Uncertainty, Complexity + Changing Conditions: A Cohesive Frame To Advance Agility In The Built Environment

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ABSTRACT: Buildings are arguably more meaningfully approached as process versus product. A zero-carbon structure with no robust functional flexibility will become obsolete long before its physical life concludes. Robust sustainability, as viewed through the present research, resides at the nexus of durability, flexibility, and responsibility principles. The authors suggest such principles are not mutually exclusive nor incompatible with values of aesthetics and performance. Through the study of flexible architecture, particularly in residential projects, this paper establishes a novel multi-criteria decision-making framework for design projects. The theoretical framework, offering holistic and unified design criteria, corresponds to physical, functional, economic, technological, social, legal, and political facets that instigate and propel building. The methodological approach of the research follows three sequential stages: literature meta-analysis, survey of experts, and case studies. Theory is evoked, including recent considerations of open building, holistic design, and systems thinking (Langston 2014, Sinclair 2012, 2015; Imam and Sinclair, 2018, 2020, 2021). Industry perceptions regarding environmental, social, and economic tenets of sustainable development are identified via a purposive survey with 69 architects and researchers. Seminal cases of eight (8) award-winning projects are drawn from regions with the highest reported current and projected floor area, illustrating agility concepts in design, legislative, and/or financial ethos. Case study data, together with the strategic literature review and survey, highlights leading themes, suggesting agile systems that are composed of four key characteristics: 1) diverse approaches and strategies that can learn (design intelligence), 2) the relationship among systems and subsystems is nonlinear, 3) co-evolve with their environment, and 4) display emergent properties. The large-scale impact of climate change, now complicated by the pandemic, calls us to be resilient and more open-ended in designing our built environment. Agility proves a compelling means to proffer more inclusive distributed decision-making structures appropriate for daunting and rapidly evolving realities of contemporary life.

KEYWORDS: Agility, sustainability, flexibility, systems, holism, decision-making, design

INTRODUCTION

In a society plagued with seemingly more environmental and health problems, the notions of adaptation and responsiveness are all too prevalent. As human beings, we look in all places for holistic wellness and quality of life. Most building projects have a life expectancy, and for infrastructure projects, life can be very long. Nevertheless, we do not know what the world will be like in the future—*who can predict social change, technological change, or climate change?* There is a significant risk that today's well-intentioned design decisions will turn out badly. As many people have realized, it is a good idea to design for *flexibility*. Yet, most research in this field expose but do not probe. Obvious questions that might and should be asked after the vast amount of evidence offered in the literature remain unanswered. For example, why is it that, *after more than a century of attempts to design for flexibility, the issue is still marginalized to the profession at large?*

The term *flexible* has a very broad definition in architecture, in part to allow the inclusion of a range of strategies that provides adaptability in response to a particular change or need. In one definition, flexible buildings are "designed to respond easily to change throughout their lifetime" (Kronenburg, 2007, p. 6), and in another, it is a building "that can adjust to changing needs and patterns, both social and technological" (Till and Schneider, 2007, P. 4). While there are many ways one might define *flexibility* and *adaptability* with respect to building design, it is obvious that to endure a building for a prolonged period; the structure needs support from more than just the environment. In other words, architecture must be functionally, economically, and technologically relevant. Thus, this paper introduces a measure that is more independent, responsive and holistic; a measure that integrates aspects of durability, flexibility and responsibility; a measure that introduces layers of physical, social, environmental and economic factors in the form of continuously evolving and dynamic framework; a measure that we refer to as *Agile*.

