DESIGNING A BENCHMARKING PLATFORM TO SELECT VDC/BIM IMPLEMENTATION STRATEGIES

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ABSTRACT

Recent VDC/BIM use surveys in the AEC industry and studies on implementation cases and models have provided insight into the adoption patterns of VDC/BIM methods. They have also shown the need for more systematic tools to identify the best implementation strategies that lead to improved performance at project and company levels. At the same time, the growing number of companies and projects implementing VDC/BIM presents an interesting benchmarking opportunity.

This study is an initial step in the formulation of a benchmarking methodology to support AEC companies in the selection of VDC/BIM implementation strategies. Using empirical information obtained from surveys, the methodology will assess how and how much VDC/BIM implementation strategies impact processes and results of companies and projects. We explored three mathematical methods to understand and communicate the relation between strategies, processes and outcomes: Data Envelopment Analysis, Factor Analysis, and Structural Equation Modeling. The first method describes the efficiency of various implementation strategies to produce certain impacts on processes and outcomes. The factor analysis methodology reduces the strategy information into unobservable variables (factors) that are used for the structural equation modeling method to describe and quantify the impacts of these implementation factors on the company's and project's outcomes.

This paper describes the preliminary design of the benchmarking platform and the potential of the three mathematical methods for the analysis of benchmarking data.

Keywords: VDC, BIM, Implementation Strategies, Benchmarking

1. INTRODUCTION

Companies implementing VDC (Virtual Design and Construction) and BIM (Building Information Modeling) face challenges that range from technical, such as interoperability issues, to managerial, such as training and leadership practices (Gilligan and Kunz 2007; Azhar et al. 2008; Kaner et al. 2008; Manning and Messner 2008). These challenges impose hard decisions to companies about how to implement VDC/BIM to accomplish their objectives. Many companies adopt VDC/BIM for limited reasons and use poorly designed implementation strategies, leading to incomplete or limited impacts on project and company performance. Other companies may have the right motivation and focus but experience long or slow implementation processes with uncertain results that can put in risk the successful adoption of VDC/BIM and the realization of its benefits.

On the other hand, reports on the use of VDC/BIM in the AEC (Architecture, Engineering and Construction) industry show a positive implementation trend (Gilligan and Kunz 2007; Kaner et al. 2008; Manning and Messner 2008; Won et al. 2009). This trend presents an opportunity for benchmarking analyses of the implementation strategies that this growing number of companies implementing VDC/BIM are using. Here we use the concept of benchmarking as defined by Camp (1989): *Benchmarking is the search for industry best practices that lead to superior performance*. Thus, the challenge is to understand the relation between the VDC/BIM implementation strategies and the projects and companies performance and to communicate this relation to companies that plan to implement VDC/BIM.

This research aims to develop a methodology to systematically identify the relationship between project and company performance and their management strategies that lead to successful VDC implementation. By identifying how and how much management strategies (controllable factors) impact VDC implementation success (process factors) and project and company performance (outcome factors), the proposed methodology will support the selection of the best implementation strategies that should allow companies to take full advantage of the benefits of VDC methods, minimizing waste of time and resources during the process.

This paper presents the general concept of this benchmarking platform and the exploration of three mathematical methods to understand and communicate the relation between strategies, processes and outcomes: Data Envelopment Analysis, Factor Analysis and Structural Equation Modeling.

2. GENERAL CONCEPT OF THE BENCHMARKING PLATFORM

Figure 1 depicts the general concept of the VDC/BIM benchmarking platform.

