategic Questions	Step-by-Step Execution Guide	Practitioner's Toolkit	Case Study Example
Opportunity Scouting - Identifying Emerging Trends	• What emergent trends and market shifts indicate new opportunities? • How can AI-driven analytics or scenario planning identify high-impact areas? • What early signals of disruption can be leveraged?	1. Conduct market foresight analysis and technology horizon scanning. 2. Use AI-driven trend detection and competitive intelligence to anticipate shifts. 3. Engage in speculative prototyping to explore radical possibilities.	• Trend Mapping Framework • AI-Powered Market Foresight Tools • Competitive Intelligence Dashboards	OpenAI & Google DeepMind: Using AI-driven foresight to identify emerging capabilities in generative AI.
Exploration - Detecting Latent Affordances	• What underutilized affordances exist in existing systems or technologies? • How can serendipitous discoveries be systematized into structured innovation? • What hidden assets (data, materials, behaviors) could serve new functions?	1. Map overlooked affordances and emerging patterns in user behavior. 2. Conduct scenario planning exercises to uncover potential latent functionalities. 3. Build lightweight conceptual prototypes to test affordance potential.	• Affordance Mapping Toolkit • Scenario Planning Framework • Behavioral Data Analytics	AI-driven healthcare diagnostics: Identifying hidden patient biometrics for predictive disease modeling.
Recombination - Creating Novel Solutions	• How can cross-domain recombination generate unique solutions? • What modular frameworks allow for flexible adaptation of existing technologies? • How can exaptation and bricolage drive creative repurposing?	1. Establish interdisciplinary collaboration teams to merge insights across domains. 2. Prototype and test recombined technologies before full-scale integration. 3. Apply effectuation—leveraging existing capabilities rather than waiting for ideal conditions.	• Recombinant Innovation Playbook • Modular Technology Prototyping Toolkit • Cross-Sector Collaboration Models	Fusion of AI and robotics: Tesla integrating neural networks for self-learning vehicle automation.
Iterative Experimentation - Testing and Refining Concepts	• What iterative prototyping methods can ensure real-world validation? • How can A/B testing, live pilots, or simulated environments optimize innovation? • What stakeholder engagement strategies refine product-market fit?	1. Deploy small-scale pilots with iterative testing cycles. 2. Utilize machine learning and behavioral analytics to refine iterations. 3. Engage in open-source collaboration to co-develop solutions with communities.	• Lean Prototyping & A/B Testing Tools • AI-Driven Product-Market Fit Analytics • Stakeholder Co-Design Framework	Open-source AI models (Stable Diffusion, Hugging Face): Iterative community refinement of deep learning models.
Adoption and Market Validation	• What strategies ensure user adoption and behavioral alignment? • How can network effects be designed into market expansion? • What partnerships enhance legitimacy and trust?	1. Conduct user adoption modeling and behavioral analysis. 2. Establish credibility through partnerships with trusted institutions. 3. Design seamless onboarding experiences to accelerate market penetration.	• Adoption & Diffusion Modeling Tools • Behavioral UX Optimization • Strategic Trust-Building Playbook	Scaling Web3 creator platforms: Expanding decentralized revenue models for digital workspaces.
Scaling & Systemic Integration	• What mechanisms enable large-scale adoption and ecosystem expansion? • How can modularity, platform thinking, and regulatory integration reinforce scaling? • How do co-optation strategies align innovation with systemic interests?	1. Develop a networked scaling strategy that integrates emergent adoption patterns. 2. Implement modular and API-driven systems for adaptability. 3. Align with regulatory bodies to ensure compliance and strategic expansion.	• Platform Scaling Strategy Guide • Open Innovation & API Ecosystem Tools • Policy Integration Blueprints	M-Pesa and UPI: Leveraging mobile financial infrastructure for large-scale economic inclusion.
Long-Term Institutionalization & Policy Alignment	• How can policy frameworks support long-term viability? • What governance models ensure regulatory adaptability and institutional buy-in? • How can large-scale funding mechanisms sustain transformation?	1. Secure institutional support through public-private partnerships. 2. Develop adaptive policy frameworks that accommodate future innovation cycles. 3. Establish long-term funding models for sustained impact.	• Public-Private Partnership Frameworks • Adaptive Governance Models • Sustainable Funding Mechanisms	Regulatory AI frameworks: Establishing long-term governance models for ethical AI deployment in policy.

