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ANALYSIS OF THE ADOPTION AND IMPLEMENTATION OF VIRTUAL REALITY TECHNOLOGIES FOR MODULAR CONSTRUCTION

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ABSTRACT: To achieve successful adoption and implementation of process technologies in the construction industry requires a better understanding of practices of innovation management. Defining innovation as the process of applying something new, a research project is being undertaken to contribute to a better understanding of its concomitant practices. The project focuses on virtual reality technologies within a specific application of modular construction. From a potential adopter's perspective, the process of technology adoption and implementation is often less than satisfactory. The research project is addressing this by furthering the understanding of the innovation process in a case study through the following objectives: 1) defining the basic competency requirements beyond the standard construction engineering and management domain for both modular construction and virtual reality technologies, 2) determining the basic challenges in the adoption and implementation of modular construction and virtual reality technologies, 3) establishing the details of a case study through the definition of usage scenarios for the application of virtual reality technologies to modular construction, 4) developing the technological environment required for the usage scenarios through the configuration of existing technologies, and 5) capturing the case study and assessing the use of virtual reality technologies to further a definition of innovation management. Communication is identified as the best fit for the case study of the application of virtual reality technologies to the process of modular construction engineering and management. The conceptual framework of assessing innovation management practices that employs the concept of capability maturity is presented as predictive indicator for the adoption and implementation that is to follow.

KEYWORDS: virtual reality, modular construction, innovation management, technology adoption

1. INTRODUCTION

Many practitioners and researchers alike, agree that the architectural engineering and construction (AEC) industry can improve its overall performance (measured in terms of cost, time, safety, quality, sustainability, etc.) by creating a better business environment that encourages innovation. Innovation is defined in this context as "application of technology that is new to an organization and that significantly improves the design and construction of a living space by decreasing installed cost, increasing installed performance, and/or improving the business process (e.g., reduces lead time or increases flexibility)" (Tooles 1998).

The research described focuses on process technologies within the AEC industry as a class of innovations. Process technologies are loosely defined as any tool or technique that supports the management of a civil engineering project during execution from concept, through design, construction and operation, to decommissioning. This focus area presents some interesting challenges and some corresponding gaps in the knowledge area. From a potential adopter's perspective, it is difficult to objectively assess process technologies for adoption and implementation, as there are not many decision making tools and techniques for industry to properly identify needs and match corresponding solutions. Overcoming this challenge requires a direct link to performance, whether at the organization, project or industry level, whereas currently the focus has been on operational savings. For example, it is easy to measure the time savings of switching to recording information electronically versus on paper; however an assessment of the knock-on positive effects of performance by having this information conveniently archived is a bit more difficult to measure. Some of the questions to answer include: how do we improve the performance of the AEC industry through the effective development and appropriate adoption and implementation of process technologies; what are the techniques to support practitioners in the analysis of new process technologies; and what contributes to a strategy for increasing the impact and rate of process technology adoption within the AEC industry?

The approach that has been taken is to assess the performance of the process of construction while taking into account the management practices being applied. A modest research project is being conducted jointly by the University of New Brunswick's Construction Engineering and Management Group (UNB CEM) and the National Research Council of Canada's Centre for Computer-Assisted Construction Technologies (NRC CCCT). The short term research objectives are to study the implementation of a specific advanced process technology (i.e., virtual reality technologies) for a specific scenario in the industry (i.e., modular construction). The research is also intended to contribute to a broader research program of more formally assessing the impact of innovation management practices on industry performance. The research project hypothesis states that the maturity of management practices at various levels within an organization with respect to process technologies can be measured and correlated with the performance in adoption of technologies.

The paper reports on work in progress by first providing background on the topics of virtual reality (VR) technologies and their advantages, modular construction approaches and their advantages and challenges, and a method of assessing management practices. Details of the industry case studies being used in the research project are provided, followed by a description of the methodology being taken to assess the adoption and implementation of the technology, as contributing to the assessment of innovation management practices at an organizational level.