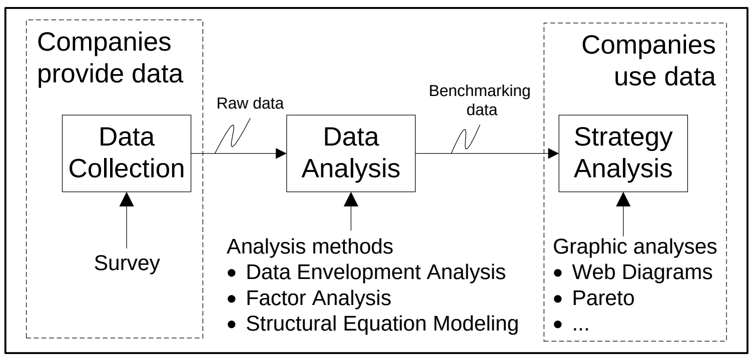


Figure 1: General concept of the VDC/BIM benchmarking platform

The platform will use a survey to collect raw data from companies about strategies they have used in their VDC/BIM implementations, the performance of some processes and evaluations of their results. These raw data are analyzed with three mathematical methods (data envelopment analysis, factor analysis, and structural equation modeling) to understand how implementation strategies relate with processes and results. Then, we produce a set of graphic outputs –such as web diagrams and Pareto graphs– that allow companies to perform strategy analyses, understanding the relation among implementation strategies, processes and results and estimating the potential impact of their implementation alternatives.

2.1. DATA COLLECTION

Based on previous data collections about VDC/BIM implementations, use and case studies (Gilligan and Kunz 2007; Gao and Fischer 2008; Kunz and Fischer 2009), we developed and applied an initial survey to understand VDC/BIM implementation process identifying obstacles, drivers and success factors, based on data from 26 US and Chilean companies that had gone o were still undergoing a VDC/BIM implementation (Alarcon et al. 2009). We are using that initial survey as the basis to build our survey for the benchmarking platform. The questions of this benchmarking survey are organized in categories and these categories are organized in 3 sections. The first section collects controllable and uncontrollable variables that define the implementation strategy selected by the company and the implementation context respectively.

- **Uncontrollable Variables:** These are variables that the company cannot change, usually characteristics of the company, project, or the environment. (e.g. company size, type of contract, leader characteristics, etc.). The uncontrollable variables define the implementation context.

- **Controllable Variables:** These are variables that a company can change (e.g. training of staff, stakeholder's involvement, etc.). Some variables may be controllable for some companies and uncontrollable for other ones (e.g. type of contract).
- **Strategy:** A set of decisions made by the company about controllable variables**.**

The list below describes examples of controllable variables although some of them may be uncontrollable for some companies and projects.

- **VDC Implementation Initiative**: it refers to the company's implementation goals and factors related with the purpose of using VDC/BIM.
- **Innovation Culture**: It is described by the team's attitude toward the research, innovation and development.
- **Training & Learning**: It refers to a company's policies, methods and actions regarding the training and learning of the VDC/BIM team for a better implementation.
- **Leader/Champion Characteristics**: It describes the leader of the VDC/BIM implementation (leadership, experience, knowledge, seniority level, and role).
- **Implementation Characteristics**: It describes the specifics of the implementation such as the VDC/BIM existing platform during the implementation, the company's use of VDC/BIM software tools, information about the models used (stage of implementation, level of detail), information previously available, etc.
- **Stakeholder's Involvement**: It describes the role of different stakeholders in the VDC/BIM implementation.
- **Communication & Coordination**: It refers to the use of standards and standard-enabled software to communicate and coordinate the work of the different stakeholders.
- **Control and Feedback**: It refers to the use of metrics and the communication of the successes and failures of the VDC/BIM implementation to the employees.

The second section of the survey gathers the impacts on communication, design and construction processes due to the VDC/BIM implementation. The third section corresponds to the results on cost, time and quality obtained due to the implementation.

Currently, we are using the exploration of mathematical methods to analyze the data that could potentially be collected with our survey to refine the survey questions.

2.2. DATA ANALYSIS

The purpose of this analysis is to understand how and how much VDC/BIM implementation strategies impact processes and results of companies and projects. This understanding will provide companies with benchmarking data so they can decide on their strategies to implement VDC/BIM to obtain expected results decreasing unnecessary efforts and failure risks.

From our exploration, we propose three mathematical methods for this data analysis: Data Envelopment Analysis (DEA), Factor Analysis (FA) and Structural Equation Modeling (SEM). DEA measures the efficiency of a unit by estimating the empirical production function, which represents the best values that could make the outputs from the entries, obtained from the vector representing the inputs and outputs obtained by the units analyzed (Charnes et al. 1995). DEA will be used to evaluate the efficiency obtained by the different companies and to compare their VDC/BIM implementation strategies and results in order to understand the relation between efficiency and the use of VDC/BIM implementation strategies. Efficiency could be used like a performance indicator of the success of VDC/BIM implementation in obtaining expected results, this will depend on the definition of inputs and results in the efficiency formula. To determine the efficiency of a company we compare the use of its entries and results with the use of entries and results obtained by the best one.