5.6 Practicing in the Meshwork: A Pragmatic Invitation

The notion of a co-evolving meshwork of constructs—entangled, recursive, and fluid—may initially appear disorienting to practitioners accustomed to planning tools, structured roadmaps, and clear phases. It resists linear sequencing and eludes prediction. However, this complexity is not a source of paralysis. Rather, it is the very soil from which novelty, opportunity, and strategic advantage grow.

Within this meshwork, constructs do not follow one another in predictable order. They co-arise, resonate, and reconfigure depending on local contexts and evolving constraints. Innovation emerges not from a master plan, but from attentive engagement with what the system is offering—often in subtle or oblique forms. Occasionally it arrives with fanfare, but more often it appears as a faint signal at the periphery, or as what might be called a bleeding T-bone steak: an opportunity so glaring that it demands recognition, yet easily missed by leaders trained to trust dashboards over dynamics.

Recognising these signals—knowing when the system is inviting engagement—requires more than analytical skill. It demands what might be called contextual acuity: a capacity to sense evolving patterns, interpret emerging logics, and respond in ways that are timely, relationally attuned, and humble. This is not a retreat from strategy. It is strategy recast as an ongoing practice of situated judgment.

As Tsoukas and Chia (2002) remind us, transformation is not imposed upon an organisation; it emerges through "a continuous reweaving of actors' webs of beliefs and habits of action." This reweaving is neither top-down nor accidental—it is enabled through organisational conditions that allow for oxygen: the interpretive, temporal, and structural space in which constructs can interact, new configurations can be explored, and adaptive sense-making can flourish. Organisations that rigidly pursue efficiency or procedural control often suffocate these possibilities (Argote & Hora, 2017).

It is important to recognise that many leaders have been modelled—and rewarded—for exercising control, prediction, and risk minimisation. These instincts are not inherently flawed. They have been functional in many contexts. However, in conditions of complexity and systemic emergence, they become maladaptive. Letting go—not of accountability, but of the illusion of full control—becomes a strategic act of maturity.

As Stacey (2011) argues, leadership in such contexts is not about directing from above but about participating in the emergent flow of communicative action, establishing the minimal structures necessary for self-organisation, improvisation, and adaptation. Practicing in the meshwork, then, is a form of generative pragmatism. It requires acting with awareness, with humility, and with the capacity to read when emergence is unfolding and when strategic response is most potent.

This is not a mystical posture. It is a disciplined attentiveness to the system in motion. It is an invitation to leaders and innovators to move from managing plans to co-shaping possibilities, and to see in the meshwork not confusion, but a living source of situated opportunity.

6. Conclusion and Future Directions

In this manuscript, we ventured out to "Exapt, Adapt, and Disrupt", to unlock systemic innovation, demonstrating how transformative adaptation unfolds through the dynamic interplay of eight key constructs. By integrating exaptation, serendipity, emergence, co-optation, bricolage, affordances, recombinant innovation, and effectuation (Table 1) into a unified framework, we provide a comprehensive account of the mechanisms driving adaptation and innovation in complex environments (Figure 1). In addition to this structured process view, we introduced a complementary systems-level perspective—captured in Figure 2—that conceptualizes these constructs as part of a co-evolving meshwork, where innovation emerges through their recursive, relational interplay. Through this synthesis, we have deepened theoretical understanding and established a structured, actionable approach that equips scholars and practitioners to navigate uncertainty, harness emergent opportunities, and drive systemic change.

Rather than viewing creativity as a spontaneous, individual phenomenon, this framework highlights how it emerges through dynamic interactions, constraints, and the recombination of existing elements—making it an intrinsic part of transformative innovation (Montuori, 2017).

