Dismantling Silos

From Creative Collaboration to Collaborative Creativity

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A thesis submitted in partial fulfillment of the
requirements for the degree of

Master of Science in Construction Management

University of Washington

2014

Committee:

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Program Authorized to Offer Degree:
College of Built Environments

University of Washington

Abstract

Dismantling Silos: From Creative Collaboration to Collaborative Creativity

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The building industry is comprised of a multitude of specialists, each contributing something unique to the process. What once took decades of planning, physical labor and project oversight is now routinely accomplished is a matter of months, while also dealing with exponential increases in complexity. In so doing, the requisite array and subsets of Designers, Architects, Engineers, Contractors and Consultants have become increasingly disjointed. This thesis is an attempt to understand more fully the systemic nature of the Architecture Engineering and Construction (AEC) industry and to examine some opportunities currently presented for a re-thinking of the design and building processes that can contribute to enhancing project

quality and outcome by approaching the problem holistically.

The case studies herein, while divergent in strategy and organization, are both rooted in effective collaboration leading to innovative solutions. Further analysis investigates various criteria integral to working better together within the design and construction industry. Forming project teams, integrated in purpose and enabled through collaborative creativity, is a step toward an industry-wide reevaluation of best practices and working across disciplines more effectively.

This thesis document is represented as a logical progression, first providing background information concerning the evolution of the construction industry, innovation, collaboration and alternative processes. The remainder of the document delineates two case studies (Hertfordshire House by Facit Homes and 87 Dikeman by SHoP Architects) followed by an analysis of the criteria identified through the framework of Planning and Implementation of Effective Collaborative Working in Construction (PIECC) as being integral challenges to address in this effort.

Acknowledgements

to those who gave me an opportunity

Jason, Greg and Bob

to my professors

AnnMarie Borys for believing in my potential

Joel Loveland for asking the obvious question

Carrie Dossick for encouraging me to think outside the box

Yong-Woo Kim for providing a foundation of research and of process

and to my wonderfully supportive family

...Thank You

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INTRODUCTION

The building industry is comprised of a multitude of specialists, each contributing something unique to the process. What once took decades of planning, physical labor and project oversight is now routinely accomplished is a matter of months, while also dealing with exponential increases in complexity. In so doing, the requisite array and subsets of Designers, Architects, Engineers, Contractors and Consultants have become increasingly disjointed. Few outsiders truly see the frequent back-and-forth, checking and rechecking, redrawing and reworking necessary to bring a project together. Even so, errors and lack of coordination still occur, requiring costly and time consuming field modifications that affect everyone involved. As a society, much emphasis is placed on the finished product or object. Little or no thought is given to the many processes and participants involved in the realization of a concerted effort. Affecting large scale change and lasting solutions requires a shift in focus; a shift away from the finished object and toward the process itself. This thesis is an attempt to understand more fully the systemic nature of the Architecture Engineering and Construction (AEC) industry and to examine some opportunities currently presented for a re-thinking of the design and building processes that can contribute to enhancing project quality and outcome by approaching the problem holistically.

Included herein is an evaluation of two case study projects with analysis involving various criteria integral to working better together within the design and construction industry. The cases, while divergent in strategy and organization, are both rooted in fostering the talent and contributions of each team member, leading to innovative solutions.

The specific line of inquiry in addressing the case studies herein is the following research question:

1. Is BIM/VDC in the Cloud a viable substitute to Integrated Firm Organization in regards to effective collaboration and design for fabrication?

Drawing from the literature review and the context of the case study evaluations, the following hypotheses are proposed:

a) The approach of BIM/VDC in the Cloud should excel at the technological and project management related areas, such as geometry coordination and design for fabrication.

b) The approach of an Integrated Firm Organization should have greater potential to excel in terms of business, such as interpersonal relationships, morale and value.

Forming project teams, integrated in purpose and enabled through collaborative creativity, is a step toward an industry-wide reevaluation of best practices and working across disciplines more effectively.

This thesis document is represented as a logical progression, first providing background information concerning the evolution of the construction industry, innovation, collaboration and alternative processes. The remainder of the document delineates two case studies (Hertfordshire House by Facit Homes and 87 Dikeman by SHoP Architects) followed by an analysis of the criteria identified through the framework of Planning and Implementation of Effective Collaborative Working in Construction (PIECC) as being integral challenges to address in this effort.

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LITERATURE REVIEW

Design as a profession is a relatively recent adaptation of problem solving, continually evolving to address the needs of the time in creative, inspiring, and effective ways. Everything around us is essentially a designed and made object intended to satisfy a particular set of needs and constraints. The staggering array of options and viable solutions illustrates that multiple methods of approach can lead to success, in whichever terms that success may be defined, financial, aesthetic, functional, etcetera. It is interesting to note, however, that many of the so called “solutions” are quickly rendered obsolete, either by new needs, changing tastes, or advances in technology. Changes are often incremental and limited in their reach and effect. Such is the case in the AEC industry, slowly evolving in terms of the fundamental structure and in some cases reluctant to adopt new modes of thinking. A more radical departure from the status quo is warranted in search of bettering the built environment and associated processes in design and construction.

Professionalization

Abstracting the approach to design from the profession of design, it is apparent that they are not one in the same. Prior to the modern age, problems of all types and scales were examined and solutions presented, all without a formal profession to do so successfully. Rather, the most fitting solutions were produced by those with the unique knowledge and vision necessary. An example of one such visionary thinker is recounted by Tim Brown in his book, "Change by Design."