1.0 BACKGROUND

"A concern for greater flexibility in buildings arose in the 1950s as a reaction against the excesses of 'form-follows-function', which argued that all parts of a building should be determined by, and destined for, specific uses. In practice, however, even if these uses could be identified, no allowance was made for new developments over time, yet alone the changes of use that happen in many buildings." (Weston, 2011)

The idea of integrating flexibility to accommodate future needs as well as minimizing energy footprint throughout the physical life of the building is undoubtedly the ultimate holistic objective for architecture in our modern society (Langston, 2014). In 1972, Sir Alex Gordon, former president of the Royal Institute of British Architects (RIBA), argued that *good architecture* should be designed for loose fit, long life and low energy (Gordon, 1972). Today, Gordon's objectives, known as the 'three Ls', can be interpreted as durable, flexible and sustainable. A thorough consideration of these parameters' objectives and how they have so far been addressed in the literature has been discussed in Imam and Sinclair (2018 and 2020). Furthermore, Imam and Sinclair (2021) introduced *environmental*, *social,* and *economic* facets as an essential core to qualitatively define Agile Architecture. A design team can have all technical sustainability *prerequisites* in place—air-tight envelope, efficient HVAC systems, renewable energy generation, low VOC materials, etc.—yet the project can still fail the *test of time*. As a senior architect—survey respondent—puts it, "it is as if we have all the raw materials, but where is the fire?" The theories of sustainable architecture that we have been studying treat *flexibility*, *technology*, and *innovation* like a *black box*. Indeed, what we are missing is a *process* for converting the *raw materials* of future-proof design ideologies into real-world successes. Once a design team is committed to *designing for the future*, what should it do? What process should it use? How should it be held accountable to performance milestones? These are all questions the Agile methodology is designed to answer. The theoretical frame introduced in this paper is viewed as a medium to aid designers, developers, and policymakers—and by implication incorporated in the decision-making process—in applying and realizing greater project Agility.

2.0 SURVEY STUDY: *HOW THE INDUSTRY PERCEIVES FLEXIBILITY*

"…I am a strong believer that all the resources and technologies are available to create low energy/carbon buildings. It is as if we have all the raw materials, but where is the fire"? (Survey respondent: Architect, over ten years of experience in the AEC industry)

Sustainable design intervention is much more likely to be accepted if it considers how the stakeholders perceive and interpret high-performance buildings. From a psychological perspective, "a person's perception of how a system operates is often referred to as a *mental model*. This might come from educated understandings via literature and mentorships or simply from practical experimentation with the controls—and in both cases, their mental model might or might not be accurate" (Gabe, Walker and Verplanken, 2016). Within this context, the survey conducted here aimed to reveal the structure of participants' mental models regarding the *sustainable* and *flexible* building design processes.

2.1 Participants and design

The survey was aimed at three focus groups, namely, architects, researchers and policymakers. The literature suggests that these stakeholders are key influencers constantly affecting buildings' decision-making process. Despite the research efforts to recruit an equal number of participants in all focus groups—given that all participants hold equal value in formulating the framework —the practical realities of recruiting experienced participants led to challenges and proved to be more difficult than anticipated. The survey collected a total of 69 valid responses. Nonetheless, the survey resulted in big discrepancies between the three focus groups, with 73.9% (51) architects, 21.7% (15) researchers and 4.4% (3) policymakers. An online questionnaire was conducted to capture insights into current mindsets and practices regarding Agile architecture—the nature of questions concerned designers' approaches to Agility. The survey was distributed and administrated digitally via Qualtrics web-based platform, and answers were completely randomized. The questionnaire is structured using a pre-determined set of closed-ended questions, while select questions have an open-dialogue option for comments and further explanation.

2.2 Survey method

The survey adopted a nonprobability sampling method, namely, purposive sampling, where each potential subject had a known probability of being selected for the questionnaire (Robinson, 2014). The participants' selection method within the purposive category is *judgement sampling* (ibid), following a non-random sample selected based on a pre-identified set of requirements. By using minimum quotas, this strategy ensures that key groups are represented in the sample, thus avoiding any biased selection or conclusion. Participants were recruited using online open-source professional and academic networks (i.e., LinkedIn, Academia and Research Gate). An invitation email or post was circulated via direct contact (e.g., LinkedIn or Academia messages) or posting on relevant LinkedIn groups with at least 1000 members to approach an active and up-to-date audience. The invitation message included a brief description of the project and a link to an online questionnaire that participants could access from their computers. Key survey questions and insights are discussed below.