FA deals with the redundancy of input variables by defining factors that group the contributions of those redundant variables (Aaker and Day 1983). Variables that have a high correlation will be part of the same factors.

SEM quantifies relationships between factors, processes and results (Buckingham and Saunders 2004). We start with a hypothetical causal model assuming relationships between variables, then simultaneous multiple regressions are performed to determine the degree of causality between variables. The main objective is to determine how well the independent variables (controllable and uncontrollable factors) predict the dependent variable (process variables or results). SEM is useful to measure the impact of a particular strategy component on a process or a result.

2.3. STRATEGY ANALYSIS

This area of the benchmarking platform is where companies take advantage of the benchmarking data to explore the potential impacts that different VDC/BIM implementations strategies may have in their processes and results. The companies interact with graphical outputs of the data analyses such as Pareto diagrams, web diagrams, sensibility analysis, etc.

3. MATHEMATICAL METHODS AND EXPECTED STRATEGY ANALYSES

To better illustrate how we plan to use the mathematical methods to analyze the survey data, we will use the set of hypothetical data in Table 1, as actual data is not yet available. Each column represents a company's scores (from 0 to 100, for a range of very poor to great performance) regarding a set of strategic elements implemented and impacts on the company's processes.

Table 1: Hypothetical data for illustration of the mathematical methods

		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
Strategy elements	Implementation Initiative	100	50	51	90	40	35	34	53	23	100	100	80	12	12	34	23	23
	Training & Learning	100	40	50	80	10	10	21	23	56	70	80	100	12	1	23	12	56
	Team's attitude	70	30	60	90	5	8	30	30	60	80	50	100	34	0	40	1	39
	Trearning & Learning	90	100	70	10	90	80	36	12	34	56	56	23	32	23	6	34	12
	Leader Experience & Knowledge	100	40	50	20	40	60	40	34	32	80	76	10	40	10	6	30	20
	Leadership	80	30	80	30	90	90	90	30	10	67	80	10	30	60	90	20	10
	Implementation	90	20	56	68	30	20	12	53	23	23	34	45	12	54	12	67	7
	Communication & Coordination	80	40	90	80	3	10	10	80	20	80	10	40	30	10	30	0	80
	Control & Feedback	100	15	100	90	20	30	23	100	32	12	12	12	12	12	23	1	67
Impacts on processes	Communication Processes	100	20	50	90	40	30	2	80	23	34	23	23	12	23	34	6	12
	Design Processes	90	90	40	19	85	100	56	23	1	45	45	34	6	12	12	34	78
	Construction Processes	80	40	100	95	20	20	23	56	23	12	23	54	12	56	12	78	12
	% reduction of RFIs:	60	5	10	50	30	10	0	60	20	10	5	8	5	10	10	5	0
	% increment of Design Alternatives:	40	60	12	0	50	60	15	5	0	14	15	30	10	0	5	5	10

3.1. DATA ENVELOPMENT ANALYSIS

Data Envelopment Analysis (DEA) is a technique to measure the relative efficiency of comparable units in order to improve their performance. Efficiency is defined as a fraction of the weighted sums of the outputs divided by the weighted sum of the entries. In our case, a unit corresponds to a company, the entries correspond to controllable and uncontrollable variables, and the outputs correspond to the impact on the processes and results. To determine the efficiency of the unit j, we must solve the following system.

$$Max\ h = \frac{\sum_{r=1}^{R} u_r \cdot y_{rj}}{\sum_{i=1}^{I} v_i \cdot x_{ij}} \qquad where\ \frac{\sum_{r=1}^{R} u_r \cdot y_{rj}}{\sum_{i=1}^{I} v_i \cdot x_{ij}} \leq 1 \quad ; \quad j = 1 \ldots J\ and\ u_r, v_i \geq \varepsilon > 0, \forall\ r, i.$$

y_{rj} = the value of the rth output of jth unit.
u_r = the weighting given to the rth output.
x_{ij} = the value of the ith input for jth unit.
v_i = the weighting given to the ith entry.
h_j = efficiency of the jth unit

Figure 2 shows the efficiencies for our hypothetical companies, strategies and results, as defined in Table 1. We group the companies by efficiency in three levels: Efficient ($0.9 \leq h \leq 1$), Moderately efficient ($0.4 \leq h < 0.9$), and Inefficient ($h < 0.4$) companies.