Brown describes how Isambad Kingdom Brunel, operating at the height of the Industrial Revolution in the 19th Century, designed the Great Western Railway, among other notable projects, clearly employing an expanded view of Design Thinking. Not merely content with anchoring Bristol as a thriving port by building a railway to unprecedented standards, he envisioned an experience; one that would require new innovation and integration:

> What Brunel said that he wanted to achieve for his passengers was the experience of floating across the countryside. Now, this was back in the 19th century. And to do that meant creating the flattest gradients that had ever yet been made, which meant building long viaducts across river valley [such as the one] across the Thames at Maidenhead and long tunnels such as the one at

> Box, in Wiltshire. But he didn't stop there. He didn't stop with just trying to design the best railway journey. He imagined an integrated transportation system in which it would be possible for a passenger to embark on a train in London and disembark from a ship in New York. One journey from London to New York (Brown, 2009).

Realizing a grand vision and accomplishing things that had never been considered before, required acknowledging the need to re-think the system at large. Being able to see beyond the task at hand and effectively create a whole that is greater than the sum of the parts, is needed to affect real change with lasting impacts.

Through out the subsequent 150 years, the establishment of distinct professions in areas of industry, trade and design gradually eroded the visionary attitude embodied by the likes of Brunel. A narrowing of views, responsibilities and services created stability in the economic system and fostered standardized practices and products, for better or worse.

Only recently has there been a notable resurgence of design thinking as a strategy for innovation. Corporations and entrepreneurs alike are seeking to break out of the rigidly defined box that has been so meticulously structured by regulations and by common perceptions among employees. The Design

Thinking Bootcamp held at Stanford University is just one example of such efforts.

The Division of Labor

The Industrial Revolution brought with it many new possibilities and increasingly complex solutions to the needs of a rapidly changing world. In order to meet these needs, specialized subsets of industry began to materialize, spurring innovation and advancement in many fields. To the benefit of society, specialized knowledge and skills began to raise the general standard of living for all. This concept is by no means new. It is simply a division of labor amongst an organized society, cooperatively working together for the greater benefit of the whole. The self-reinforcing cycle of specialization and exchange of services for goods or other services creates a sort of momentum, encouraging increasing levels of specialization (Ridley, 2010).

This process has continued for centuries and is evident in most all modern products and services we know today. For example, the mind-blowing complexity of the computer processor, able to perform many millions of calculations per second, has been undeniably influential and has made a tremendous impact on our modern world. However, the processor itself, made mostly of silicon and small amounts of other materials, is utterly useless by and of itself. To have any significant value, it requires the incorporation into a larger system, including other hardware, computer programming, inputs and outputs and a means by which to display information and interact with its user. Each part of the system has a specialized function, designed by a specialized team with specialized knowledge. They utilize their skill and knowledge to provide something that no one else can. It is only through the effective collaboration of the various people and technologies involved that they are able to produce meaningful results.

Industry Fragmentation

In a striking parallel and to no surprise, the Architecture Engineering and Construction industry has followed the same path of specialization as many other industries. Even the commonly used acronym AEC distinctly segregates the various fields, inherently describing a division of labor, responsibility, and also liability. Along with all the positive aspects of specialization, also come particular challenges. Belabored in many texts, the organizational structure of the building industry into particular groups, sometimes referred to as “silos,” has created barriers to effectively working together and has caused significant inefficiencies (Deutsch, 2011). Explaining such inefficiencies in detail is beyond the scope of this investigation, but include areas such as errors and omissions, reproduction of work, contract liability, intellectual property, procurement methods, and many others. The volatility of the market, changing codes and regulations, and the desire to reduce one's own risk has undoubtedly stifled innovation and advancement in the industry.

As these inhibiting factors are widely known, many efforts have been made to provide some sort of remedy. Contract structures and procurement methods have been modified in order to create a more cohesive and equally vested team for a particular project. These organizational strategies, known as Design/ Build and Integrated Project Delivery, are intended to encourage and facilitate collaboration among the separate parties involved. Various technological strategies have also been implemented and are gaining significant traction. Building Information Modeling is increasingly becoming the industry standard for design documentation. Providing a means for a three dimensional representation of the building to be embedded with rich database information has greatly enhanced detail and accuracy in the design. It has also allowed for more reliable clash detection by combining separate BIM models together to check for conflicts before construction begins and errors are discovered in the field, effectively reducing unnecessary modification costs.

Increased document coordination, clash detection, 4D sequence modeling, and quantity takeoff are just some of the possible applications. Yet, the full potential of BIM is yet to be seen. Its adoption as the industry standard is steadily growing, but hindering the collaborative possibilities are concerns regarding liability and intellectual property. These concerns are likely a consequence of the fragmented industry and overly complex procurement and delivery methods. As important as collaboration is, self-preservation and risk aversion often supersede in priority. The integrated approaches described earlier assume additional risk, but significantly reduce or eliminate many collaborative barriers. Continuing through to operations and maintenance, BIM standards applicable to building operations and maintenance are still in the process of refinement. The Open Standard Consortium (OSCRE), the Construction Operations Building Information Exchange (COBie), and the BuildingSMART alliance (openBIM) standards are aimed at formalizing the interoperability of the various software platforms and the exchange of information databases used in design, construction, real estate, and facilities management. The implementation of such standards is indispensable as the complexity and schedule of projects continues to increase. The many conveniences afforded us by modern technology have made great strides toward effective collaboration of industry participants. However, the current direction of facilitating transitions among disciplines is limited in its ability to truly affect great change. It is simply not enough to address the technical workings without addressing also the underlying organizational and team structures.