The framework articulates three fundamental principles. First, repurposing and recombination demonstrate how latent affordances can be identified and strategically redeployed to generate novel solutions, leveraging processes such as exaptation and recombinant innovation (Gould & Vrba, 1982; Weitzman, 1998). Second, the interplay of agency and systemic context highlights that innovation does not emerge in isolation but results from the ongoing negotiation between individual decision-making, environmental constraints, and structural affordances (Sarasvathy, 2001; Holland, 1998; Felin & Zenger, 2020). Third, iterative and collaborative processes underscore the importance of experimentation, feedback loops, and collective intelligence in refining and scaling adaptive solutions (Baker & Nelson, 2005; Sawyer, 2005; Bogers et al., 2019). Together, these constructs and principles reveal not only the architecture of transformative adaptation, but also its emergent, dynamic nature—inviting both structured action and interpretive responsiveness. This study demonstrates how these constructs, in combination, drive transformative adaptation across diverse domains, including technology, design, entrepreneurship, and social systems.

6.1 Theoretical and Practical Contributions

This research contributes both theoretically and practically to the study of adaptive innovation, responding to the increasing need for resilience and flexibility in complex systems. By offering a structured synthesis of interdisciplinary perspectives, it advances academic discourse while also delivering actionable strategies for practitioners.

6.2 Theoretical Contributions

The framework bridges disciplinary divides by synthesizing insights from complexity science, sociology, and entrepreneurship, providing a multidimensional perspective on innovation and adaptation (Arthur, 2009; Sarasvathy, 2001). By integrating these perspectives, it accounts for the dynamic interplay between individual agency, systemic affordances, and emergent properties, offering a more holistic understanding of adaptive processes (Gibson, 1979; Barabási, 2002; Yun et al., 2022) (Table 2).

Additionally, this research extends existing theories by systematically mapping how these constructs interact, revealing emergent synergies that deepen our understanding of innovation in complex environments (Holland, 1998; Norman, 1999). This includes conceptualizing these interactions as part of a co-evolving meshwork, in which constructs operate relationally as well as functionally—shaping and reshaping innovation trajectories over time. It expands the conceptual reach of constructs such as exaptation and bricolage, demonstrating their applicability beyond their original disciplinary contexts to domains such as entrepreneurship, digital transformation, and organizational behavior (Gould & Vrba, 1982; Baker & Nelson, 2005; Andriani & Cattani, 2021).

6.3 Practical Contributions

From a practical perspective, the framework offers strategic pathways for navigating the volatility, uncertainty, complexity, and ambiguity (VUCA) of modern environments (Bennett & Lemoine, 2014). It provides actionable tools for decision-makers, emphasizing how effectuation enables flexible strategy formation and how bricolage supports resource-efficient problem-solving under constraint (Sarasvathy, 2001; Weick, 1993).

Furthermore, the framework underscores the importance of scaling innovations through modularity and network effects, offering guidance for organizations seeking to sustain systemic transformation. Case studies such as CRISPR in biotechnology, decentralized finance (DeFi), and AI-driven drug discovery exemplify how adaptive innovation unfolds through iterative recombination and emergent coordination (Weitzman, 1998; Wagner, 2014; Stokes et al., 2020). These cases also highlight how constructs may interact dynamically—as part of a co-evolving meshwork—shaping innovation trajectories in ways that are context-sensitive, recursive, and sometimes unexpected. By structuring adaptive strategies into a coherent model, this research provides a decision-making toolkit applicable across industries and policy domains (Table 3).

The interdisciplinary nature of the framework also facilitates cross-sector collaboration, offering a unifying model for addressing systemic global challenges such as climate resilience, digital governance, and social equity (Folke et al., 2010; Liu et al., 2021). In these contexts, adaptive networks and innovation ecosystems play a crucial role in ensuring long-term sustainability and transformation.

By synthesizing theoretical rigor with practical relevance, this study advances the understanding of transformative adaptation while equipping practitioners with structured methodologies for implementation. The framework acknowledges both the strategic utility of constructs and the relational complexity in which they operate—inviting practitioners to navigate innovation not only through discrete tools, but through patterns of interaction that evolve over time.

