### Summary for CIFE Seed Proposals for Academic Year 2020-21

<table>
<thead>
<tr>
<th>Proposal number:</th>
<th>2020-15</th>
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</thead>
<tbody>
<tr>
<td>Proposal title:</td>
<td>A bottom-up approach to generate VDC application patterns by comparing structured production objectives data</td>
</tr>
<tr>
<td>Principal investigator(s)¹ and department(s):</td>
<td>Prof Martin Fischer, Tulika Majumdar</td>
</tr>
<tr>
<td>Research staff:</td>
<td></td>
</tr>
<tr>
<td>Total funds requested:</td>
<td>$ 60,647</td>
</tr>
<tr>
<td>Project URL for continuation proposals</td>
<td>http://</td>
</tr>
<tr>
<td>Broad Category Addressed in this Research²</td>
<td>quality of life for society, community, and people / experience improved for all stakeholders</td>
</tr>
<tr>
<td>Project focus area addressed by proposal³</td>
<td>Team Collaboration / Project Collaboration/ Feedback in Construction /</td>
</tr>
<tr>
<td>Stakeholders’ benefitted by the research⁴</td>
<td>Research is primarily expected to benefit each of the following stakeholder groups: Owners, Designers, Builders, and Operators/Facility Managers</td>
</tr>
<tr>
<td>Expected time horizon to impact the industry</td>
<td>2-5 years</td>
</tr>
<tr>
<td>Type of research⁵</td>
<td>Exploration</td>
</tr>
<tr>
<td>Industry Involvement</td>
<td>If you have an industry partner lined up, please specify company.</td>
</tr>
</tbody>
</table>

Despite the increasing number of professionals implementing VDC on their projects, it is not clearly understood why some applications of VDC achieve a desired outcome while others do not. The variation in the VDC practices can be explained by a number of factors such as the role of the VDC practitioner, resources available, etc.

Observed Problem: Implementation of VDC is complex and it is not clearly understood why some applications achieve their desired outcome while others do not.

Primary Research Objective and Solution: To generate a patterns in VDC practices based on a comprehensive analysis of a large dataset.

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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.
external and internal relationships, standardized VDC practices within the company, etc.

We analysed a pilot dataset of 24 VDC applications from the certificate program conducted by CIFE (Skanska, Norway, 2018). 67% of the applications were able to provide quantified evidence of achieving their desired outcome to some degree. Every participant in the program chose a VDC application area for his/her project aligned with its project objectives. Participants then established VDC practices to achieve the desired outcome. The degree to which a VDC application achieved its desired outcome was measured by the production metrics tracked for that application. The pilot study generated the following key insights based on patterns on the VDC practices which emerged from the data.

- Quantified VDC application objectives lead to a higher degree of success of a VDC application
- The outcome of a VDC application improves if all three production metric categories (ICE, BIM and PPM) are tracked.
- Tracking more production metrics has no correlation with the degree of success.
- Benchmarking / standardization of metrics is required to improve the desired outcome.

Using advanced statistical methods such as machine learning, this research will collect data and conduct a comprehensive analysis of hundreds of such VDC applications across different project types, phases, sizes and delivery methods to generate many more such patterns in VDC practices.

The research output will provide a pathway to increased VDC adoption by generating insights which can be used by VDC practitioners, researchers and educators.

dataset of production objectives data from 300 VDC applications using advanced statistical methods. As observed in a pilot study on a limited dataset, these patterns can be used to generate insight on the factors which most influence the outcome of a VDC application.

Anticipated Value to CIFE Members and Industry: This research will provide a pathway to a widespread adoption of VDC applications.

Proposed Research Approach and Methodology:
We will collect and analyze data from 300 VDC applications from the certificate programs conducted by CIFE using advanced statistical tools such as machine learning. This will generate patterns in VDC practices put in place by practitioners which can then be used to document, explain and predict outcomes of VDC applications.

Anticipated Research and Theoretical Contributions: This research will build upon existing research on VDC applications but will use a significantly different approach to generate and compare VDC applications. It will add metrics based predictions to the body of knowledge which primarily provides documentation and explanation of VDC implementations through case studies. In addition, it will consider all the elements of VDC, (BIM, ICE and PPM), including partial applications.
**Engineering or Business Problem**

In recent years, there has been an uptake in the number of companies trying to implement VDC on their projects. CIFE has been conducting a VDC certificate program for AEC professionals around the world since 2009. The current interest in VDC among AEC professionals can be gauged by the number of certificates given every year, which can be seen in Figure 1.