Dismantling the Silos

It is not enough to facilitate collaboration among the existing “silos” of Architecture, Engineering and Construction. No matter how creative the solution may be to enable collaboration, the inherent flaw of segregation will still exist. A new approach, a shift away from creative collaboration and toward collaborative creativity, is needed in order to truly address the larger systemic issues of the AEC industry. Similar to Brunel, but with some modification, the application of Design Thinking is warranted. As previously illustrated, specialization and specialized knowledge is not the problem. The problem is in the way in which that specialized knowledge is aggregated and implemented. The notion of the Master-Builder is simply not viable in today's complex building environment. No one person can nor should be in total control of every aspect of the process. Neither should the process be governed by only a select few, as is the standard today. The process should be much more open. Perhaps a new approach of 'Open Design Thinking' can be applied. Addressing not only the task at hand, but also the larger system, Open Design Thinking would provide the opportunity to embrace and leverage the specialized knowledge and ideas of all involved, regardless of hierarchical standing and title. The appropriate empowerment of all team members would encourage more active involvement in problem solving and lead to increased innovation and greater project success.

In a more open design environment, one might easily see that disparate and conflicting ideas or opinions are sure to be presented. Differing viewpoints are often seen as inhibiting to progress or contentious. The creative process thrives, however, as new possibilities bubble to the surface in a decidedly non-linear fashion. As business professor Roger Martin puts it, one must "exploit opposing ideas and opposing constraints to create new solutions."

To do so, one must first examine how truly great ideas and genuine innovation take form. Effectively, where do good ideas come from?

Novel Ideation

Speaking of observed trends regarding innovation, Steven Johnson illustrates the historical perspective. He shows that often breakthroughs are described in terms of a flash, a stroke, an epiphany, or a “eureka! moment.’ However, the truth of the circumstances is usually not that of the solitary genius huddled over the microscope, but rather in the context of a larger group around a conference table. Great ideas form not in an instant, but over a period of time and are informed by any number of different stimuli. This phenomenon is known as “the slow hunch,” meaning that the ideas need time to incubate and gradually fade into view before they can be fully comprehended and articulated (Johnson, 2010).

Obtaining a conference table sufficiently large to accommodate everyone involved in a building project is both highly improbable and highly ineffective. Getting anything productive accomplished in a large group environment is certainly a challenge. This is why most often the traditional approach is taken, gathering a selective group and forming an institution to pursue a specific purpose, much like the selective fragmentation in the AEC industry. The two opposing rationales to this approach can be illustrated using the 80/20 rule, also known as the Pareto Principle. The basis behind the principle is that in any situation, most of the results are determined by a small number of causes, or 80 percent of the work was done by 20 percent of the people. This places a high perceived value on the effectiveness of that 20 percent. However, the opposing view calls into question not only the quantity of the work contributed but also the quality. The key discovery or breakthrough may very well come from someone outside the select 20 percent. However, considering the coordination costs associated with managing a larger group, most are willing to take that risk and hope that results obtained by the selectively chosen group of 20 percent will be good enough (Johnson, 2010).

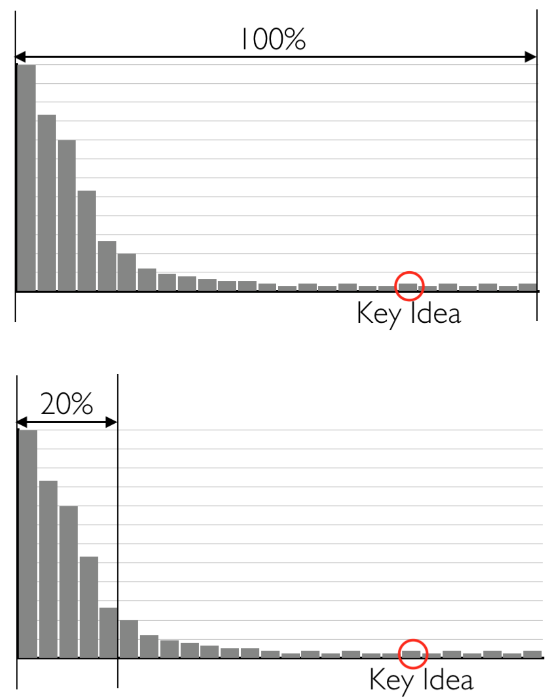

Figure 1 The Pareto Principle

Recasting Labor

Accepting the Pareto Principle as the status quo, excluding the potential contribution of the other 80 percent, regardless of the quality of their contribution, reveals a critical flaw in the system. Why not just re-think the system in order to capture the lost value? Applying the 80/20 rule directly to the traditional organization of the AEC industry the pattern is clearly illustrated. On the left, the individual with the key idea is excluded simply by the organization of the system. On the right, the open nature of the system encompasses all the participants, including the key idea. All the same parts and pieces are included in both examples; it is merely the organizational relationships that change.