2. POINTS OF DEPARTURE

To place this research in the context of assessing performance in the construction industry, Figure 1 is presented depicting a high level process view of construction (Fayek et al. 2008). Measuring the performance of the process at some level of granularity (e.g., activity, project, organizational, sector, industry) typically measures the ratio of outputs to inputs (A to A) and the extent to which objectives are achieved (C), under a given set of conditions (B), while employing a set of practices (D). The research described in this paper explores innovation management practices (D) and it does so at the organizational level of granularity. The aggregation (e.g., to a sector level) and/or specialization (e.g., to an activity level) of the assessment is not covered in the scope of the framework developed. In order to study this a specific innovation and scenario for application is required

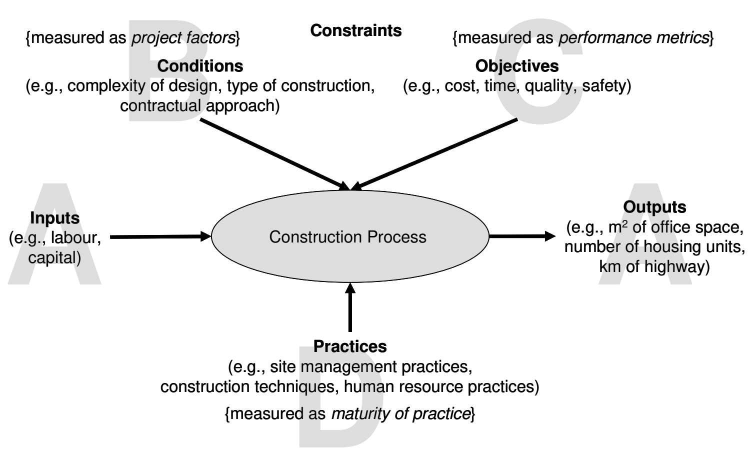

FIG. 1: A conceptual model for assessment of the industry (from Fayek et al. 2008)

2.1 Virtual Reality in Construction

The application of virtual reality technologies and tools in construction has been one of the widely discussed and researched topics in the construction industry scholars' community during the past decade. Many perceive the tools offered by VR to be very useful in assisting with the visualization and enhancing the understanding of spatial as well as temporal aspects of the construction process. Those specific advantages of the application of VR tools bring about overall benefits in general planning and scheduling of construction projects.

The previous research completed in the assessment of virtual reality for construction application by many researchers has proved that the use of 3D and walk-thru technologies could assist in the development of more complete and accurate schedules through having a significant impact on the schedule review process (Songer et al. 2001). Another area of application includes the use of 4D tools for educating or training purposes. Messner and Horman (2003) proved through a study that 4D assisted in a better understanding of construction plans especially for inexperienced personnel.

Whisker et al. (2003) performed experiments to study the application of 4D in an Immersive Virtual Environment (IVE). In the experiments it was shown that the use of IVE assisted in reducing the planned schedule duration by 28%, identifying constructability issues and evaluating schedule dependencies. A rather practical study application was developed for a strategic decision support system for virtual construction (VIRCON) (Dawood et al. 2005). The main target of the system was to enhance the ability to trade-off temporal aspects with spatial aspects in order to come up with a more developed construction schedule. More recently, Dawood and Sikka (2008) studied the benefits of 3D/4D as a communication tool. Their study and practical experimentation proved that the use of 4D models is a more efficient tool for communicating and interpreting construction plans compared to traditional 2D CAD. The study also proved that the findings are valid even amongst experienced personnel who are accustomed to using 2D CAD.

Four major categories have been identified for the benefits of VR application for the construction industry. Those classes serve as initial categorizing guidelines for the assessment of the specific VR technology adoption within a modular construction context. The four areas of possible improvement are: scheduling, space planning, communication, and training and educational applications.

2.1.1 Scheduling

The development of construction schedules is one of the most comprehensive tasks in construction planning as it requires input of various sorts of information as well as involvement of many participants especially for larger projects. Due to the importance and complexity of construction scheduling, various efforts have been put into providing aiding tools and applications and integration of some of those tools for more efficient scheduling. Various software applications have been developed to assist in having more complete and accurate schedules and establish formal scheduling approaches. The integration of such software with 3D or 4D visualization has been studied and is expected to further boost scheduling capabilities of construction managers. The use of 3D and walk-thru can assist in the creation of more "correct" schedules (Songer et al. 2001). Correctness includes three characteristics: completeness (measured by the number of missing activities), valid activity relationships (measured by errors such as physical impossibilities, redundant or looped relationships) and reasonable activity duration. Less significantly, but still advantageous, 3D and walk-thru also assists in creating "good" schedules (Songer et al. 2001). Goodness metrics include end date, critical path, and float and resource fluctuation. The use of 4D can also assist in detecting scheduling logical errors more frequently, faster and with fewer mistakes and also compensate for lack of practical experience (Kang, Anderson and Clayton, 2007).