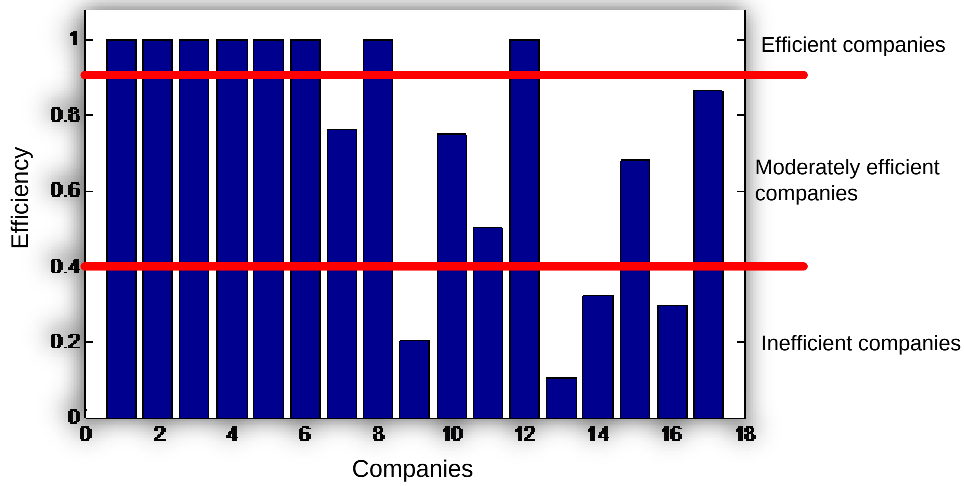


Figure 2: Efficiencies for the example companies.

Using these groups, we can create the web diagram shown in Figure 3 where curves of equal-efficiency companies tie the average scores of those companies for each implementation strategy element (input variables in the DEA method).