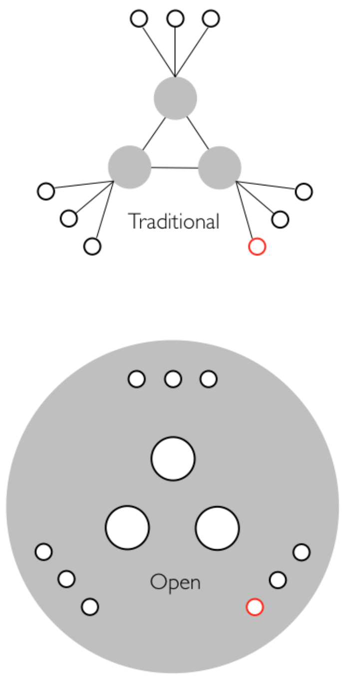

Figure 2 Open Organization

By capturing 100 percent of the participants, the system may then benefit from an expanded range of potential solutions, allowing quality to outweigh quantity. This open organizational model only works if there is equal access and a free flow of information. The traditional model limits full access to only those in the center triangle and excludes those on the periphery. The open model does not restrict access to information, reducing potential miscommunications and inadvertent omissions. The rigidity of the traditional organizational model is so ingrained in the AEC industry that its effects linger, regardless of efforts to structure it otherwise through alternative procurement methods such as Design/Build and Integrated Project Delivery. Speaking to this problematic mind-set that has been cultivated by tradition, Paolo Tombesi states,

> …the theoretical faculty to provide overarching instruction, originally ascribed to the architect and still reflected in the abstinent insistence of much architectural literature on correlating single architect authors and building artifacts, has left an indelible mark on the way many architects think and talk about design - as an activity largely autonomous from the rest of the industry, closely associated with the work (and the services) of the architect plus fellow engineering professionals but culturally separated from construction (Tombesi, 2010).

A more open organizational model implicitly suggests a re-thinking of the traditional roles, responsibilities, and methods of communication. Changes that will have lasting impact must address this systemic view of the industry. Tombesi views design, in its most reductive terms, as a "problem-defining, problem-solving, information-structuring activity that defines a specific course of action." In these simplified terms, the building process then becomes a system of design production independent of any one profession.

The most critical aspect then becomes how the many parties involved, with their collective specialized knowledge, are able to coordinate themselves in collaborative creativity, all participatory in the design process. One could identify this collective as "The Project-Firm" (Tombesi, 2010).

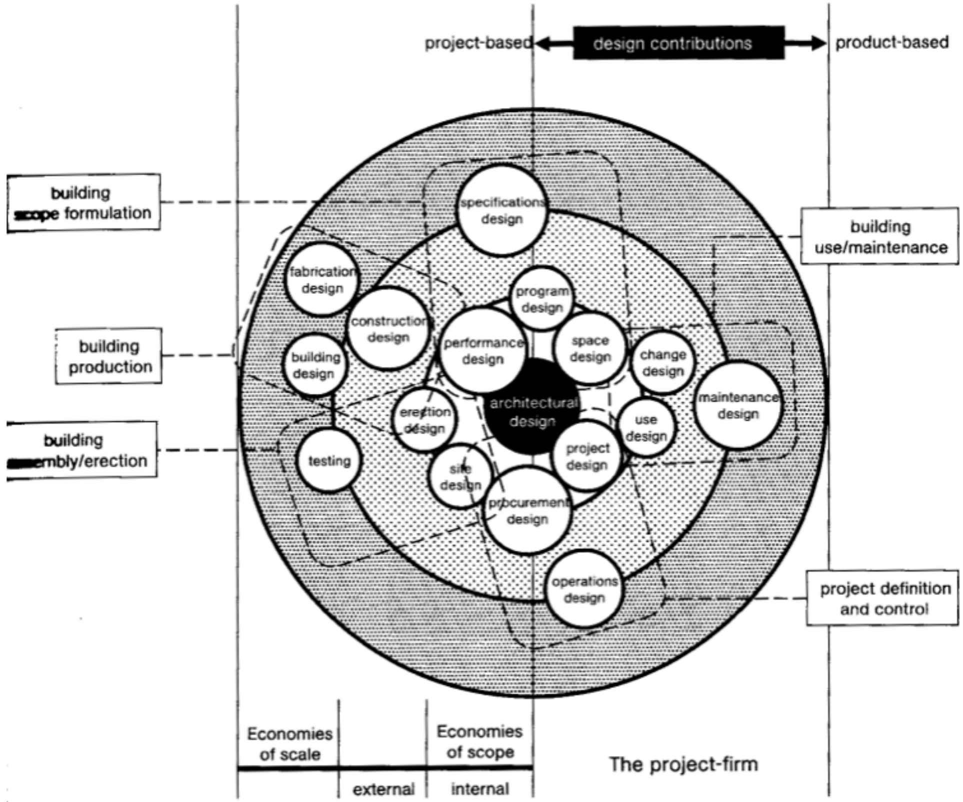

Figure 3 The Project-Firm

Integrated Practice

The majority of AEC companies today are organized as separate and distinct organizations, each with their respective specialized services. The contracting and delivery methods available are continually expanding to include more integrated solutions, not only to achieve lower costs and accelerated schedules, but also to better utilize the expert knowledge of the various specialty disciplines. Existing literature describes an integrated project team as being, “where different disciplines or organizations with different goals, needs and cultures merge into a single cohesive and mutually supporting unit with collaborative alignment of processes and cultures” (Baiden, 2006). Some companies have seen a distinct advantage with the integration of two or more disciplines operating under one roof. Multiple variations of integrated practices exist, depending on unique company goals and principles. Multidisciplinary Design, Design-Build, Full-Service Development, and Architect-Developer are some examples of successful strategies in terms of design and construction integration.