2.3 Results

– ***Representation and beliefs about flexibility in architecture***

Our initial questions probed respondents for their understanding of *sustainability* and *flexibility* in building design. Specifically, we asked architects how they understood "meaningful sustainability" and, within that context, *who* and *what* influences how buildings are designed for flexibility. Unsurprisingly, given the industry's prevailing discourse around outlining sustainability solely in the frame of operational energy/carbon reduction, *operational energy consumption* was weighted as *first* in terms of its importance in creating meaningful sustainable building design, with 63.75% and 25.5% of architects granting it first and second places respectively. Furthermore, the role of "flexible building design" in establishing meaningful sustainability seems to be confused amongst participating architects. Participants' votes are scattered amid ranking levels, with no clear direction. Survey participants from researchers, however, ranked *"flexible building design" in second place* in terms of its significance in creating meaningful sustainable built environment. Moreover, we asked architects and researchers about encountered *sustainability resistance* and *barriers* in the market. "We are not in control," noted an architect with over ten years of experience in the AEC industry. This, in part, is due to the misalignment of incentives between stakeholders (i.e., circle of blame; see Imam and Sinclair, 2020).

– ***Perceived benefits and limitations of current practices***

Next, we explored participants' evaluations of *current design philosophies and guidance* for flexibility—as concluded by the literature review. Interestingly, when asked about design philosophies that impact long-term buildings' flexibility, holistic building layers approach along with durability (longevity) characteristics ranked first. However, participants' votes were scattered between the first four ranking levels, indicating a relatively confused direction regarding sound design philosophies that can impact buildings obsolesce. To interpret limitations of current practices, the survey asked participants to evaluate *design methods* and *parameters* in terms of their *practical implementation* to designing for flexibility. Participating architects considered *previous project precedents* as the main method they use to guide their designs for new projects. On the other hand, *user feedback* was weighted as the least relevant to inform the design process in a "real-world" setting. Though, it can be argued that the essence of *good design*—as defined by Sir Alex Gordon—is lost in such a disconnected design approach. How can we rely on *previous projects* with no *user feedback* to inform new designs? Following such a dilemma makes us utterly blind to the essence of designing for change, designing for Agility. Thus, the Agile framework allows constant feedback for re-evaluation, namely, the build-measure-learn loop (see Imam and Sinclair, 2020).

– ***Perceived alternatives to current practices***

In an industry obsessed with numbers— such as capital costs, immediate revenue potential, kilowatt-hours of operational energy, operational greenhouse gas intensity —we asked architects and researchers how to keep buildings relevant, alive, or flexible. To the authors' surprise, the majority of survey respondents did not suggest a quantitative practice as the solution (i.e., *tools to measure or quantify flexibility*); instead, nearly 75% of architects and 85% of researchers ranked *framework to guide collaborative design teams* as potentially having the greatest influence in better preparing the built environment to surviving the test of time. Also, *increased awareness among industry stakeholders* came as a close second on the architects' list of possible advocates for flexibility. Since the literature indicates that most flexible design approaches are based on the building layers idea, it was necessary to ask survey participants from architects and researchers if they would consider using Stewart Brand's building layers diagram in a workshop or meeting to facilitate a discussion around flexibility. For participants' convenience, the layers diagram was copied below the question. 70.6% of respondents from architects said "yes, I'd use it," while 15.7% said "yes, I'd use it, but I'd change it," and 11.8% said, "no, I wouldn't use it." On the other hand, 100% of respondents from researchers answered with "yes, I'd use it." Our data suggest that in order to encourage the adoption of new agile practices, techniques, or technologies, we may need to address bigger questions about what Agility is, why it is necessary, and means/methods to implement it, in order to be successful, and hence the significance of the present research.

3.0 CASE STUDIES: *CURRENT PRACTICES*

"Flexibility is not the exhaustive anticipation of all possible changes. Most changes are unpredictable. Flexibility is the creation of margin – excess capacity that enables different and even opposite interpretations and uses." -Rem Koolhaas

There is still a lack of consensus as to what design criteria would best maximize the flexibility of existing and future buildings. Thus, we investigated the unifying principles of Agile architecture through analyzing contemporary applications to understand the unique factors required to develop long-term sustainable environments. The significance is that examining how existing buildings have adapted to change can arguably identify the key factors needed to develop new, improved Agile buildings.