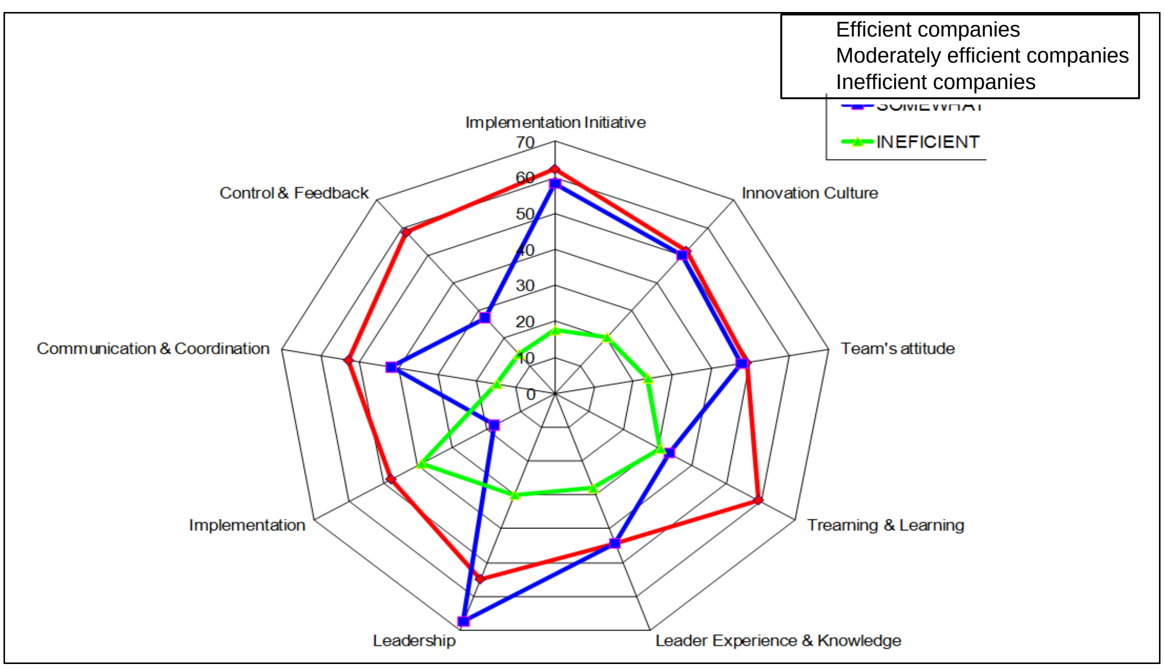


Figure 3: Average score for the implementation strategy factors of each efficiency group of companies.

Companies can use this type of diagram to compare the implementation strategies used by other companies that had different degrees of efficiency in their VDC/BIM implementations. The axis for each strategy element depicts how much of that element was developed by that type of company. Thus, companies can estimate the potential efficiency level of their own implementation strategies.

3.2. FACTOR ANALYSIS

As we do not know in advance how strategy elements relate to processes and results, there may be variables that behave very similar to other variables in terms of their relation with the performance of companies and projects. Factor Analysis (FA) identifies factors or components–which are not directly observable– that group input variables that have high correlation.

One of the FA outputs is the component matrix, which represents the weight of each factor (or component) in each of the input variables. An orthogonal rotation of the component matrix makes the factor associated with each variable more clear. Table 2 shows the rotated matrix for the data set of Table 1, where we identified three factors (columns in the table) that group three input variables each.

Table 2: Rotated matrix for the Table 1 data set. In this table, factors are called components.

Rotated Component Matrix

	Component		
	1	2	3
Implementation Initiative	0,83	0,37	0,24
Innovation Culture	0,94	0,02	0,22
Team's attitude	0,92	-0,18	0,21
Training & Learning	0,02	0,86	-0,04
Leader Experience & Knowledge	0,33	0,83	0,16
Leadership	-0,19	0,77	-0,02
Implementation	0,15	0,14	0,68
Communication & Coordination	0,45	-0,13	0,74
Control & Feedback	0,11	-0,01	0,94

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

Thus, the nine original input variables (strategy elements) can be reduced to three factors based on the similarities in the way they impact the company's and project's processes.

Another result of the FA method is the component score matrix which represents the contribution of each of the strategy elements to a component's (factor's) value. Then, we can use these contributions to calculate a weighted average of the strategy elements values for each factor. This weighted average represents the value for the respective factor or component. Figure 4 shows the values of Factors 1 and 2 for each of the companies, identifying the efficiency level of each company. A potential reading of this type of graph is to note that some efficient companies have a low value for Factor 1 (i.e., they have low values for the respective strategy elements of Factor 1 in Table 2) but have a high value for Factor 2. Also, we could read that, in general, inefficient companies tend to apply these factors to a lesser degree than efficient companies. Figure 5 shows a web diagram with these 3 implementation factors for the three efficiency levels.