Multidisciplinary Design

A classic example of integration is that of Skidmore, Owings and Merrill (SOM). The company augmented its design services with the integration of structural engineers. John O. Merrill, and architect and structural engineer, joined SOM as a founding partner in 1939 and is credited with establishing the multidisciplinary nature of the firm. Leading primary advances in skyscraper design over the past 75 years, the firm has continued to see success with their interdisciplinary business model. In contrast to the solitary architect, SOM advocated a new architectural approach to teamwork and comprehensive design by establishing a corporate image, operating as a single, multifaceted entity.

Integrated Design-Build

Extending the scope of service to include the design as well as the construction phases, Design-Build has become increasingly prevalent in recent decades. Benefitting from increased coordination and a singular point of reference for the owner, Design-Build is beginning to supplant the traditional process involving multiple parties and separate contracts. An integrated design-build firm would ideally be one company that provides both design and construction services for all their projects, opposed to a strategic partnership between a separate designer and a separate builder attempting to work closely together on a project-by-project basis.

Full-Service Development

Similarly, some developers have expanded on the basis of integration by incorporating in-house architecture and engineering staff. Streamlining the process, the developer then may exercise greater control over the cost, direction, and schedule of the project, albeit sometimes at the sacrifice of design quality and innovation. However, such a trade-off mentality is not always the case, as is illustrated by some recent examples of design-focused integrated practices.

Architect-Developer

One of the first and most prominent examples of the Architect-Developer can be found operating in San Diego, California. Jonathan Segal is a traditionally trained architect who turned to developing his own projects as he became disillusioned by the limiting nature of the traditional architect/client relationship. His first independent project was a set of 7 row homes on an undesirable downtown lot in 1990. The high-design homes sold quickly and Jonathan has never looked back. Operating as developer, architect and general contractor has helped keep his costs low. Rather than pouring money into high-end finished, Segal focuses more on the quality of space created. The high market demand, multiple design awards, as well as offers from other developers to purchase his properties suggest that he found a winning combination. Others have followed, operating at multiple scales and crossing building types.

Firms such as Gluck+, FLAnk, Alloy Development, DDG Partnership, and SHoP each have found a successful niche by integrating varied specialties and services to provide a more cohesive and comprehensive design and construction process.

The above examples of cross-disciplinary collaboration are somewhat different than the concept of "partnering," which is commonly used today (Cotts, 2010). A partnership arrangement is usually on a project-by-project basis and involves multiple, distinct entities. Such an arrangement can work very well and has been shown to be an effective approach, especially when the companies are co-locating for the duration of the project (Kim/Dossick, 2011). However, depending on the nature and context of the partnering agreement, certain challenges may arise. The experience and qualifications of each party may be mismatched. Also, in any new partnership, there is sure to be a period of "settling in" where the partners will be learning about each other and discovering kinks in the process. As a particular partnership carries on, perhaps through multiple projects, such idiosyncrasies may be worked out and the two parties can operate more cohesively as one. However, with the current nature of competitive bidding and overlapping projects, the same partnership may not have the opportunity to work exclusively together on all projects. Furthermore, appropriate Information Technology (IT) needs to be in place and utilized in a consistent way among all parties in order to easily communicate and share information when a partnership is physically and/or geographically separated. One strength of integrated practice lies in the consistency and continuity of individuals along with the establishment of a singular company identity, culture and process.

However, the reality is that not every project will be designed and constructed in an organizationally integrated firm environment. How then, might we work together if we must be separate? Although not within the same organization, we can, as an industry, have a unified vision; and that is a start.

Process Design

Always striving for a better way to design and construct our built environment, the collective AEC industry is seemingly in a constant redefinition of process and best practices. Each new strategy has its list of pros and cons, along with various camps of ardent supporters and derisive nay-sayers. Whether the goal be to make the process more efficient, less wasteful, more capable or less isolated, the proliferation of options for designers and builders alike is certainly in no short supply. There are certainly those more resistant to change than others. Not wanting to rock the boat, many in the industry are more willing to accept the faults and inefficiencies than to venture into unfamiliar ways of doing things. Industry-wide adoption of new technology and processes takes time, resources and buy-in by those taking the risk.

Industrialization of the Construction Industry

Much has been said in the way of incorporating industrial processes into the construction trade. In many regards it has the potential to reduce errors and to speed construction times. Others fear that it will make for a monotonous array of minimal variation. Designing for fabrication can have a wide range of meanings. The degree to which a building or its components are prefabricated or pre-assembled can range from simply using standardized building materials to 95% complete modules ready for delivery to the site. Whether industrialized processes and products are viewed as a limiting or an enabling factor depends on who you ask. Arguments can be made for either side of the debate. One thing is certain, something must change in standard practice in order to keep pace with the increasing complexity of modern buildings and escalating expectations in terms of design quality, sustainability, cost and schedule. Furthermore, we as an industry must not lose sight of a common goal, that of making space and environments meant to be enjoyed and inhabited by people.