3.1 Methods and strategy

Case studies are arguably to be the preferred strategy when "how or "why" questions are being posed and when the focus is on a contemporary phenomenon within a real-life context. In such a setting, the literature suggests the case study research strategy to be an *explanatory* one (Yin, 1981, p. 59; Yin, 2003, pp. 2, 5-10). Hartley (1994 and 2004) argues that data collection and analysis are "developed together in an iterative process," which allows for theory development to be grounded in empirical evidence (Hartley, 1994, p. 220; Hartley, 2004, p. 329). The data is then organized around the research hypotheses and key themes and questions. Finally, the data is examined to understand how far they fit or fail to fit the expected hypotheses (ibid). In other words, "data analysis entails a search for patterns in data" (Neuman, 1997, p. 426). Neuman elaborates that once a pattern is identified, it is interpreted in terms of a social theory or the setting in which it occurred and that the qualitative researcher moves from the *description* of a historical event or social setting to a more *holistic interpretation* of its meaning. Thus, the goal of this study was to uncover patterns, determine meanings, construct conclusions, all of which are vital components to build the Agile theoretical framework. Figure 1 explains the rationale behind selecting the eight global case study buildings.

Having the case studies drawn from five global regions —USA, China, Europe, India and Africa—helps draw generalizable theories and conclusions to the residential building design industry. Also, the case studies include different building scales and typologies while showcasing different responses to various contexts and conditions (e.g., affordability, land size, original obsolete functional use). The residential projects studied in this research are listed in Figure 2. All cases were constructed or retrofitted during the 21st century and had been recognized for national, state, or regional architectural distinction. The present research introduced these intriguing projects through in-depth analyses with Agility and sustainability front of mind and aimed to learn from the success and failure of each project. The qualitative method introduced avoids any set position or assumptions and instead critically evaluates each project objectively in the context *of durability, flexibility,* and *sustainability*. Case studies data, in tandem with the strategic literature review, highlights leading themes, ideas and practices for Agile architecture.

3.2 Identifying design patterns for Agility

The basis of analysis leading to the identified design patterns (illustrated in Figure 4 and reflected in the *Agile Design Toolkit*) was three-fold. 1) desk-based studies, 2) empirical observations, 3) applicability evaluations to the wider residential typography. From the empirical observations, several distinctive characteristics and properties of Agility constructs were extracted and organized in a list of interrelated applications/patterns. This list was then categorized into observed patterns, design limitations, or design gaps. For example, suppose an item repeatedly highlighted in the literature and deemed important in the survey study yet was not observed as a case study pattern. In that case, it is regarded as a gap (if deliberately overlooked) or a limitation (if certain boundaries prevented its implementation). Each pattern was then discussed and reorganized in a hierarchy relating to the theoretical perspective on Agility's physical, functional, and performance constructs. From the original twenty-eight (28) design patterns identified, ten (10) patterns (recognized as limitations or gaps) were identified as key deficiencies in the marketplace, and contextual barriers against formulating/implementing the Agile design framework—or any attempt to design for future performance and use. Thus, the proposed Agility framework attempts to bridge this gap of misalignment by building on and organizing the benefits of long-term sustainable buildings—in the context of the identified patterns and the associated theoretical labelled hierarchy highlighted in Figure 4—which is accounted for within the processes of design, construction, operation, and reuse.

The identified patterns and theoretical hierarchy can help formulate a framework for strategic design advice that can be used at the very beginning of a project's life. The Agile framework—discussed in the following pages—has the potential to assist in the transformation of the building industry towards more lifelong sustainable practices and help mitigate the effects of a changing climate. Providing a means by which the industry can design new buildings that have a high potential for *adaptive reuse* much later in their lives will clearly assist this endeavour.

