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DEFINING A RESILIENCE FRAMEWORK FOR PROJECT DELIVERY

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Abstract: Resilience has been studied in diverse disciplines, including structures, transportation, and construction. The essence of resilience is commonly described as an ability to bounce back from some form of adversity, disruption, or change. Unlike the idea of risk-control that tends to fend off these "unwanted" activities, resilience embraces such disruptions and allows a transition from resisting to recharging before and after the disruptions kick in. This feature makes resilience truly desirable for construction project delivery where the disruptions in terms of risks and changes are ubiquitous. Overall project performance is still vulnerable to disruptions like design, budget, and political issues. Pre-planning alone is insufficient to address the risks that are inevitable or unpredictable. Instead, we need to build resilience into the project when the risk is looming, especially for project development as a whole. This research aims to fill a gap by defining resilience in project delivery and resilience measures for the project delivery process. Based on key properties found in the literature and through a case study, a resilience framework is defined in the context of construction project delivery. Resilience works in different modes – resistance and recovery – at different project stages which are accounted for in the framework. In addition, there are different dimensions of resilience that are specified according to the concerns at each project stage. Lastly, the framework attempts to create measures to assess the level of resilience at each project stage. The conceptual framework shows how resilience is incorporated within a typical project delivery process, including the resilience mode, the dimensions of resilience, and potential measures of resilience. The proposed framework is expected guide future research into the resilience assessment criteria that enable more resilient construction project delivery.

1. INTRODUCTION

Increasing concerns about risks in construction have given rise to research on resilience. Given advanced technologies and planning techniques, numerous control and preventative measures are applied in construction management. However, a smooth project delivery, more than often remains challenging, in part because certain risks are inevitable and unpredictable. Given the inevitability of those risks, there is a need for building an inherent toughness – resilience – as a part of the project delivery process.

Resilience, as a research topic has been studied in diverse disciplines. Yet relevant studies in construction, especially for project delivery are lacking. One objective of this research is to define resilience for construction project delivery in terms of different properties, dimensions and operating modes. The result is presented in a conceptual framework. By integrating resilience ideas with critical project stages, the framework can serve as a resilience assessment matrix in which assessment criteria are provided based on the project delivery process.

2. BACKGROUND

2.1 Resilience

The influence of resilience is evident by its reach across diverse disciplines. The concept of resilience first emerged from studies conducted in the 1970's in the fields of psychopathology, psychology, education and public health. By examining the risk factors upon children's development, the researchers investigated and developed protective factors that enable children and youth to not only survive, but thrive in spite of risks (Rutter, 1979). For organizational resilience, it emerged as an inherent ability to absorb, recover and adapt despite the presence of adversity (Vogus and Sutcliffe, 2007). A resilient response framework was developed to simulate a generic process of organizational adjustments to disruptive events (Burnard and Bhamra, 2011). Likewise, supply chain resilience commonly refers to the capability of supply chains to respond to disturbances and disruptions (Barroso et al. 2011). A typical disturbance represents both predictable and unpredictable events which directly affect the normal operation and stability of a supply chain (Barroso et al. 2011). Coping with the disturbances requires the separate assessment of two dimensions: vulnerabilities and capabilities, in three phases: anticipation, resistance and recovery/response (Pettit et al. 2010).

Resilience in engineering fields is relatively new (Hosseini et al. 2016), and largely focuses on the ability of a system to maintain and regain operations after or in the presence of disturbances (Hollnagel et al. 2006). Particular attention is drawn to infrastructure systems such as nuclear plants, dams, and transportation networks and their performance in response to natural disasters or emergency events. One conceptual framework was presented to define seismic resilience of communities and performance measures of critical community functions, such as power, water, and hospital systems (Bruneau et al. (2003). Another scenario-based framework was developed for seismic resilience assessment for a hypothetical seaport terminal (Shafieezadeh and Ivery, 2014), consisting of several modules for hazard intensity measures, repair requirements and recovery plan for assigning resources. Resilience also emerged as a part of building design objectives. Per Hassler and Kohler (2014), simple oversizing of the building component, spaces, redundancy and reparability can enhance the resilience of buildings for unknown uses and adaptions. By contrast, the modern resilient approach, as a long term design principle (ex: applied in structural design) provides a specific, tailored solution to a particular set of building functions. Almufti and Willford (2014) proposed a rating system for seismic design that not only ensures the "life-safety" but also allows more repairable damage by an earthquake to the building components, for achieving "beyond-code" seismic resilience. The literature shows that a common motivation for resilience stems from hazards, changes, and risks, collectively called "disruptions" to normal conditions. The focus of resilient engineering systems is thus resilient performance. The performance measures assess the impact of disruptive incidents on the affected systems in terms of the losses versus the speed of recovery. The results allow the impact-mitigating strategies to be developed.