Lean Construction

Lean Construction is a derivative of the Toyota Production System (TPS) authored by Taiichi Ohno in the 1970's. James P. Womack, founder of the Lean Enterprise Institute established in 1997, identifies 5 principles inherent in the Lean Production methodology:

1. Precisely specify value
2. Identify the value stream
3. Make value flow without interruptions
4. Let the customer pull value from the producer
5. Pursue perfection

The main focus of Womack's interpretation was to drive the elimination of waste. However, a closer examination of the Toyota Production System reveals there to be more complex and underlying considerations than are not clearly represented in Womack's definition of Lean Production.

Waste is also a factor in TPS, although in combination with two other, more fundamental issues. The three components are:

1. Waste (Muda)
2. Variability (Mura)
3. Overburden (Muri)

The definition of waste is further refined by Ohno to include not only material waste but also worker motion, material transportation, waiting, excessive processing, inventory and rework. Overburden, sometimes called overproduction, is considered the root cause of the other types of waste. By attacking the source of overburden, an expanded definition of waste is also addressed. Variability relates to the flow of process between tasks and the production rate. Variation in output creates inconsistencies and conflicts, ultimately resulting in a slower and less efficient flow. By addressing the aforementioned components, the outcome is not just a reduction in waste, but an overall operational stabilization.

Effective Collaboration

The process of collaborating in construction has undoubtedly been subject myriad configurations and strategies. Attempting to gather key findings from successes and failures in collaboration, Mark Shelbourn and Dino Bouchlaghem outline a promising framework: the Planning and Implementation of Effective Collaborative Working in Construction (PIECC). The framework directly addresses specific issues resulting from ineffective collaboration, as defined through a series of in-depth workshops with industry professionals (Bouchlaghem, 2012). The results of the first workshop were distilled to identify the top considerations resulting from ineffective collaboration and ranked in order of importance. The findings are summarized in the chart below.

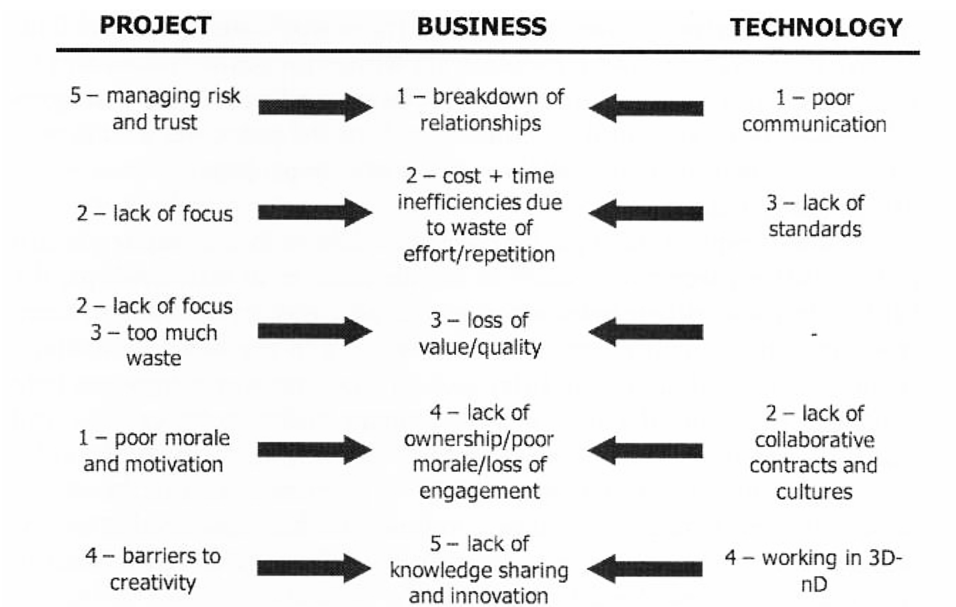

Figure 4 PIECC Workshop Task 1 Results Summary

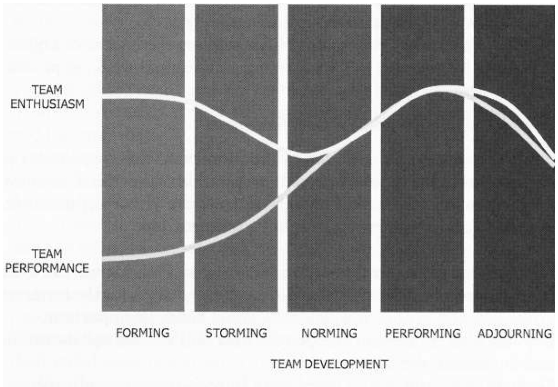

Figure 5 Tuckman's model_without PIECC

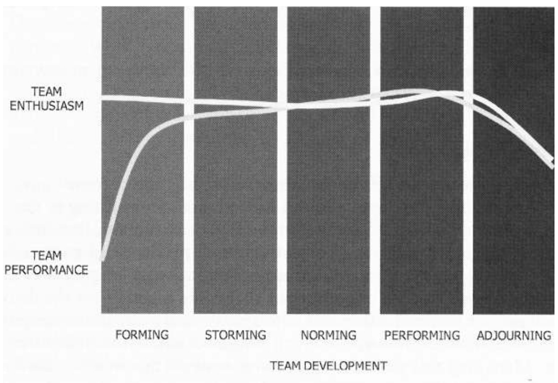

Figure 6 Tuckman's model_with PIECC

The top 4 of the 23 suggested processes most effective in collaborative working are:

1. Appoint a collaboration champion
2. Develop a shared vision
3. Define roles and responsibilities
4. Agree on standards and procedures

The full framework is a step by step guide to assist in getting the most out of a collaborative endeavor (see Appendix A). As illustrated in the associated charts, application of the PIECC framework is intended to accelerate team performance and maintain team enthusiasm throughout the duration of the collaborative effort (Tuckman, 1965). Although intended to provide a simple and straight forward path to success, the PIECC framework does require significant advanced planning, beginning before the team has been organized, to establish the viability of a proposed collaboration. The fast pace of many projects, along with the limited say in who ultimately ends up on the team, may prove to be challenging in its application.