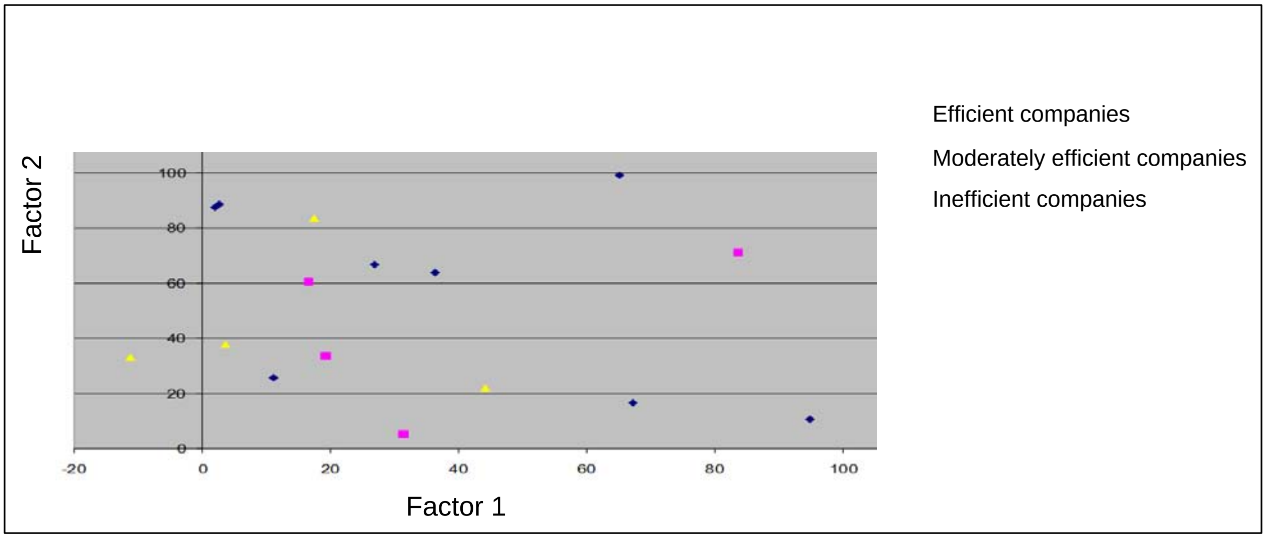


Figure 4: Scatter diagram for different efficiencies in the factors space “Training & Learning Processes” – “Company’s Organizational Culture”

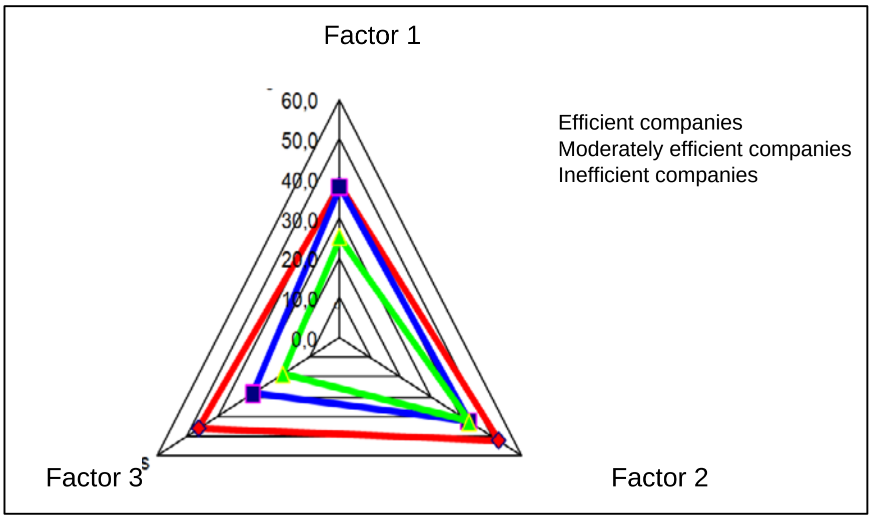


Figure 5: Web diagram of the three factors identified by the FA.

3.3. STRUCTURAL EQUATION MODELING

SEM aims at understanding the causal relationships among the inputs (strategy factors), processes and results. The method starts with a hypothetical causal model assuming relationships between variables. Then, the method runs simultaneous multiple regressions to determine the degree of causality between variables. Figure 6 exemplifies a causality diagram including the three factors identified with the FA methodology and other variables in our study. The numbers in the arrows indicate the causality degree from 0 to 1. The double arrow between quality and cost indicates correlation without causality. The value 0.23 above cost represents a variance proportion that is not explained by the preceding variables.

