Summary for CIFE Seed Proposals for Academic Year 2020-21

Proposal number:	2020-13
Proposal title:	3-Force 3-Factor model to shape digital strategy
Principal investigator(s)[1] and department(s):	Martin Fischer, Civil & Environmental Engineering
Research staff:	Ashwin Agrawal
Total funds requested:	**$ 60,647**
Project URL for continuation proposals	https://cife.stanford.edu/Seed2019%20DigitalTwin
Broad Category Addressed in this Research[2]	economy / experience improved for all stakeholders
Project focus area addressed by proposal[3]	Automation
Stakeholders' benefitted by the research[4]	Owners, Designers, Builders, and Operators/Facility Managers
Expected time horizon to impact the industry	< 2 years
Type of research[5]	Exploitation
Industry Involvement	WSP, SLAC (Stanford Linear Accelerator)

[1] The PI(s) must be academic council member(s) at Stanford.
[2] Remove the categories that do not apply to this research proposal.
[3] Remove the focus areas that do not apply to this research proposal.
[4] Remove stakeholders that you do not anticipate to primarily benefit from this research.
[5] **Exploitation -** "refinement, choice, production, efficiency, selection, implementation, and execution;" **Exploration** - "search, variation, risk taking, experimentation, play, flexibility, discovery, innovation." For more information please take a look at the following article.

Abstract (up to 150 words)	**Observed Problem is …** Lack of understanding about the fundamental forces and factors affecting the digital transformation leading to haphazard technological decision making by the company and the customers **Current research update is …** Formulated a 3-Force 3-Factor model to understand the underpinnings that affects a digital strategy formulation **Proposed research is …** Develop a detailed and validated version of the current model to gain actionable insights

1. Business Problem

The rise of digitalization over the last couple of decades opens new avenues for the construction industry in terms of value creation. It offers opportunities for dramatic improvements in effectiveness and efficiency through visualization, information integration, and automation. People often believe that digital transformation can be achieved by implementing new technology for their operations and business. Digital success is not about technology. It's the digital strategy that drives the digital transformation in a firm (Gerald C. Kane 2015). Therefore, the key to reap the benefits of digitalization in construction is to develop a good digital strategy for the business.

In essence, the purpose of digital transformation is to create value for the company and its customers (Ross n.d.). The digital strategies to achieve this transformation might appear different on the surface, but the underlying driver is the same, value creation. Often, however, people define value too narrowly or vaguely, leading them to miss many factors which affect it. This lack of understanding about the fundamental forces and factors leads to haphazard technological decision making, ultimately resulting in choosing an inappropriate digital strategy for the firm.

Value creation essentially hinges on three forces applied by: the product/service being delivered by the firm; the process being followed by the firm and the firm's organization itself (explained later). Awareness of these forces can help a company stake out a digital strategy that is more likely to succeed. We have developed a 3 Force - 3 Factor model that helps to create this required awareness amongst the firms for a better and informed digital strategy formulation. This model was developed with seed funding for the current academic year. We now propose research to apply this model

2. Related work and Points of Departure

Since digitalization is still in a very pre-mature phases in the construction industry, the authors couldn't find much relevant work around digital strategy formulation and digital transformation for the construction industry. Therefore, motivation has been taken from the very well-known framework, "Porter 5 forces", in the management sciences, "5C model" in the manufacturing literature and "POP" in the construction management literature which would be described in the section one. This would be followed by describing the concept of 'digital twin' and 'value' which are central characters of our framework in section two. Finally, in the later half of the proposal, these concepts will be merged together to form the foundation of our framework.

2.1. Motivating Frameworks

2.1.1. Porter's 5 forces

The Porter's 5 forces (Porter 2008) provides a strategic tool to analyze the underpinning forces for profitability in an industry by looking at a more holistic picture. What's important to note here is that it focuses on the core value affecting the business, 'profitability'. If we translate this in our case, it would be 'value', as this is the only thing which matters to the customer. In addition, approach of the framework of focusing on fundamental structural forces is quite unique, which has inspired our framework as well. The point of the framework isn't to declare some strategy as good or bad, but to really understand the factors affecting and factors affected by undertaking the strategy.