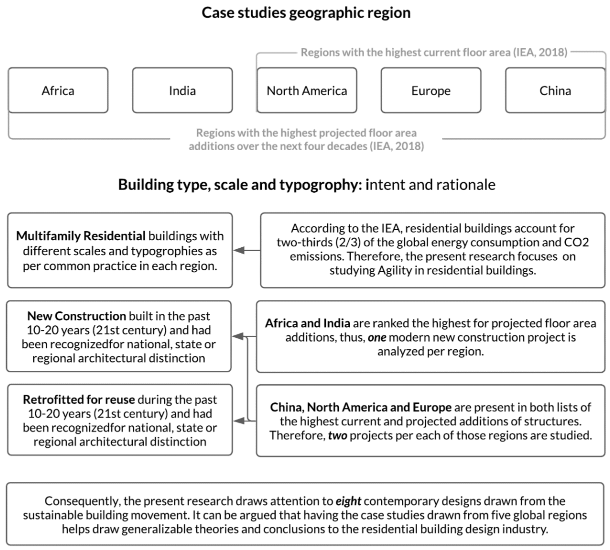

Figure 2. The rationale behind selecting the eight global case study buildings studied in the present research.

Figure 1. Selected contemporary case studies. From left (top) to the right (bottom): PATCH 22 (Amsterdam), Stacked student housing (India), 10x10 affordable housing (South Africa), 222 Jackson Avenue (USA), Yuntai apartment complex (China), Beton student housing (UK), Xizhimen apartments (China), Tiny tower (USA).

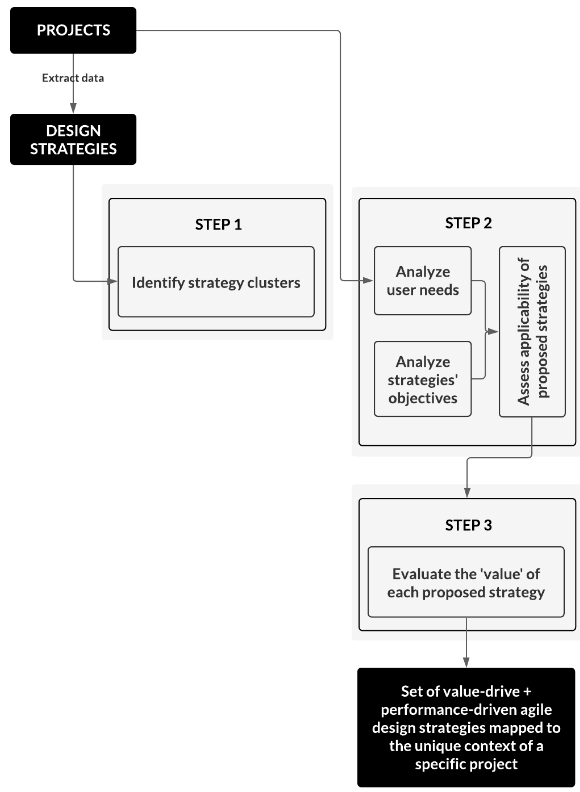

Figure 3. Model of Three-Step Data-Analysis Framework.

4.0 AGILE DESIGN TOOLKIT

"Because of different rates of change of its components, a building is always tearing itself apart." (Brand, 1994)

*"*The Agile design framework consists of two parts, 1) *Design* Toolkit, and 2) Mechanisms, Plans, and Procedures to inform *Policy*. The present paper introduces the Design Toolkit (see Imam and Sinclair 2021 for the proposed policy roadmap). The design toolkit is a three-step process illustrating the evaluation method, as shown in Figure 3.

4.1 STEP 1: Identification of *Agile Design Clusters*

The first step in the *Toolkit* groups the design strategies into clusters that display common characteristics (means of achieving flexibility, durability, and sustainability *via Agile Principles* and *Design Approaches*). Clusters are identified among design strategies by agile principles, design approaches, and change enabled (visualized in the Agile design framework Interactive; see Figure 5 for an explanatory snapshot). Each cluster includes a set of *design approaches* and strategies identified through three sequential stages: literature meta-analysis, survey of experts, and case studies. Analysis of each cluster provides information about the effectiveness, feasibility, and value of proposed strategies.