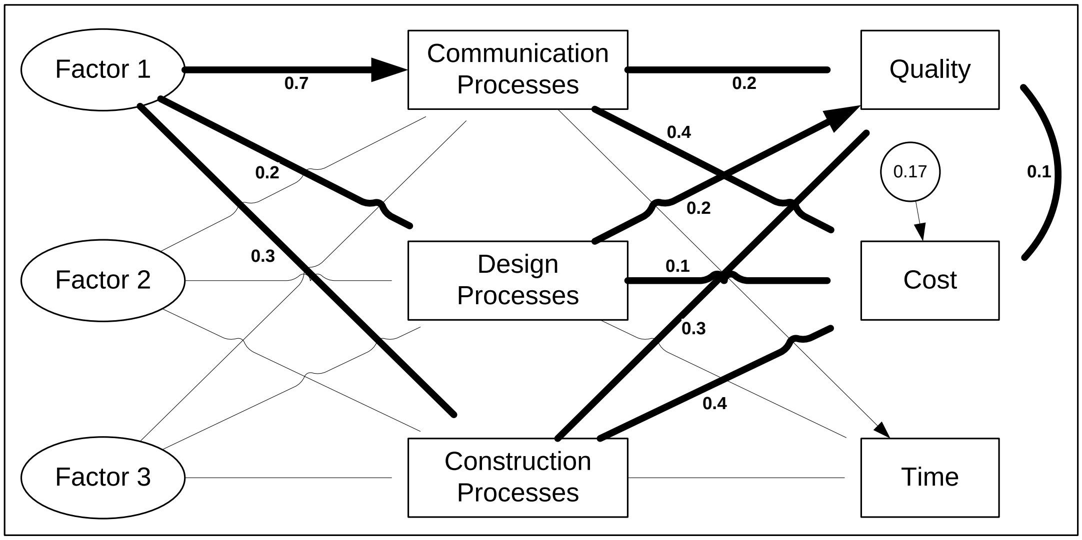


Figure 6: Example of a partial causality diagram of factors, processes and results. This diagram shows example values of the causality degrees only for the incidence between Factor 1 and Cost for clarity purposes.

Through a path analysis, we can assess how much a strategy factor impacts a result. To determine the incidence of a strategy factor, we evaluate different causal sequences (paths) between the factor and the result. In the example of Figure 6, the paths between Factor 1 and Cost are highlighted. Note that some of these paths include the segment between quality and cost. The incidence of Factor 1 over Cost is given by the sum of the products between the causality degrees in each segment of a path for all the feasible paths between them:

$$(0.7 \times 0.2 \times 0.1) + (0.7 \times 0.4) + (0.2 \times 0.1) + (0.2 \times 0.2 \times 0.1) + (0.3 \times 0.4) + (0.3 \times 0.3 \times 0.1) = 0.447$$

Similarly, we can estimate the incidence of each strategy factor over each result. Figure 7 shows a Pareto diagram of the incidences of each strategy factor and their cumulative incidence on Cost. The cumulative incidence does not reaches a value of 100% because the three factors are not enough to measure the variability of cost.