2.2 Disruptions in Construction

Similar concerns exist in construction where projects proceed in a very fluid environment. Project risk is a disruptive event that if it occurs, affects the completion of the project objectives negatively (Hillson 2009). Some ascribe this phenomenon to inadequate planning, lack of communication, design issues, or irresistible circumstances like weather and unknown conditions. The first line of the defense is to make the risks visible by factoring and classifying issues and their resulting impacts.

Based on a pre-construction brainstorming, Tran et al. (2014) proposed a list of risks specific to highway construction, such as hazardous materials, unforeseen utilities, railroad coordination, and third-party design approval. Also, in highway construction, Creedy et al. (2010) provided ten reasons for cost overruns, like design/scope change, deficient documentation, constructability, and price escalation. Forty-three factors that might cause time delays of road construction were identified in a matrix regarding the impact and the probability of occurrences and grouped into three zones according to the degree of factor severity (Mahamid, 2011). Twenty-five risks under the categories of design, financial, construction, legal and regulation risks were evaluated from interviews with industry professionals, for the building construction in general (Aboushady et al. 2013). Apart from risk factors, Eybpoosh et al. (2011) argued that the risk path, reflecting the interrelations among different risk factors is another indicator to assess the vulnerability of a project to cost overruns. It is worth noting that the disruptions in project delivery do not merely arise in the construction phase, but rather throughout the project delivery process.

2.3 Project Delivery Processes

Processes of project development are often described in chronological order. In other words, a project begins with the conceptual phase by the owner, through coordination of design and construction, to project completion. According to Oberlender (2000), developing a project has to go through the following phases regardless of the delivery methods, including project definition (to meet the needs of the end user), project scoping (to meet the project definition), project budgeting (to meet the project definition and scope), project planning (to develop the strategy to accomplish the work), project scheduling (the product of scope, budgeting, and planning), project tracking (to ensure the project is progressing as planned), and project close out (final completion to ensure owner satisfaction).

As the project moves from one phase to another, additional entities become involved and more information is obtained. Some project owners, especially the public entities, develop guidelines on project delivery processes. One purpose of doing so is to ensure the complexity of project delivery can be recognized. Instead of visioning design and construction phases only, the processes highlight other “milestones” where disruptions could arise and be handled properly. For instance, Massachusetts Department of Transportation (Mass. DOT) (2006) published an eight-step project development process defined to move a road/bridge project from problem identification to completion, including problem/need/opportunity identification, planning, project initiation, environmental/design/ ROW (Right of Way) process, programming, procurement, construction, and project assessment. Similarly, a project delivery protocol was identified based on a case that the department of Planning, Design and Construction (PDC) at the University of New Mexico (UNM) implements for standardizing its capital project delivery, as shown in Figure 1.

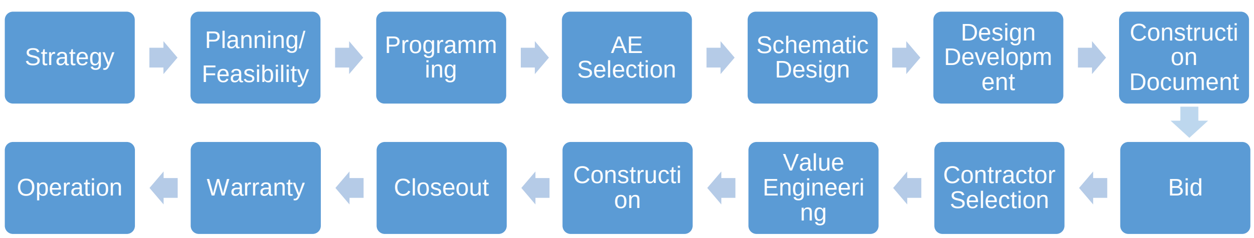

Figure 1: Project development processes by UNM PDC

2.4 Research Questions

The purpose of this research is to define a resilience framework for project delivery by answering the following questions:

1. How do we define resilience for construction project delivery processes that can resist disruptions?

2. What are the conceptual measures that assess the resilient performance of project delivery processes?

3. DEFINING RESILIENCE FOR CONSTRUCTION PROJECT DELIVERY

3.1 Definition of Resilience of Project Delivery Processes

Most research describes resilience as an intrinsic ability of the systems to continue to operate against disruptive conditions, mitigate losses and retain system performance. As noted above, disruptions in construction are inevitable, unpredictable and more importantly process-oriented. Accordingly, resilience for the project delivery process is defined as an ability associated with each project stage to plan and allocate "resources" that aim to constantly prepare for disruptions and reduce negative impact moving along the processes. Over the project delivery timespan, one disruption may appear only at a certain project stage while another can linger through multiple stages. Dealing with such disruptions requires continuous efforts linked to project stages. The efforts focus on anticipating, reacting to, and recovering from the disturbances. So the definition of resilience for project delivery emphasizes more resilient performance for different project stages than stating a property or quality of project delivery.

Depending on whether or not disruptions occur, resilience can operate in two modes: proactive/preventive resilience and reactive/restorative resilience for the pre and post-disruption environment (Vale, 2014). Accordingly, project delivery resilience can serve as follows:

1. Proactive/preventive resilience works through the project delivery process before any disruptions kick in. The goal is to either predict and prevent the possible disruptions or prepare for mitigating the impact of expected disruptions.

2. Reactive/restorative resilience takes over upon the occurrence of disturbances. In particular, for those that happen abruptly or linger, rapid damage repair and recovery to normal takes priority.

Figure 2 represents a visual explanation of project delivery resilience and how its two modes work based on the cost influence curve (solid lines) that is well-recognized in construction management. In the graph, the X-axis illustrates major project stages for a typical project delivery process where disruptions could occur in any of these stages. The y-axis on the left side refers to the ability to influence the project against disruptions from 0 to 100%. The other y-axis represents the cost to fix the disruptions from low to high. The influence curve shows that the ability to influence the project decreases as the project develops. The cost curve is the reverse of the influence curve, which means the cost to fix disruptions increases as the project moves along the life cycle. The newly-added curves stand for the trends under the proactive/preventive (square-dot & long-dash-dot) and reactive/restorative (long-dash & dash) resilience. The transition point between the two resilience modes is assumed to be at the early stage of the construction phase.