Summary

Change is in the air for the AEC industry. The organizational models and thought processes of the past will need to be drastically adapted, or thrown out completely, as we strive toward an openly collaborative industry, capable of providing innovative solutions to questions of energy consumption, resilient design, environmental responsibility, health and quality of space. It begins with a dramatic shift in the preconceived notions arbitrarily set by various titles, trades and professions. We must dare to do things differently, to take risks in search of something better, something more.

In an effort to better define how to accomplish such a task, one must more clearly understand the factors contributing to the many industry buzzwords such as collaboration champion, shared vision, expanded roles/responsibilities and lean production. What does that really look like and how do we get there? The remainder of this document is dealing with two approaches to addressing the challenges in the AEC industry. One approach is to form more holistic teams as an integrated firm organization, all under one roof. Alternatively, the more federated model of collaboration via BIM/VDC in the Cloud offers an expanded reach and flexibility in forming a team for a given project.

3

METHODOLOGY

The subjective nature of the subject matter, in addition to the limited examples of integrated organizational structures within the AEC industry, requires a method of evaluation that is mainly qualitative in nature. Ideas related to collaboration and the integration of various sociotechnical processes provides little data that can be quantified and measured objectively. Furthermore, the restructuring of labor in the AEC industry is a slow evolution that is just beginning to take place and in a limited scope.

The Case Study method has been selected as an effective means to illustrate and understand creative processes in a collaborative context, providing a qualitative investigation of the subject matter. Cases exhibiting alternative solutions to organizational barriers have been selected, each also incorporating advanced manufacturing processes in an effort to realize higher quality. The specific line of inquiry in addressing the case studies herein is the following research question: Is BIM/VDC in the Cloud a viable substitute to

Integrated Firm Organization in regards to effective collaboration and design for fabrication?

The Case Study Method

What is the purpose of the research?	To examine a single "case" (or multiple "cases") in-depth in order to understand the person or phenomenon
What is the nature of the research process?	• Studies bounded cases • Focus on natural context
What are the methods of data collection?	• Interactive fieldwork • Formal and informal interviews • Some use of quantitative measures
What are the methods of data analysis?	• Interpretational - search for themes • Structural - search for patterns in discourse • Reflective - rich portrayal of participants' views
How are the findings communicated?	• Analytical (objective) narrative • Reflective (literary) narrative

(Leedy, 1997)

Qualitative Analysis

For the purposes of this thesis, two architectural firms have been identified that have seen success in implementing atypical process and collaborative work flows as described in the previous chapter. Of those two architectural firms, specific cases have been selected, one from each firm, in order to limit the scope of the investigation and enable a comparative analysis to be performed. The two cases to be examined are:

1. Hertfordshire House by Facit Homes, based in London, England
2. 87 Dikeman by SHoP Architects, based in New York, NY

The cases were chosen due to their differences in theoretical approach, technological implementation, and organizational structure; but also because of their unified objective to improve quality by challenging the status quo of the design and building process. Comparing the cases to one another and examining the relational organizations, this study aims to highlight key similarities and differences that affect the end results and associated processes. A subjective analysis of the cases using the results of the PIECC framework is an attempt to quantify the impact associated with the differing approaches. Drawing from the literature review and the context of the case study evaluations, the following hypotheses are proposed:

a) The approach of BIM/VDC in the Cloud should excel at the technological and project management related areas, such as geometry coordination and design for fabrication.

b) The approach of an Integrated Firm Organization should have greater potential to excel in terms of business, such as interpersonal relationships, morale and value.

The findings resulting from the case study investigations are to help better understand the challenges facing the industry and illustrate successful solutions in collaborative design incorporating digital fabrication and industrial processes.

4

CASE STUDY ANALYSIS

The ultimate quality of a complex project can be addressed by two complimentary, yet opposing strategies: consolidation and diversification. For the purposes of this investigation both strategies are viewed in the context of integrated design. The organizational structure among the participants in the process has been used to identify each accordingly.

Facit Homes

We live in a world of corporate conglomerates, as well as small businesses and sole-proprietors. Each operates under the same general principle of consolidation, although at vastly different scales. The idea being that the consolidated effort results in greater control and a superior product. Facit Homes is an integrated architecture, fabrication, and construction management firm based in London, England. Taking a different approach to


Figure 7 Kitchen_As-Built

design and construction by re-examining the underlying processes involved, the company has pioneered innovative applications of technology to enhance not only the quality, but also the experience of designing and building bespoke custom homes.