Studies proved that VR technologies are a valid and comprehensive tool providing better understanding of spatial and temporal aspects and hence avoiding errors, identifying more areas of improvement and boosting confidence in generated schedules.

2.1.2 Space Planning

Space is considered one of the more critical resources in construction projects. Due to the fact that many participants or crafts are involved at any specific time in an average to large size project, the ability to plan for space distribution is difficult and often spread amongst participants. If effective communication is lacking this planning spread would face confusion, unexpected space clashes, delays and increased costs.

Naturally VR technologies will provide a better understanding of space through visualization. Project participants can effectively analyze problems regarding sequential and spatial conflicts prior to actual construction operations.

Research has covered this area of VR applications. VIRCON has a wide set of space planning tools (some produce plans automatically through simulation and databases and others used as aiding tools for manual planning). Those tools include assigning plants and temporary works to space plans, checking for possible space clashes, marking-up available space and distributing tasks over the life time of the space. The use of 3D modelling has long been used for plant design to check for space requirements and it is only natural for 3D/4D and VR technologies to be developed for the analysis and planning of space in actual construction site settings. Better space planning can lead to valuable benefits in other aspects such as reduction of overall project duration and maintaining a good relationship amongst project participants.

2.1.3 Communication

Improving the efficiency of communicating construction plans and schedules could be argued as the essential advantage from which other benefits of using VR stem. Visualization, in concept, is the process of displaying information in order to assist in understanding and evaluating it. Improved communication could lead to time savings through reduction in reconstruction. This is due to the increased ability to illustrate logic, sequence and interrelationships among construction tasks and products. Also better communication leads to increased confidence in all aspects of planning.

The traditional use of 2D designs and plans introduces unnecessary secondary stages and tasks within the planning process. It can also cause confusion when information is transferred among participants. In addition, the use of traditional 2D plans requires a variety of information storage media and hence makes the planning process vulnerable to misinterpretations and loss of information. Although the creation of 3D and 4D models and plans demands more resources initially, if applied appropriately those tools could save on the total time and effort for overall planning.

2.1.4 Training and Educational Application

The use of VR technologies as a visual communication enhancer can greatly improve the ability to learn and gain rapid experience related to various construction management and design skills. Advanced visualization tools can also assist students or trainees by providing them with the chance to assess their decisions and their impact. This option is not likely to be feasible in an actual site setting as training is mostly observatory due to the high cost of errors. Even experienced personnel might not be as willing to try a new approach or method due to the conservative nature of the construction industry. VR along with simulation has proved to provide an effective remedy such that learning is more proactive and less traditional.

Several experiments were conducted by Messner and Horman (2003) to measure the added value for students when using 4D CAD tools when reviewing construction plans. Several conclusions were drawn and the benefits of using 4D CAD included improving the understanding of sequencing issues and their importance, improving the ability to evaluate important flow concepts, quickly understating complex building models and gaining experience at faster rates.

2.2 Modular Construction

Recent increasing concentration on aspects such as cost, schedule and labour issues within the construction industry has made prefabrication, preassembly and modularization in construction more feasible than ever before. In addition to those drivers, advances in information technologies and construction engineering software made prework (a term that encompasses the aforementioned three similar construction methodologies) easier to apply and reduced its accompanying risks.

Modular construction is, by definition, a term that stands for the systematic approach of breaking down a construction product design into complete systems that are fabricated off-site with the involvement of multiple trades in a controlled environment, and then transported to the construction site and assembled with minimal effort (in comparison with their fabrication) (Haas and Fagerlund, 2002). The concept of modular construction is flexible, the implementation of modular construction strategies and methodologies cover a wide spectrum of applications and for a variety of extents of application.