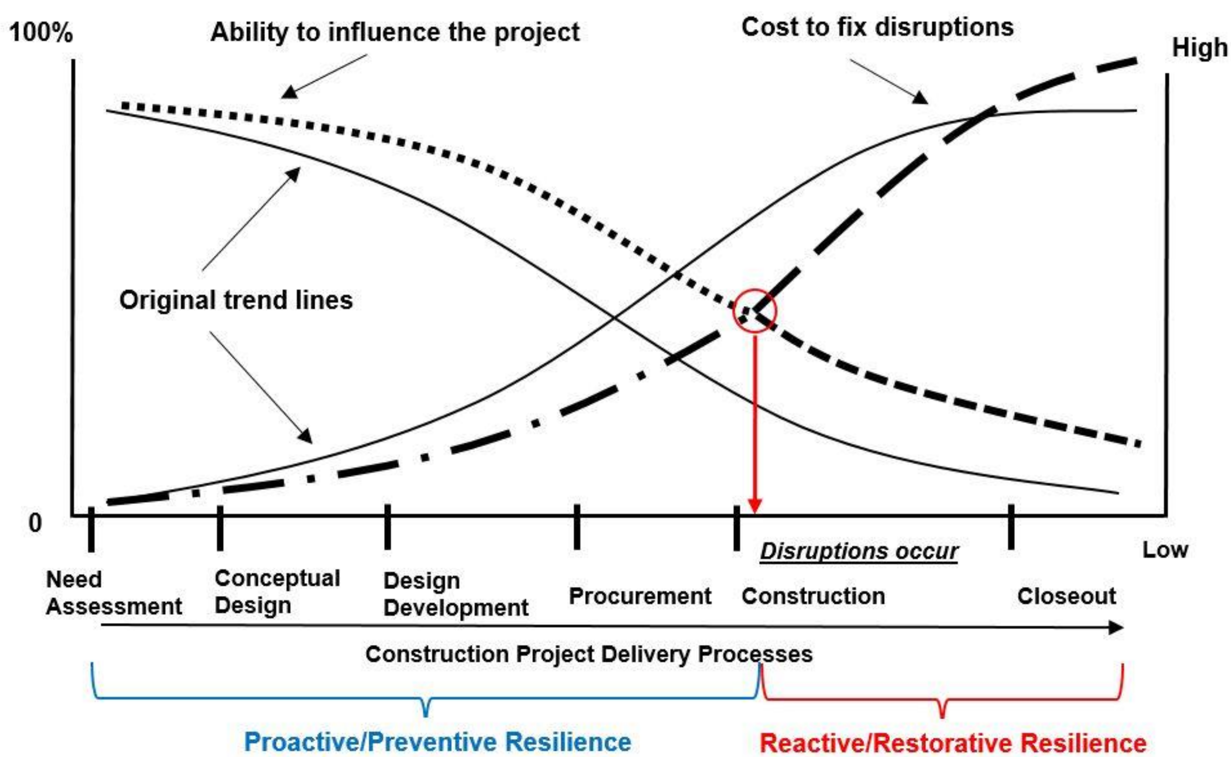

Figure 2: Resilience operates in two modes for project delivery processes

As seen in Figure 2, resilience starts from the proactive/preventive mode. Compared to the original influence curve, the ability to influence projects (square-dot line) still trends down, but the downward trend flattens over the delivery process. This is because continuously detecting and preparing for possible disruptions enhances the ability of the project to influence the outcome, such as taking more responsive actions, developing contingency plans, and having a make-ready workforce in response to actual disturbances. Also, in spite of the upward trend for the cost curve, the cost to fix disruptions (long-dash-dot line) trends up more smoothly as the disruptions occur. The slowdown in the upward trend means that the less cost is needed to fix the disruptions, as a result of the pre-detecting efforts stated above. For instance, a contractor has a vendor-managed inventory and the vendor partner regularly monitors the need for long-lead item orders. This contractor is more likely to have less-costly handling of unexpected long-lead items, compared to the situation with nothing prepared in advance.

The reactive/restorative resilience takes effect once an expected/unexpected disruption happens. The remaining part of the influence curve (dash line) continues to hold a large ability to influence. In that case, any remedial actions, e.g. a rapid repair of the losses/damage caused by a power blackout, actually make the project more "remediable" to go back to normal. Meanwhile, it is noticeable that the costs to implement changes (long-dash line) go up with a steeper slope than that of the original, and end up with higher costs. In part because extra costs (emergency workforce, budget, and any other resources) are required to make up the losses and turn the affected portion of the project around rapidly in the context of the same power blackout.

3.2 A Framework to Achieve Resilient Construction Project Delivery

In a disruption-prone environment, the resilience proposed in construction is to make resilient project performance throughout the delivery processes. To that end, a conceptual framework (Figure 3) was developed in three parts: 1) project delivery processes (disrupted or not); 2) dimensions of project performance; 3) two resilience modes along with four performance indicators. The message behind the framework is that the resilient performance of project delivery processes can be achieved in different dimensions by applying two resilience modes in terms of four performance indicators.