2.1.2 5C model

In construction we need to manage the physical world, which is the actual project and the virtual world, which is the digital technologies. A bi-direction virtual-physical coordination is essential for the construction industry to reap benefits of digitalization. The 5C model (Jay Lee 2014) is one of the most cited cyber-physical systems frameworks in the manufacturing literature. The cyber-physical systems (CPS) approach in enhancing the bi-directional coordination between virtual models and the physical construction has been lucrative for a long time to solve the issue of digital transformation in the construction industry, but not much work currently exists in the AEC literature. The important concepts in this paper is the Maslow's hierarchy kind of a representation of the different levels of technology implementation. This creates a technology agnostic framework and gives us the opportunity to think from a strategic point of view about digitalization.

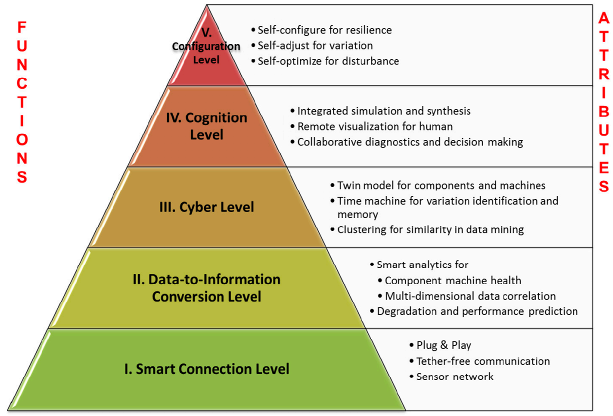

Figure 1 5C model representation for technology adaption

2.1.3. POP model

Typically, all the AEC activities can be viewed as delivering a 'Product' (or service) (P), by an 'Organization' (O) following a certain 'Process' (P) to make the delivery possible. Therefore, the aspects of a building project that the project delivery team or a company can, at least to some extent, control, fall into three categories: Product, Organization, and Process (POP) (Martin Fischer 2017). The team can decide on the shape, layout, and makeup of the building itself. We call these decisions broadly as product decisions since they refer to the physical components—products—of a building. The team can also decide who to involve and when and how. These are the organization decisions. Finally, it has to decide project participants will do when and in what sequence. This refers to the process decisions. The POP framework provides us a collection of possible 'levers' for project control that are mutually exclusive and collectively exhaustive.

2.2. Core Concepts

2.2.1 The concept of Digital Twin

A digital twin is a virtual representation of the world which enables us to use technology and at the same time establishes a bidirectional link with the physical world (motivation from the

5C framework). The digital twin concept has many interpretations owing to the wide spectrum of technologies and market needs. Digital twins gained initial momentum from high-value product manufacturing industries such as automotive and aerospace, but the concept is increasingly being adapted by the building and construction industry. It is widely accepted in the literature that the term ‘Digital Twin’ was coined by Michael Grieves in 2002 in the context of an industry presentation concerning product lifecycle management (PLM) (Grieves 2014). The concept was later adopted by NASA in Modelling, Simulation, Information Technology & Processing roadmap (2010) and the digital twin was defined as- “an integrated multi-physics, multi-scale, probabilistic simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its flying twin”.

Digital twin, extremely relevant to the Architecture, Engineering & Construction (AEC) industry, is still relatively a very new and ‘ill’ defined term due to the lack of appropriate research literature. The manufacturing industry can provide us some parallels for defining the digital twin for construction and hence a comprehensive review of the literature was done (Elisa Negria 2017). Figure 2 shows the top 100 words of the word cloud constructed by compiling the different definitions available in the literature. It is interesting to note that among the top words are ‘physical’, ‘product’ and ‘asset’, all representing that the definition is inspired from a physical tangible object, thus reflecting that most of the existing literature focuses on the ‘product’. Circling back, to the POP framework: it isn’t sufficient to just focus on the product, process and organization are equally important aspects. Hence, the product focus is one of the major short comings of the current digital twin literature.