There are various drivers and benefits to the application of modular construction. Some of those benefits are easy to recognize and some vary depending on the application scenario. The major drivers to the use of modular construction relate to the general parameters of any construction project which are cost, schedule, quality and safety. Other secondary, but still significant parameters include the environment, maintenance, design, secrecy and others. In terms of cost, there are many possible ways through which the application of modular construction can result in savings. Increased productivity of workers due to the controlled and more organized environment as well as easy access to tools and equipment in modular construction by nature reduces project costs. Another major source of decreased overall costs is the reduced cost of onsite labour. Schedule drivers are also one of the most significant when making the decision to modularize. A modular context is by nature more repetitive and includes fewer variables to account for when planning and scheduling projects. This repetitive character as well as the controlled environment also translates to more efficient and less costly quality control and enhanced safety.

Modular construction appears to have gained greater consideration during times of high construction demand and activity industry wide. For example, there was a significant rise in modular residential construction activity during the economic boom that followed the energy crisis of the 1970's. Looking at the current economic conditions and the construction industry overall, one can deduce that there will be an opportunity of increasing modular construction demand to provide for efficiency gains and ability to meet infrastructure demands worldwide. Even as the current conditions stand, modular construction can still be recognized on the rise as international efforts have incorporated it into their industry initiatives and the current NRC Construction Key Sector Group has identified prefabrication, preassembly and modularization as a new effort in its strategic plan (NRC 2008).

Observing the variety of benefits that could be achieved through modular construction, it could be presumed that its application should be highly rewarding and attractive. However, there are various implications and issues that hinder the spread of modular construction within the construction industry world wide. Modular construction represents a significantly different approach when compared to traditional onsite construction. This difference raises new issues and impediments that influence the decisions to undertake modular construction. One area of most concern is related to engineering requirements. Depending on the extent of prework, it may be necessary to complete 90% of engineering design prior to construction, as opposed to the 40% generally necessary for conventionally built projects (Tatum et al. 1987). In addition to the need for early design completion, there are additional factors to be addressed. Specific dimension or loading limitations due to transportation constraints are one of the most prominent factors in modular construction.

Scope flexibility is also expected to be decreased with modular construction. A well defined scope is essential for effective project planning and to avoid any changes later in the life cycle of the project which are significantly more costly in a modular construction scenario when compared to traditional methods. Finally the increased demand for very effective coordination and communication among participants is a barrier to modular construction as an option. The distribution of the work load, formation of work breakdown structures, progress monitoring, scheduling and organizational structures might all need alterations from the traditional sets to provide for a successful modular construction project. All those alterations require highly effective communication and collaboration among participants.

2.3 Opportunity of VR Application in Modular Construction

Observing the aforementioned impediments of modular construction it can be concluded that VR application opportunities exist and can assist in facilitating modular construction. Haas and Fagerlund 2002 and others recognized the importance of computer integration and technological advances such as 3D CAD and the possibility of its application in modular construction. VR technologies go beyond the capabilities of 3D design to include aspects such as time and more effective communication. Also, the application of VR would be facilitated due to the need to have a significant proportion of the engineering design completed prior to commencing construction activities. The completed engineering design would provide for all the input to generate useful virtual reality tools that can be applied to enhance performance.

Enhancing physical interface management could be one of the most direct and initial advantages of using virtual reality technologies. The visualization enhancement provided by VR technologies would assist the engineers in assessing the complex modules and plan for efficient assemblies in terms of fabrication as well as installation.

Another aspect that can be improved is spatial planning for transportation concerns. While trading off with temporal aspects engineers can implement virtual reality technologies to generate efficient transportation schedules and plans.

Mitigating the reduced scope flexibility could also be another advantage for VR application. VR allows for effective communication of plans with other participants of projects during early stages. This would allow owners to have a better idea of the end product and perhaps suggest alterations prior to initiation of work. This would also increase confidence and improve the relationship with the owner. Increased efficiency of communication will have additional general benefits to the overall project at which coordination of multiple sites is needed. Distribution of information among participants can be enhanced and also VR technologies can provide the interface drawings and visualizations needed in modular construction projects in addition to traditional plans.

3. CASE STUDY FINDINGS

The VR technologies to be implemented are developed in partnership with the NRC CCCT. In addition, two industry participants were identified and secured for the practical application of the VR technologies and adoption assessment. The two companies offer a unique perspective on varying prefabrication technologies and applications which should assist in having an unbiased and more comprehensive understanding of the prefabrication industry and its technology challenges. Following meetings with the industry participants to initially identify the direction and general needs and challenges within the prefabrication construction industry, further analysis was performed to identify which VR technologies are available and match the needs and resources of the industry. Limitations of the VR technologies were identified as well as challenges to their practical application.