4.2 STEP 2: Assess the effectiveness of Agile strategies

The two subsequent steps in the *Toolkit* reflect the expected decision-making process for selecting a design strategy for a particular project. Next, a building user's needs are examined and classified, and design alternatives (*Step 1: Design Clusters*) are considered that would fulfill the user's needs.

– ***Interactions within and among systems: The relationship is nonlinear***

A key element in the present research is the definition and analysis of a building as *layers of systems and subsystems, which interact with one another*. Evidently, systems do not necessarily interact hierarchically, nor do they interact in a single pattern. Thus, these interactions must be thoroughly examined in a project-by-project evaluation framework. The general systems of a building are divided into four general categories, namely, structure, enclosure, services, and interior finish. Each category of systems can be further divided into subsystems. Slaughter (1997) concluded group system interactions into three general categories: *physical interaction, functional interaction, and spatial interaction*. *Physical interactions* among building systems can be through a connection, intersection, or adjacency. A roof element, for instance, can be mechanically connected to the structure, inserted through the structural elements, or simply rest upon the structure. Systems can *interact functionally* in ways that enhance, complement, or disintegrate current functions. For example, an exterior wall can provide additional shear capacity to a structural framing system; operable windows can complement a ventilation system, but if poorly incorporated, can sacrifice the performance of heating or cooling systems. Finally, *spatial interactions* occur when systems operate independently within a particular spatial region or space. For instance, lighting within a room spatially interacts in various ways with different interior surface finishes. While such systems are not physically or functionally interrelating, their spatial interaction may be crucial for the owner's perception of the space (Slaughter, 2001).

– ***Change types reimagined: Allowing designs to co-evolve with their environment***

A building system can be expected to experience different types of changes throughout its lifetime: *changes in function*, *changes in capacity*, and *changes in flow*, each of which can be further partitioned into more specific changes. The present research expands on Maury's (1999) types of change to capture what the authors view as necessities of the 21st century. *Changes in function* occur to achieve specific objectives: 1) upgrading existing functions, 2) incorporating new functions to achieve new objectives, and 3) modifying to accommodate changes in usage class or alter the function of the building entirely. *Changes in capacity* relate to a facility's ability to meet certain performance requirements (e.g., prescriptive assembly requirements for higher efficiency) and include 1) changes in loads or conditions, 2) increase and/or decrease in overall building volume, and 3) performance-driven design and thermal resilience. *Changes in flow* refer to the movements within and around a building and can relate to 1) environmental flows, such as heating, cooling, and ventilation, and 2) the flow of people or objects around or through a building space. While these change types do not describe in detail the specific changes, a building undergoes, most specific changes can be classified into one of these general types.

– ***Expecting user needs: Display emergent properties***

User needs can be defined in a matrix form as the intersections of *building subsystems* and the *change types*. The horizontal axis of this matrix should delineate the building systems and subsystems, and the vertical axis should list the *eight general change types* defined earlier. The present research classifies user needs according to three timeframe categories: Short-term (1-5 years), medium-term (5-15 years), and long-term (15-30 years). *Short-term* needs are common, clearly defined, and likely to be forecasted at the time of initial construction. *Long-term* needs are often large changes (e.g., a change in usage class) and can be more uncertain and difficult to forecast accurately early in the construction process. *Medium-term* needs have characteristics that fall between the short and long-term needs and are often tracked to predicted technological advancements. The level of Agility achieved by a design strategy is assumed to be constant with time (i.e., strategies have the capacity to accommodate change at an indefinite time change – in the short, medium, or long-term). Because of the interactions between systems, some strategies may require changes to the design and/or construction of another system or subsystems. For example, a building's ventilation system could use the plenum beneath a raised access floor to distribute air rather than use conventional steel ducts, allowing ventilation patterns to change by simply adding or moving floor panels containing vents. While the strategy provides flexibility to the heating, ventilation, and air conditioning subsystems (within the services system), implementing the design strategy requires changes to the finish system. To capture these factors in the analysis, the design team should use the proposed *matrix* (the intersections of building subsystems and the change types) multiple times (i.e., repeat matrix table per building system to separate the subsystems undergoing a design change from the subsystems receiving added flexibility).