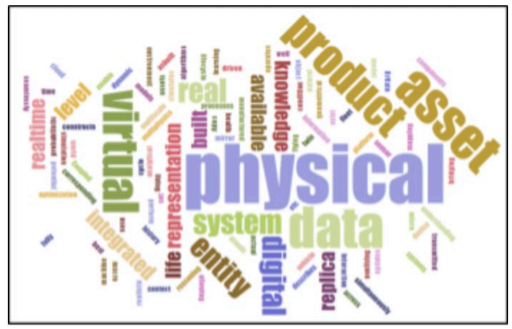

Figure 2 Word cloud for definitions of digital twin in literature

2.2.2. The concept of value

‘Value’ is a commonly used measure in lean manufacturing. In construction, the concept of value was introduced by (Koskela 1992). Essentially, value adding activities are the “Activity that converts material and/or information towards fulfilling the requirement of a customer, and the customer is willing to pay for it”. It brings in the customer centric view, which is a very important factor in the construction industry. This definition doesn’t necessarily imply, that all the activities which aren’t value adding must be removed. For e.g. regular project meetings of the participants is one of the key elements for a successful project, but essentially is a non-value adding activity. This further motivates for better classification activities as: Value adding, Non-Value adding but essential, Nonvalue adding.

3. Digital Twin Framework developed with current seed funding

As described above, digital twin is a very fuzzy term. We start by asking ourselves, what exactly is ‘digital’? and what are we ‘twinning’? Answering these questions led us to the concept of ‘value’ as described above. More details about digitalization will be presented in section one below followed by discussion about twinning in section two. These two novel concepts will be merged together via a spring representation model in the section three of the framework. Finally, section four will talk about the different factors affecting our forces of the framework.

3.1. What is digitalization?

Digitalization is the use of digital technologies to change a business model and provide value-producing opportunities resulting in more revenue (Ross n.d.). But still digitalization in this form is very fuzzy. Is documenting in excel or having a full-fledged predictive 3D BIM digitalization? This led to the development of levels of digitalization inspired by (Harris 2007), representing the different levels at which digitalization can take place, each having a different value proposition.

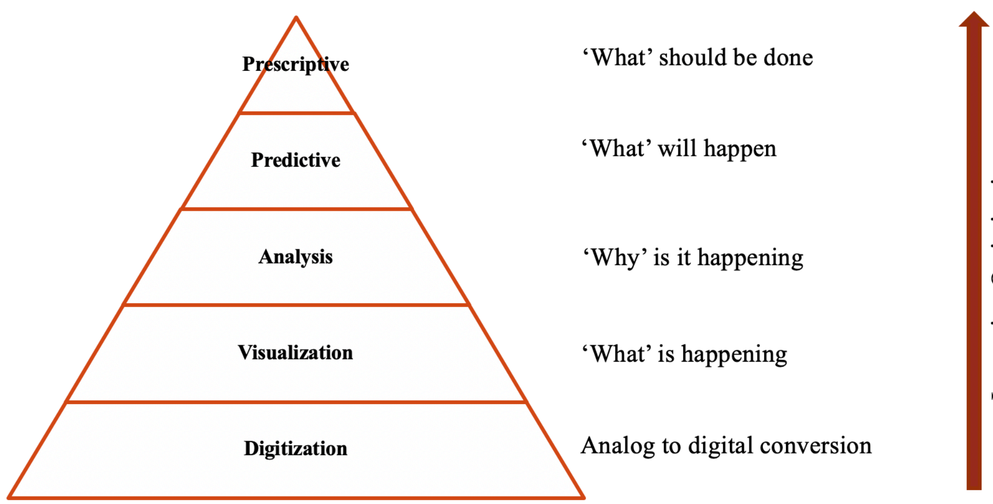

Figure 3 Different levels of digitalization

Figure 3 shows the different levels of digitalization in a Maslow’s hierarchy format (inspired from 5C framework) suitable for the construction industry. Description about each level is as follows:

- **Digitization**: The most basic level, essentially converting analog data to digital format. This acts as the base for all the other upper levels. It comes with limited benefits like better document management, enhanced security features etc. which have become an operation necessity now a days. All the technologies like digital document managements etc. lie in this category.
- **Visualization**: This level essentially helps us to visualize what is happening in the world in a better way. This may include wireless monitoring, Augmented reality/Virtual Reality, BIM, Drone technology etc.
- **Analysis**: Here we start to get insights from the data and are answering the questions around why certain things or situations are occurring. Data analysis become a common part at this

stage. The progression towards a digitally mature organization starts happening at this stage. All the basic data analytics, parametric methods etc. lie in this zone.