3.1 Initial Identified Challenges

There were two major challenging areas that were identified after meetings with two construction companies specializing in two different areas of prefabrication. The first company specializes in mass production of wooden wall panels. The company utilizes an imported system which is mostly automated for the fabrication of specifically designed wall and floor panel sections. The company fabricates wall panels for large housing projects and was initially a traditional general contractor which decided to make the transition to prefabrication about a year ago. The second company specializes in the production of composite wall panels. The panels are fabricated using a patented design utilizing both concrete and cold rolled steel. The company aims more at securing larger projects which provide for more feasible investment. Originally the company specialized in manufacturing machinery used for fabrication of steel office supplies. Following a decline in the manufacturing industry, the company decided to go into the construction business and apply some of the manufacturing principles to gain an advantage. The company still attempts to manufacture their own machinery for specific tasks such as welding whenever possible, although that is limited to resources and investment feasibility (size of projects). Table 1 provides an overview of each company illustrating the unique and different perspective each offers.

TABLE 1: An overview of the case study participants.

Factor	Company A	Company B
Location	Southern Ontario	Southern Ontario
Company Background	Construction (general contractor) background	Manufacturing background
Product	Wooden Panels	Composite Panels (Concrete/Steel)
Main Market	Housing	Industrial
Source of Fabrication System	Purchased	In house developed / Patented

Each of the two companies offers a unique and different view of prefabrication in construction. It was noticed early on that not only their processes but also their approach towards prefabrication is rather different. Nevertheless, both identified the same two major issues as their main challenges: integration and communication.

3.1.1 Integration

Integration has been identified as one of the significant issues causing delays within the production processes. Also, integration issues and complications were found to exist on two major fronts: integration between architectural drawings and construction designers/detailers, and the integration between completed design and the machinery used for the manufacturing of designed assemblies. Existing integration issues are mainly an underlying form of interoperability. Interoperability is a varying and widely discussed topic with continuing long term efforts to resolve case specific interoperability issues. The general approach to resolving interoperability issues, which was the same followed by the selected industry participants, is to use an off-the-shelf application or software or one that is developed by a third party specializing in software. The companies then attempt to standardize the software within their systems in order to limit any integration issues. However, interoperability or integration issues and problems have been found to always exist and rarely totally remedied. Integration still is one of the major bottle necks within production processes for two major reasons: the involvement of various participants and hence it is difficult to have one standardized approach adopted by all involved. Second, because of the fact that the prefabrication industry's demand for integration solutions is limited in volume, few software developers are willing to offer efficient and tailored solutions for their integration issues; and even those offered are charged in total to the single specific order which makes them rather costly.

3.1.2 Communication

General communication and education issues with multiple players within the industry have been raised as another general concern. Modular construction is relatively new in Canada as a significantly different and more progressive methodology when compared to Europe for example. This causes clients, architects and subcontractors to handle modular construction, even in its most simple forms, with scepticism and worries of increased complexity in assembly and reduced flexibility such as aesthetic options. Enhanced, more effective and practical communication is needed to establish confidence within the industry and educate of modular construction advantages and use. Some of the communication challenges that were identified were: ability to communicate the available options to the architects and clients and the ability to communicate the assembly processes or functionality of the end product to the architect, client and more importantly subcontractors who will be undertaking assembly on the site. The communication issues identified were more directly related to opportunities for VR application tools as to enhance the efficiency of communication and in some ways promote the methods of prefabrication through educating the participants.

3.2 Virtual Reality Technologies

Following identifying the main challenges faced by the industry participants the focus was then on assessing the VR technologies available, their limitations and how they could be tailored to fit the needs of the industry. An initial visit to NRC-CCCT facilities in London, Ontario was planned and an overall assessment of their available facilities was conducted. The VR facilities include state of the art environments and hardware such as the theatre, cave and motion capture area as well as other more portable options such as the 3D scanner, LCD's and compact and powerful processors. In addition, the VR tools and technologies available have been implemented in various manufacturing as well as construction oriented applications. Alongside sophisticated modelling and visualization for the auto manufacturing industry, examples of previous projects include training environments for crane operators and motion capture of human/environment interactivity. The following is a summary of the significant aspects of the available VR technologies related to the research project at hand:

- The use of portable VR hardware has very few and case specific limitations which are not likely to exist within the scope of the usage scenarios to be applied.
- In terms of software, various programs are available for use in multiple applications such as basic 3D design software, more advanced graphics software, animation and interactivity software as well as in house programmed software for specific applications.
- Software programs can be integrated and combined for a more complete and practical usage scenario.
- Previous work on creating a VR model for a basic demonstrative construction application has been done and the findings of the project (in terms of resources required and effort) are considered.
- It was identified that in order to have a real VR application, interactivity was a vital element to exist within the VR tools to be offered to the industry participants.
- In order to have a feasible application, it is necessary to have tools that can be used on a continuous basis. For example, directories of components that can be repeatedly used instead of single custom or project specific applications.

3.3 Project Direction

Following the visits and meetings with both the industry participants and NRC-CCCT, the following scope has been formulated:

- The main focus of the project is on the application of VR technologies as communication process technologies and tools with all types of participants.
- Minor assessment and consideration of integration issues will still be considered. Integration issues would be addressed strategically rather than technically.
- The application of the VR technologies will include interactive elements and not only advanced illustration tools.
- The creation of reusable tools is an essential aspect and that can be accomplished through creating directories of objects or tools which facilitate continuing use of the VR technologies rather than keeping it case specific.

In order to establish an adequate technological environment suited for the practical application of the VR technologies by the industry participants, four major steps need to be completed:

- Gather additional information and feedback regarding the specific needs of the participants and their use of the VR tools.
- Acquire all detailed design information from the participants needed to create the VR environment.
- Start with the creation of the basic 3D models and components of the VR environment.
- Complete the VR tools by introducing interactivity elements to the 3D environment as well as adding the element of time for the creation of 4D models.

There are various options available for the creation of the 3D components in terms of software. On the other hand, the use of hardware such as the 3D scanner is not likely due to the difficulty of establishing smart models using those tools (models that include groupings, components, hierarchies … etc.). The NRC CCCT facilities and technical support enables importing 3D models made using any of an array of software options such as 3D CAD, Maya, 3D Max and Google SketchUp. Due to the experience of the researcher with Google SketchUp, the relative simplicity of the construction models, when compared to other manufacturing modelling, and the free availability of the software (for both model creator and end user), Google SketchUp was selected to create the 3D environment. However, the models created with Google SketchUp will be later enhanced graphically using Maya before incorporating interactivity and time elements.

4. INNOVATION MATURITY FRAMEWORK

Process maturity modelling gained its greatest attention in the software manufacturing industry (Finnemore et al. 2000) and is based on the earlier concepts of process improvement such as the Shewhart plan–do–check–act cycle, as well as on Philip Crosby's quality management maturity grid which "describes five evolutionary stages in adopting quality practices" (Crosby 1979). Researchers at Carnegie Mellon University used this concept in the development of the Capability Maturity Model (CMM) (Paulk et al. 1995). CMM highlights the five thresholds of maturity which a process must transition through in order to be sustainably improved. Initially a process is (1) chaotic or ad-hoc and must be made (2) repeatable; after which it must be (3) defined or standardized. The process must then be (4) managed, i.e. measured and controlled. Ultimately, the process must be (5) optimized, i.e. it must be continuously improved via feedback and through the use of innovative ideas and technologies. The assessment of the maturity of a process at the organizational level entails determining the extent to which the process is defined, managed, measured and controlled; and this is commonly achieved by observing the practices within the organization. A more general definition is that maturity may be viewed as a combination of actions, attitudes, and knowledge rather than constraining the definition to a single set of actions or procedural norms (Andersen and Jessen 2003). Closer to the construction industry and management of projects are more recent maturity models that include the Project Management Process Maturity (PM)2 Model (Kwak and Ibbs 2002), the Standardised Process Improvement for Construction Enterprises (SPICE) Model (Sarshar et al. 1998), and the related research area of learning organizations in construction (Chinowsky et al. 2007).

The assessment of maturity of innovation management practices builds upon previous work on this topic. Willis and Rankin (2009) have defined a maturity model to assess management practices within the construction industry at an industry level. The model uses a three level construct for maturity where a practice is: (1) immature in that it is ad hoc in its application, (2) transitional mature in that it is defined and repeatable, and (3) mature in that it is measured and improved. The levels correspond to a range of zero (where it does not exist) to one (where it is fully mature).