4.3 STEP 3: Assess the value of Agility

The benefits of agile design strategies can be in many forms: reduced financial costs, shortened construction schedule and/or downtime, climate resilience, thermal comfort, avoided premature functional or physical obsolescence. These costs and benefits are intended to be realized by different parties in the construction process, which likely occur at different milestones during the life of the building. Thus, the present research identifies *three* timeframe categories: *initial design and construction, operations and maintenance, and change implementation*. These timeframes help describe the distinct types of construction activities that occur in the life of a building. The only clearly quantifiable measure used is an order of magnitude estimate of the cost, as compared to conventional techniques. Since cost estimates performed by contractors may vary widely depending on their capabilities, geographic location, and current construction market, estimates to determine the specific cost should be evaluated on a project-by-project basis. For design strategies that are considered overly complex by the design team, the costs cannot be accurately estimated using currently available techniques in the literature. This, however, urges the necessity to develop a novel *construction process simulation software.* Financial costs for the operations and maintenance (O&M). Phases are often not documented by building owners and managers, yet another obvious limitation to overcome through future research. Instead, costs are judged to likely increase or decrease based on the extent and type of new O&M activities required for systems affected by a design strategy, as compared to systems of conventional designs. To lend a level of repeatability to the "less quantifiable" measurement, the present research suggests describing *measures* in terms of explicit criteria. For example, procurement concerns are classified as either 'yes' or 'no' depending on whether unconventional materials are required, based on the assumption that specialty materials will be more difficult to procure than conventional materials.

4.0 A CONCLUSION AND A BEGINNING

This brings us back to our initial question: *How do we design for time?* From the authors' perspective, technical feasibility alone does not accomplish an agile solution. The concepts and means of Agility discussed in this paper bring an emphasis on process and enabling the building to 'learn' and the users to 'teach' or shape the space themselves. Agility aims for the design to become an ongoing social process between the designer, user, and community within. The designer is *responsible* for enabling durability, flexibility, and sustainability to take place, as opposed to attempting to control experiences and anticipate the future. In reality, architecture is placed inside a rather unpredictable context where it is forced to respond to and act on exogenous demands or suffer premature obsolescence. It is here where *good* design takes place through the