This manuscript explores transformative adaptation through the integration of eight key constructs: exaptation, serendipity, emergence, co-optation, bricolage, affordances, recombinant innovation, and effectuation. These constructs were examined both individually and in combination to understand their theoretical significance and practical applications. To unify these insights, we developed a comprehensive framework that captures the mechanisms underlying adaptation and innovation in dynamic contexts.

6.4 Limitations and Avenues for Future Research

While this study offers a novel framework for understanding transformative adaptation, it has limitations that point to directions for further research.

As a conceptual synthesis, its strength lies in its theoretical coherence rather than empirical validation. While the framework integrates multiple constructs into a structured model, its applicability across diverse real-world contexts remains an open question. Future research should empirically test its constructs using qualitative and quantitative methods, exploring its generalizability across industries and geographies (Eisenhardt, 1989; Weick, 1995).

Another limitation lies in the context-dependent nature of certain constructs. Concepts like bricolage and serendipity may manifest differently across cultural and organizational environments, shaped by institutional norms, resource constraints, and social attitudes toward improvisation (Johannisson & Olaison, 2007; Merton & Barber, 2004). Further studies could explore how these contextual factors influence the effectiveness of different adaptation strategies, using comparative analyses across sectors and regions.

Finally, while the case studies provided offer illustrative applications, they remain selective. Expanding empirical examples to include sectors such as public policy, healthcare, and education could further demonstrate the framework's versatility. Longitudinal studies could provide deeper insights into how these constructs evolve over time, capturing the dynamics of transformative adaptation in practice.

6.5 Reflections on Future Research Directions

The framework developed in this study opens multiple avenues for advancing research on adaptive innovation. Beyond empirical validation, future studies can refine its scope, integrate it with emerging domains, and explore its implications across diverse societal challenges.

One critical avenue is cross-cultural analysis. Constructs such as effectuation and co-optation are inherently shaped by cultural norms, influencing how decision-makers perceive and navigate uncertainty (Hofstede, 2001; Selznick, 1949). Investigating these variations across different cultural and institutional settings could deepen our understanding of how adaptive strategies function in diverse environments. For example, examining how collectivist versus individualist societies approach bricolage or serendipity could reveal new insights into innovation dynamics.

Another promising direction involves computational modeling. Simulations of construct interactions could help identify emergent patterns and refine the framework's predictive capabilities (Holland, 1998; Barabási, 2002). Such models might, for instance, explore how serendipity and bricolage interact in resource-scarce settings or how co-optation and scalability influence systemic change. This line of inquiry could enhance both theoretical clarity and practical applications in forecasting and scenario planning.

The integration of this framework with rapidly evolving fields such as artificial intelligence, climate adaptation, and global health could further expand its relevance (Arthur, 2009; Donovan, 2012). AI-driven systems could benefit from principles of exaptation and affordance recognition, fostering more adaptive and human-centered technologies. In climate adaptation, the framework's emphasis on emergence and scalability aligns with efforts to design resilient strategies for sustainable development. Investigating these intersections could generate valuable insights for interdisciplinary research.

Finally, longitudinal case studies would provide empirical depth by tracking innovation initiatives over time. Examining how constructs such as effectuation, serendipity, and scalability interact across different phases of innovation cycles would yield a richer understanding of how transformative adaptation unfolds in practice (Sarasvathy, 2008; Wagner, 2014). These studies could inform both academic discourse and applied strategies in entrepreneurship, policymaking, and technology development.

In an era marked by complexity, uncertainty, and accelerating change, understanding how adaptive systems evolve is more relevant than ever. The framework presented here serves as both an analytical tool and a strategic guide, offering pathways for future inquiry that bridge theory and practice. By refining and expanding this work, scholars and practitioners can contribute to a more nuanced understanding of innovation, ensuring that adaptive strategies remain at the forefront of addressing global challenges.

6.6 Declaration of AI Assistance

During the preparation of this work, the author used ChatGPT to identify redundancies, structure tables, organize references, verify citation accuracy, and generate alternative title suggestions. All content was subsequently reviewed and edited to ensure academic rigor, and the author takes full responsibility for the final manuscript.

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This manuscript is based on secondary research and synthesis of existing literature. All referenced studies and data are cited appropriately and available in public or academic domains.

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