Figure 2 depicts a conceptual framework for how innovation management practices will be assessed for the case study companies. Innovation management has been broken down into factors that influence its outcome. The factors will be grouped and each grouping is assessed based on the plan-do-check-act management cycle. The assessment is completed through a series of questionnaires structured to determine the level of maturity within an organization. The maturity is reported with respect to the level *achieved* and *remaining* for improvement for each management cycle step (e.g., bar chart) and can also be compared against other organizations in a benchmarking exercise (e.g., radar chart).

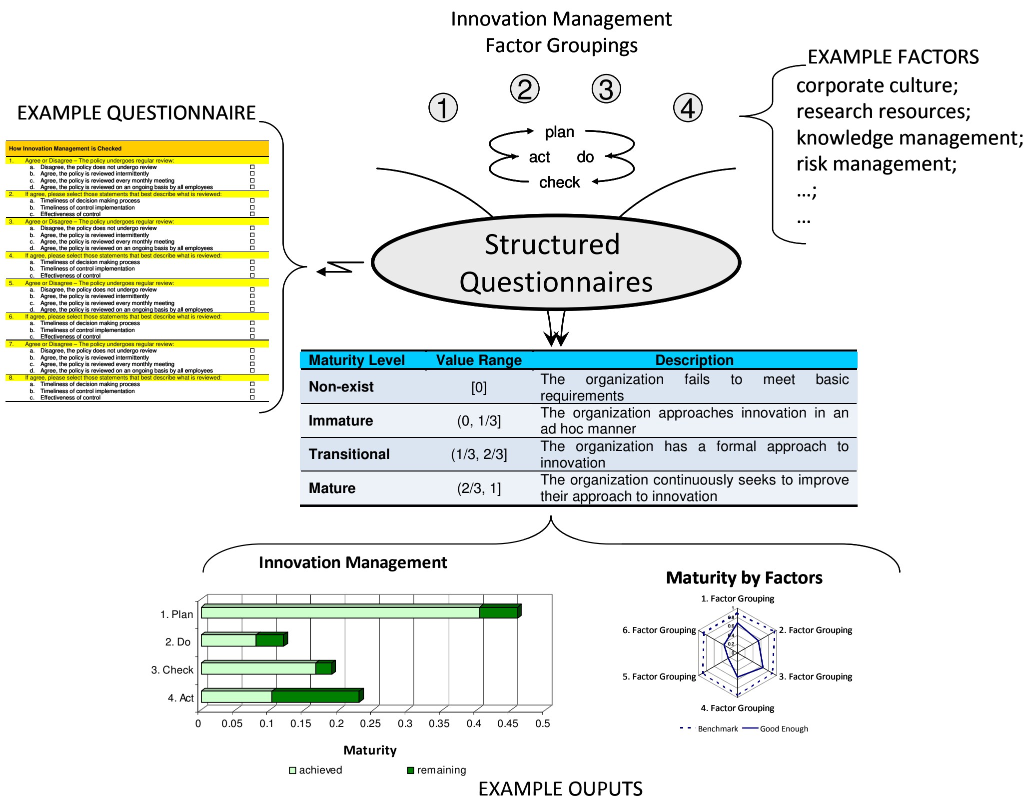

FIG. 2: Conceptual framework for assessing the maturity of innovation management processes.

5. NEXT STEPS

The case studies are being used as a step in validating the factors and groupings. A weighting of factors will then be completed based on pair-wise comparisons by employing the analytic hierarchy process, where each step within a grouping is weighted and then each grouping of factors is weighted. When completed for a group of experts, the geometric mean of the results will be used to determine the contribution to the maturity scores. This allows for analyses as is presented in Figure 2. The chart is indicating the relative importance associated with each step within innovation management along with a maturity score (achieved) and opportunity for improvement (remaining) at an organizational level. This will then give a comparison with the level of success in implementing VR (performance impact), however a case study of two will not be significant, therefore a broader study will be conducted.

The paper is reporting on work in progress that is intended to support the development of a means of assessing the innovation management practices of construction industry organizations. The results will be used to identify correlations with performance and as a predictive tool for implementation and adoption of process technologies.

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