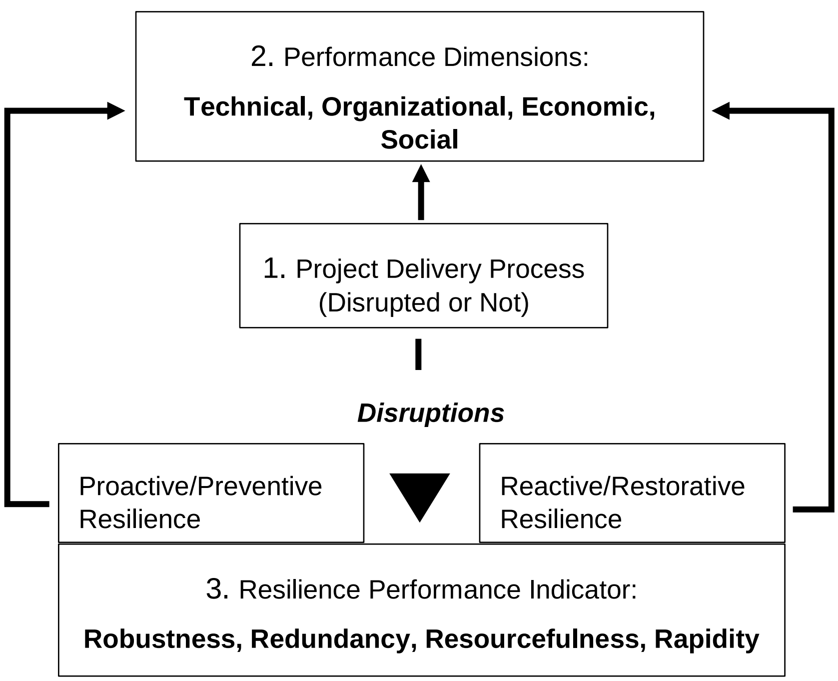

Figure 3: A framework for resilient project delivery processes

When it comes to resilient performance, Bruneau, M., et al. (2003) presented a comprehensive view to exploring the seismic resilience of communities with four indicators: robustness, redundancy, resourcefulness, and rapidity. Based on their findings, we tweaked these "4Rs" in the context of construction project delivery. The purpose is to make them as generic criteria for assessing the resilience performance of individual stages of the delivery process.

- Robustness: toughness, or the ability of each project delivery stage to withstand a specified level of disruption without the loss of critical project objectives.

- Redundancy: the extent to which a project is interrupted at any stage of the delivery process when the project still proceeds with all the project objectives accomplished.

- Resourcefulness: the ability to detect and prepare for disruptions by establishing priorities and allocating resources to meet established priorities and objectives.

- Rapidity: the ability to make up the losses due to disruptions and ensure that the interrupted project activities bounce back to normal in a timely fashion.

The "4Rs" are not explicit enough to understand how these features can enable resilience in a project delivery process. So we conceptualize project delivery resilience further in light of various project needs in four interrelated dimensions: technical, organizational, economic, and social, the same as what Bruneau, M., et al. (2003) identified for the seismic resilience of communities. Below is how the four dimensions are viewed in the context of construction project delivery.

- Technical dimension considers if the building, infrastructure, and facility can be built according to the technical specifications, and be able to function when subjected to disruptions.

- Organizational dimension refers to the capability of all the entities that manage or participate in a project by planning and carrying out necessary resources and actions to achieve the "4Rs" of resilience pre and post disruption.

- Economic dimension indicates the capability of a disrupted project to withstand both direct and indirect economic losses resulting from the disruptions.

- Social dimension reflects the measures designed to ensure the critical social needs are addressed, such as safety, legal rules & regulations, aesthetic value, and branding message. And to what extent the negative consequences caused by the disruptions can be reduced.

4. CONCEPTUAL MEASUREMENT OF PROJECT DELIVERY RESILIENCE

4.1 Conceptual Assessment Matrix

To evaluate the resilient performance for project delivery, this research developed a set of performance measures that all phases of the delivery process can be evaluated against. Thus, the "4Rs" (resilience indicators) and four project dimensions constitute a conceptual assessment matrix as shown in Table 1. In this matrix, the measures are illustrated by some common practices and provision of resources in construction.

Table 1: Resilience assessment matrix

	Robustness	**Redundancy**	**Resourcefulness**	**Rapidity**
Technical	Quality materials, tools, equip, and design that ensure all the functions	Conservative design of project parameters	Software systems for comprehensive problem detection & tracking	Technical solutions for emergency notification & recovery

Organizational	Continued functions for project delivery	Contingency resource planning	Awareness of operating environmental plans & resources to cope with disruptions	Time tracking for recovering disrupted project functions
Economic	Avoidance of direct/indirect economic losses	Contingency budget	Strong monitoring of project financial status	Timely assessing for financial losses, and solution alternatives
Social	Avoidance of safety and health hazards, violation of rules & regulations, and disturbance to communities	Alternative means of provisions for social needs	Plans and resources to meet social needs	Responsive actions to mitigate negative social consequences

4.2 Case Study

The generic performance measures can be further refined to address specific disruptive circumstances. The following shows how the assessment matrix gets applied to a case project delivery process. The case used in this study is from a standardized delivery process (Figure 1) implemented by the department of PDC at UNM for its capital project development. The delivery process includes major phases from conceptual project development, through design, procurement, construction and occupancy for design-bid-build projects.