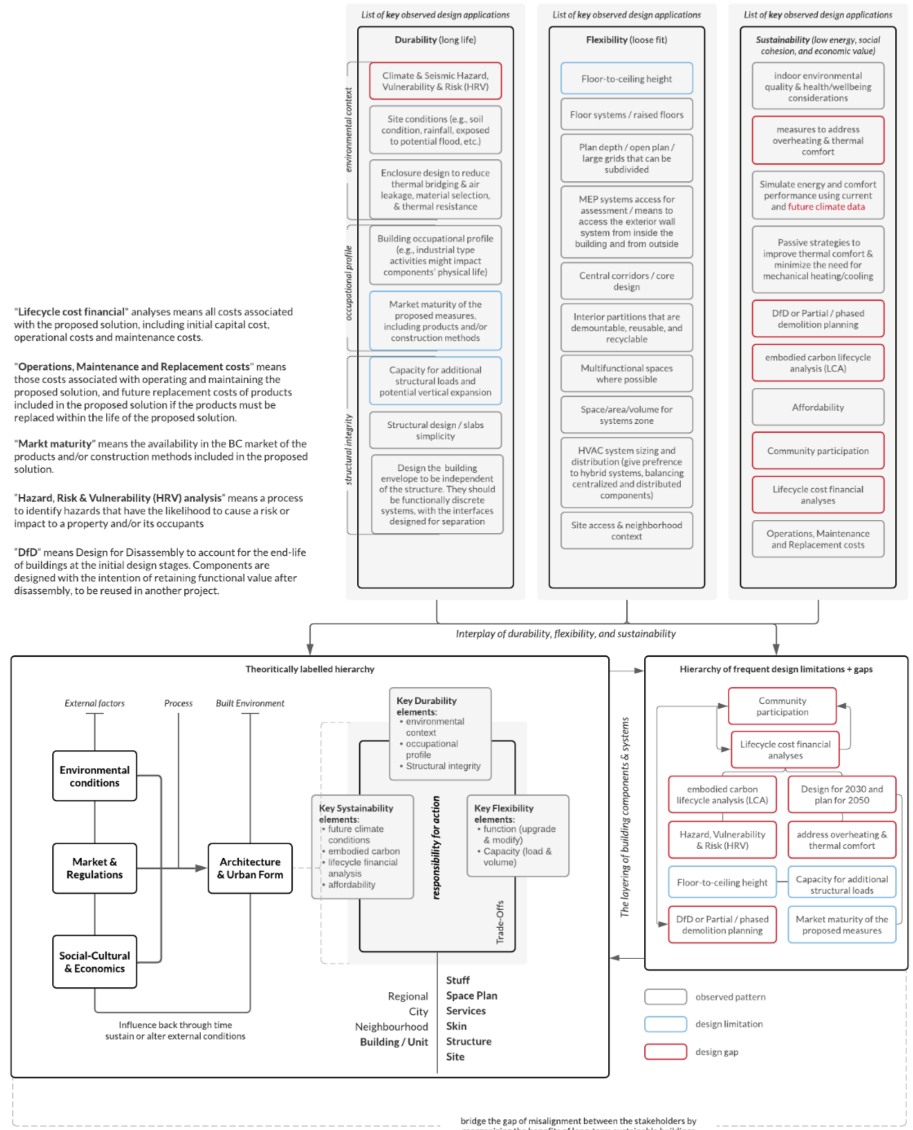

Figure 4. Identified patterns for Agile design through case study analysis.

conscious understanding and negotiations of these demands towards synthesized solutions which recognize the dynamic nature of the context in which the building exists and will continually evolve with time. We view Agility as a design principle that brings *time* and *change* to the forefront of thought but requires a reconceptualization of time through shifting mindsets and unifying of values. That said, placing architecture in context may suggest to under design rather than over design, to leave space unfinished as a mechanism for engagement. The unprecedented consequences of COVID-19 and climate change mark what the authors see as *the beginning of the end* of traditional architecture and urban design as we know it. Incongruously, almost every traditional AEC organization, while trying to figure out its place in this changing world, is stubbornly trying to build a bulwark to protect old models that can't possibly survive the sea of change underway. Thus, from the authors' perspective, if *change is the new problem*; *Agility is the new solution*.

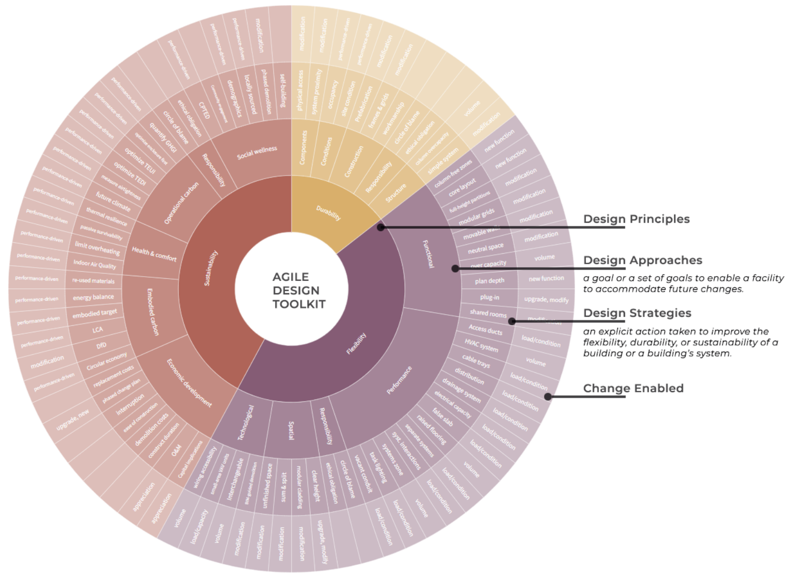

Figure 5. Explanatory snapshot of the Agile Design Toolkit [Interactive](). The Toolkit should not be used in isolation to this paper.

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