![Figure 1. Left: Number of VDC certificates given by CIFE since the program started in 2009. Right: 200 AEC professionals at the first large-scale VDC certificate program conducted through a collaborative effort of CIFE, Stanford Centre For Professional Development, Norwegian Institute Of Science and Technology and 10 industry mentors from Norway in 2019.](image)

Despite the increasing number of professionals implementing VDC on their projects, it is not clearly understood why some applications of VDC achieve a desired outcome while others do not. The VDC framework shown in Figure 2 is the common vocabulary used across CIFE’s certificate programs. While the framework is simple, implementing VDC is complex.

![Figure 2. The VDC Framework](image)

We analysed a pilot dataset of 24 VDC applications from a single certificate program (Skanska, Norway, 2018). 67% of the applications were able to provide quantified evidence of achieving their desired outcome to some degree. Every participant in the program chose a VDC application area for his/her project aligned with its project objectives. Participants then established VDC practices to achieve the desired outcome. The degree to which a VDC application achieved its desired outcome was measured by the production metrics tracked for that application.

The pilot study indicated that either PPM practices in the company were more advanced than ICE and BIM or tracking and measuring PPM metrics is easier than the others.

![Figure 3. Production metrics from the pilot study based on the certificate program at Skanska, Norway in 2018](image)

Left: 52% of the 33 production metrics which achieved their desired outcome belonged to the PPM category.

Right: 45% of the total 91 quantified production metrics tracked in the pilot study belonged to the PPM category.
The variation in the VDC practices can be explained by a number of factors such as the role of the VDC practitioner, resources available, external and internal relationships, standardized VDC practices within the company. Some practices are heavy on BIM but low on PPM, others are heavy on a combination of BIM and ICE. In order to understand the factors which have the highest degree of influence on the outcome of a VDC application, it is important to study a sizable number of patterns in VDC practices, including partial applications. This requires a comprehensive analysis of hundreds of VDC applications across different project types, phases, sizes and delivery methods. This is the motivation for this research.

**Theoretical and Practical Points of Departure**

This research will build on the extensive research on VDC done at CIFE and other institutions, such as:

A characterization framework consisting of several factors and measures to provide documentation and explanation of BIM implementations using case studies (Gao, 2011).

A VDC and lean method to coordinate mechanical, electrical and plumbing disciplines (Khanzode, 2011).

Analysis of VDC implementations using a Bayesian approach (Rischmoller, Fischer and Kunz, 2012).

A VDC scorecard assessing the maturity of VDC practices using a holistic, quantifiable, practical and adaptive scorecard (Kam, Senaratna, McKinney, Xiao and Song, 2016)

Analysis of VDC implementations using a Bayesian approach (Rischmoller, Fischer and Kunz, 2012)

A VDC and lean method to coordinate mechanical, electrical and plumbing disciplines (Khanzode, 2011)

Analyzing VDC implementations using Lean principles (Alarcon, Mandujano, Mourgues, 2013), Characterizing the maturity levels of BIM uses in the planning and design phase of building projects (Rojas, Herrera, Mourgues, Ponz-Tienda, Alarcon, Pellicer, 2019)

Selecting the appropriate BIM tools (Xu, Mao, Wu, Li, 2017)

Selecting adequate VDC metrics for continuous improvement (Belsvik, Laedre, Hjelseth, 2000)

This study will attempt to take the existing body of knowledge further by adding “predictions” based on production objectives to existing studies on “documentation and explanation” based on metrics. In addition, it will analyze single VDC practices as well as a combination of VDC practices, for which there isn’t enough existing literature.

**Research Methods and Work Plan**

Through the certificate programs we have access to data on VDC applications carried out across different project types, phases, sizes and delivery methods and the VDC practices put in place to achieve a desired outcome. For the pilot study, we manually analyzed data from 24 VDC applications on 17 different projects by studying the final monthly reports submitted by program participants. Figure 4 illustrates the process of analyzing the data. On a dataset 12-13 times the size of the pilot study, we will use advanced statistical tools and machine learning to generate patterns for each dataset. Figure 4 below shows the research method used for the pilot study.
We used the following variables to create and organize the dataset:

- Project type, phase, id
- Participant role, id
- VDC application category, id
- Production metric category (BIM, ICE, PPM)
- Target for production metric
- Factor for quantified production metric
- Controllable factor tracked by category (BIM, ICE, PPM)
- Target for controllable factor
- Factor for quantified controllable factor

As the data for controllable factors was inconsistent, we based our analysis for the pilot study on production metrics alone. We created sub-datasets to perform exploratory data analysis on the structured data by project type, phase, VDC application objective, production objective category etc.