Suppose UNM plans to upgrade all the existing laboratories located in multiple buildings, as a part of the campus master plan in five years. For a resilient project delivery, the project team has to pick it up from the very beginning of the "strategy" phase with the focus on economic and social dimensions. First and foremost, the team involving PDC planers and the UNM provost is to prepare and present capital requests for this project to the NM Higher Education Division and State Board of Finance who will determine if the funding requests can be approved or not. The main concern for this phase stays at the economic dimension with a potential disruption of the funding. With the resilience matrix, the team needs to sit down and go through it. The purpose is to review resilient measures identified already based on previous experience to meet the "4Rs" indicators. Take the proposed measures as examples, the "4Rs" indicators aim to avoid economic losses (robustness), allocate contingency budget (redundancy), monitor project financial status (resourcefulness), and assess financial losses (rapidity). To turn these measures into specific actions, two scenarios are discussed for proactive/preventive measures prior to possible funding cuts, and reactive/restorative measures in case of the funding cut. From PDC's perspective, the group managers in charge need to anticipate and prepare for such disruptions by 1) identifying reliable funding resources suited for purposes of the project; 2) hiring someone who is knowledgeable about the state funding application and approval processes so that person can monitor and follow up actively on the approval status; and 3) allocating contingency in the initial budget. Or in the case of the funding cut, the team should timely assess the extent of funding deficiency, and adjust the scope of project accordingly.

As the project moves on to the "planning/feasibility" and "programming" phases, the team still needs to keep alert and revisit the assessment measures. For the same project, say the feasibility analysis covers not only technical/constructability issues but also takes social needs into account. Disruptive incidents in this regard are critical to the project progresses and if not handled properly will cause safety, health hazards, legal and environmental issues. The resilient measures should be in place prior to and after such disruptions, including enforcement of all rules with respect to safety, legal, aesthetic requirements; involvement of public opinions; periodic review of social requests; and emergency plans for loss control. Likewise, the similar practice in terms of anticipating, preparing, and responding to the disturbances will constantly repeat for other project phases as the project moves along.

It is worth noting that the priorities for different project phases will vary. For instance, as the project gets into the design and construction phases, the team needs to shift attentions to technical and organizational dimensions where related disruptions are more likely to occur. For a specific issue like delayed delivery of certain electrical boxes which slows down the electrical rough-in, the team from an organizational aspect, can correspond the “4R” indicators to the measures, such as prefabricating most rough-in portions for robustness, having vendor-managed inventory for long-lead items for redundancy, short interval scheduling of material ordering for resourcefulness, and having on-call vendors for rapidity. Even though we look at these measures by phases, performing a resilient project delivery is a continuous effort because the disruptions evolve as the project progresses. For example, to the same issue of funding deficiency, the measures mentioned above at the “strategy” phase don't necessarily guarantee a completed settlement. At the phase of “planning/feasibility”, the team has to do something like working with the end users and planning a multi-phase development to make sure the most critical lab facilities get upgraded first. Doing so is to build the “robustness” of the project from the organizational perspective to withstand an existing issue rippled from the previous phase.

Another point to remember is that the resilient measures are not static. In the long run, this process (and practice) is to provide valuable assessment data for building a database which allows real resilient project delivery because of the customized measures to changing disruptions.

5. DISCUSSION AND CONCLUSION

This study defines resilience in the context of construction project delivery. During the delivery processes, various disruptions arise and evolve as the project stages change. In this regard, the resilient processes embrace such disruptions by acting in two modes - proactive and reactive in response to pre, during, and post disruptive events. The resilience modes are characterized by the “4Rs” indicators - robustness, redundancy, resourcefulness, and rapidity that describe a desirable status a project is expected to retain in the presence of disruptions. These indicators also serve as the benchmark criteria each project phase can be examined through.

To present how the resilient project delivery works, we developed a conceptual framework in three parts. The resilience indicators (part 1) are linked to four dimensions (part 2) – technical, organizational, economic, and social from which most projects can be evaluated. In between there comes the whole project delivery processes (part 3). The “4Rs” indicators along with the four project dimensions form an assessment matrix which initiates a conceptual measurement for resilient project delivery. As a starting point, we identified “global” resilience measures in the matrix. Also, a case study was presented showing how the assessment matrix can be applied to a real delivery process for capital project development.

As emerging efforts exploring resilience in construction, most of the findings in this research are drawn from qualitative data analysis and literature. The proposed resilience measures are forward-looking for developing a resilient project delivery process specific for a particular type of disruption. More importantly, the matrix and framework together can guide a further look into the resilience assessment with quantitative methods to address specific problems.

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