- **Prediction**: Here we start answering what will happen in the future and make decisions according to that. All the generative methods, design simulations, artificial intelligence algorithms come at this level.
- **Prescriptive**: Finally, here the machine starts recommending us what is the ideal thing to for a given situation therefore reaching the maximum degree of sophistication possible.

With each increasing level, we are increasing the degree of optimization. Now the question arises what should we be optimizing upon? We argue that we should always be optimizing for value because that is what finally matters to the customer. Value can be cost, time taken, risk, satisfaction etc., and is different for different customers and hence the 'ideal' digital twin is different for different situations as well.

3.2. What are we twinning?

To answer this question, we would like to go back to the concept of value addition and POP as described in previous sections. The ways of adding value are by:

1. Increasing value adding activities itself i.e. enhancing the product delivered. This essentially is controlled by the product or the service being provided itself.
2. Streamline the non-value adding but essential activities: The process and the organization are the things which support in making the product happen but doesn't have an inherent value in itself and hence are non-value adding but essential activities. So, this can be controlled by the process and the organization arms of the POP.

We observe that value addition for AEC is essentially controlled by POP, therefore being the appropriate thing to twin.

3.3. Spring model representation

It is evident that the project management and the digital management greatly intertwined with each other, which is well captured by the spring model as shown in Figure 4. POP is highly interconnected with each other and affects each other in some magnitude. This model also conveys that increasing digitalization on one part is affected by the advancements in others which always is the case. For e.g. You can have a limited success in 'prediction' of product if you don't include variability of 'process' & 'organization' or When you advance to a 'prediction' stage, your whole work process and decision-making starts changing. The model also tells us the finding a digital strategy is an iterative process where you start by pulling one of the springs and see its effect on others. The POP here are spring forces which affect digitalization and hence represent the 3 forces in our framework.

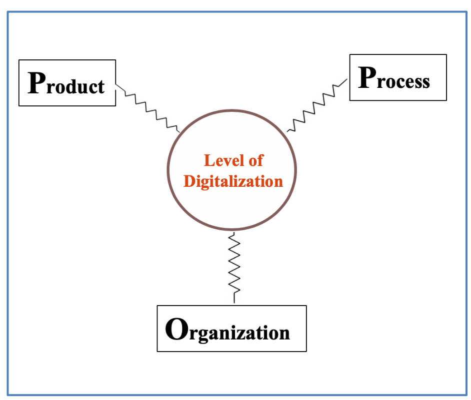

Figure 4 Spring model representation for the digital twin

3.4. Factors affecting the Forces

These unlike the forces doesn't affect digitalization directly but in fact affects the forces in one way or the other causing an indirect effect. The 3 factors identified are:

1. **Scope of value addition**: When 2 entities say A, B interact with each other (this can be any of activities of a process for example), we have many choices of optimization. We can optimize A/B independently leading to activity level optimization. In a similar way we can optimize for the flow between A, B called flow level optimization. Or we can optimize the system of A+B as a whole called the system optimization. Defining these boundaries is called the scope and it directly affects the forces.

2. **System Boundaries**: Defining system boundaries is critical, hence we introduce the concept of local v/s global optimization. In local optimization, we try to produce the most efficient given an input whereas in global optimization we produce the most efficient output. The important thing to note here is that in local optimization we are given an input which we can't change (like most design bid build projects).

3. **Level of Detail (LOD)**: The output of digitalization is as good as the details. Appropriate LOD is important to ensure feedback loops for improvements. LOD at which work is carried out is ideal for the digital twin. For e.g. LOD 200 would suit Usability, Sustainability, and Operability analysis; LOD 400 for buildability etc.

4. Proposed Research and Next Steps

The current framework provides a good broader picture of the digitalization strategy, but still lacks fine grained actionable insights. Hence, we propose a 3-phase plan to tackle the same:

Phase-1: Framework validation and detailed case studies (5 case studies – SLAC, WSP, Interested CIFE members)

Phase-2: Develop important aspects for POP

Phase-3: Fix some forces and check if it possible to simplify the framework for use with customers

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