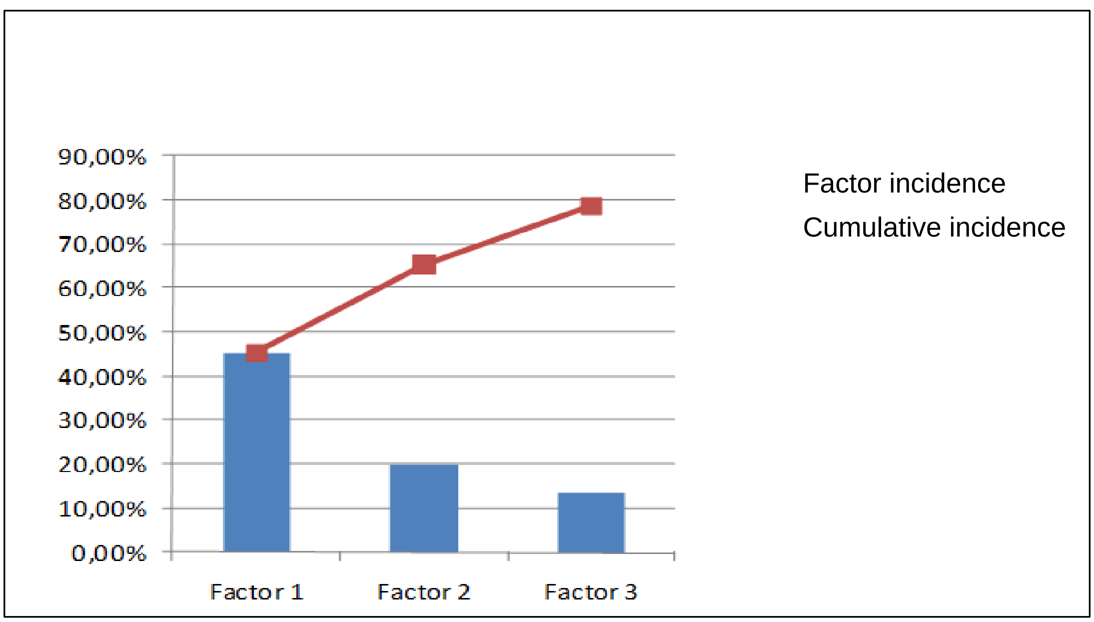
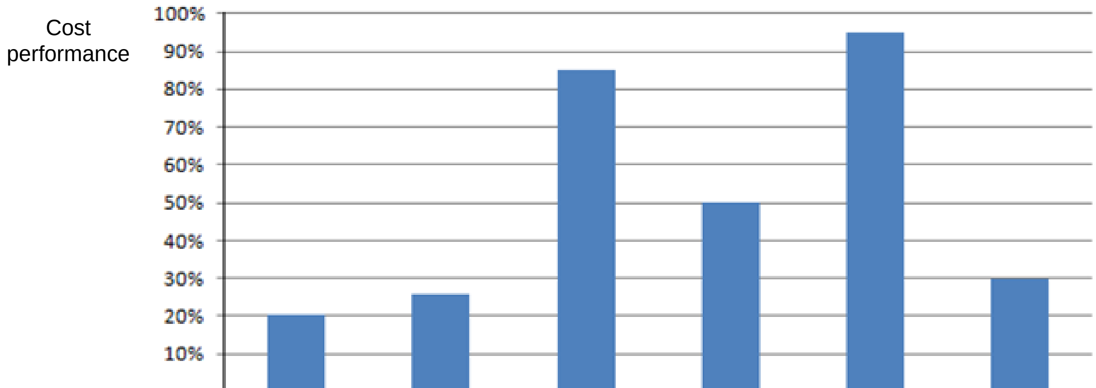


Figure 7: Incidences of each strategy factor on cost

3.4. BENCHMARKING ANALYSIS

Another type of analysis that companies could perform with the collected data is simple benchmarking or comparison of one or more of any of the variables (strategies, processes and outcomes). Figure 8 shows an example of this type of analysis where we can compare the use of one particular strategy element (i.e., training and learning) and the impact of the VDC/BIM implementation on cost for each company.



Strategy element	Survey Question	Company 1	Company 2	Company 3	Company 4	Company 5	Company 6
		20 %	26 %	85 %	50%	95%	30%
Training & Learning	Training program supporting VDC/BIM implementation	Somewhat agree (33)	Disagree (0)	Strongly agree (100)	Strongly agree (100)	Agree (66)	Somewhat agree (100)
	External software provider have been avaible for guiding, managing and coordinating VDC/BIM implementation	Disagree (0)	Agree (66)	Agree (66)	Disagree (0)	Agree (66)	Disagree (0)
	Learning method applied: Start from small/simple project to big/complex ones	Disagree (0)	Disagree (0)	Agree (66)	Disagree (0)	Strongly agree (100)	Strongly agree (100)
Strategy element total score		11	22	77	33	77	67

Figure 8: Impact analysis for strategies of different companies.

4. CONCLUSIONS

Although we have not validated the proposed benchmarking platform yet, the methods and analyses explored in this paper show a consistent structure to enable companies to learn about the potential consequences of their VDC/BIM implementation strategies.

We propose efficiency –as defined by the DEA methodology– to cluster companies in groups of interest for other companies to benchmark with. The DEA methodology enables the benchmarking by efficiency groups. The FA method reduces the redundancy of implementation strategy elements by grouping variables with similar behavior in factors or components. Finally, the SEM method allows to quantify the incidence of implementation strategy elements on processes and outcome variables.

A benchmarking platform based on these mathematical analysis methods will enable companies to learn from others in order to increase the success probability in their VDC/BIM implementations.

Our next steps are finishing and testing of the survey, data collection and validation of the benchmarking platform.

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