We used the following formula to calculate the degree of success (dependent variable) for a sub-dataset:

\[
\text{degree of success} = \frac{\text{# of production metrics which met their target in sub-dataset}}{\text{# of total production metrics tracked in that sub-dataset}}
\]

The pilot study had the following limitations:

We did not generate patterns based on a combination of VDC practices such as BIM + ICE. The degree of success was based on the number of production metrics alone as the data for controllable factors had greater inconsistency. As the analysis was done manually, the number of patterns was limited.
Expected Results: Findings, Contributions, and Impact on Practice
Previous research has established that the implementation of VDC improves a project’s desired outcome. This research will create a pathway to more widespread adoption of VDC as the patterns generated will allow practitioners to strengthen the VDC practices which are most indicative of success in their specific project context. These patterns will build upon the results from previous VDC implementation research done at CIFE to include predictions along with documentation and explanation. VDC practitioners (department leads, project managers) can use the patterns in the context of their company to standardize relevant VDC practices.

Industry Involvement
We will collaborate with CIFE partner companies and industry partners to create a robust dataset. CIFE partner companies from the certificate programs: We have access to the monthly reports submitted by the participants. As the reports have been entered manually, we may need to interview participants and/or VDC leads in these companies in order to interpret the data correctly.

CIFE Industry partners: We will share the pilot dataset with CIFE industry partners to establish the structure of the dataset. We will also partner with them to test our model on their projects to test robustness of the model.

Research Milestones and Risks

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<thead>
<tr>
<th>Research Task</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
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<tbody>
<tr>
<td>1 Prepare dataset 1 from 1st large scale program</td>
<td>May-Jun</td>
<td></td>
<td></td>
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<tr>
<td>2 Analyze dataset 1</td>
<td>Jul-Aug</td>
<td></td>
<td></td>
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<tr>
<td>3 Document results from 2</td>
<td>Sep</td>
<td></td>
<td></td>
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<tr>
<td>4 Prepare dataset 2 from individual certificate programs</td>
<td>Oct-Nov</td>
<td></td>
<td></td>
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<tr>
<td>5 Analyze dataset 2</td>
<td>Dec-Feb</td>
<td></td>
<td></td>
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<tr>
<td>6 Document results from 5</td>
<td>Mar-Apr</td>
<td></td>
<td></td>
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<tr>
<td>7 Expand testing 1: data from 2nd large scale program</td>
<td>May-Jun</td>
<td></td>
<td></td>
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<tr>
<td>8 Document results from 7</td>
<td>Jul</td>
<td></td>
<td></td>
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<tr>
<td>9 Expand testing 2: projects outside the certificate program</td>
<td>Aug-Jan</td>
<td></td>
<td></td>
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<tr>
<td>10 Document results from 9</td>
<td></td>
<td></td>
<td>Feb</td>
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From the pilot study, we observed risks which are applicable to the datasets intended for this research:

Quality of data: As the data is self-reported, there is inconsistency in the manner it is reported. In addition, the data would need to been normalized by the experience level of the participants and their understanding of VDC concepts. Also, there was a wide range of targets set for the same production metric. For example, PPC had targets varying from 80 – 97%. In this case, it is incorrect to gauge the success levels for all the PPC productions using the same measure.

Robustness of dataset: For the pilot study there were 2 instances of VDC applications which were analyzed as having achieved a high degree of success but had tracked only one production metric. These cases are likely to create noise in the dataset.
Implementation of machine learning: We intend to use advanced data analysis techniques such as machine learning to generate the patterns. This can be technically challenging.

Language: The large scale VDC program reports will be in the Norwegian and Spanish languages. Interpreting them in English might add to the expected timeline.

Next Steps
We will submit a report with our findings to our partnering companies. The report and the model will assist them in standardizing VDC practices within their organization. We will assist with the implementation of standardized VDC practices by aligning them with the insights obtained from the VDC application patterns generated.

Budget
$60,647