Bruce Bell, a founding partner and director at Facit Homes, describes the company thus,

> What we do is less about a building system and more a different way of commissioning and procuring building…We take an industrial design approach in that there is one party responsible for everything, all-in-one, which is common in the manufacturing industry but unusual in the world of construction. Take a company like Boeing; they do everything. Whereas you look at the current business model behind how homes are created and it's very fragmented, very complex (CNN, 2013).

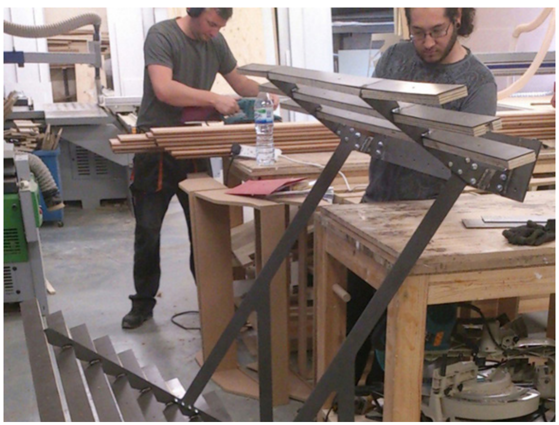
Figure 8 Prototyping

In the traditional building process, multiple companies are contracted to perform different services. Managing all the moving parts and pieces to the process can quickly become the primary challenge. To circumvent the traditional pitfalls, Facit has adopted an alternative approach including parametric and digital production methods with the intent to design for assembly. The departure from commonly accepted roles is clearly evident.

> Instead of the traditional model of the architect and consultant team, the design, engineering, research and development, prototyping, production and assembly processes are all

> undertaken by a single entity. In this way, the house is conceived as a product and the client benefits from the simplicity of a single point of contact (Bell, 2013).

Assuming the roles of designer, fabricator, and construction manager, Facit Homes intends to eliminate the complexity associated with the traditional approach to building a home. What makes their integrated process unique is the extension of streamlined collaboration beyond the realm of communication and into the realities of actual production. A critical differentiating factor to their approach is that “every design is driven by the constraints of the site, brief, environmental conditions and local planning requirements, rather than based on standard ‘typologies’ or customizable templates.” A more traditional client/architect relationship is maintained while simultaneously integrating the entire production process and follow through to construction (Bell, 2013).

The D-Process

Exhibiting some traits associated with the more widely known practices of Lean Construction, the D-Process is focused on the transition from digital design to final product while eliminating as many steps and interruptions in between as possible. In order to realize a more efficient process, Facit Homes employs a site-manufactured strategy. On-site manufacturing helps avoid the

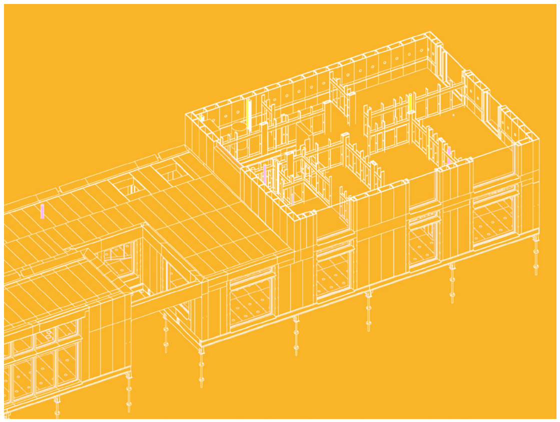

Figure 9 Facit Chassis_3D Section

Figure 10 Mobile Production Facility

complex logistics, expenses and standardization of factory mass-production resulting in no transportation of large prefab modules and decreased carbon emissions. Building components are produced on-demand, as they are needed for the construction assembly for less cost and with no lead time. Bruce Bell clarifies that “it is not a building system, but a way of working.” By combining the low cost of working on-site with the high finish of the production process, Facit Homes has struck a fine balance between economical efficiency and consistently high quality.

Enabling the process is the deployment of a specialized Mobile Production Facility (MPF). Within a standard shipping container resides a high precision CNC router capable of cutting all the necessary components from traditional sheets of plywood. The interlocking panels are joined together to form “cassettes,” each numbered and designated for specific placement. Once the cassettes are stacked and assembled together, much like Lego blocks, the completed framework of floor, walls, and roof is referred to as a “chassis” onto which the final finishes and fixtures can be applied. The chassis sits atop a series of helical foundation piers, minimizing disturbance to the site and allowing for dismantling or relocation of the building if required. The whole

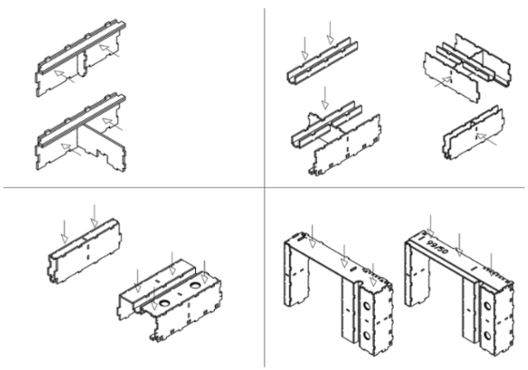

Figure 11 Cassette Assembly Sequence Diagram

building process can be completed in as little as 7 months, with the chassis being completed in a mere 8 weeks.

The design of the overall system is carefully considered and planned in detail using Building Information Modeling. For their purposes, Facit Homes utilizes Autodesk Revit for generating a detailed BIM model, including everything down to the electrical outlets and wiring chases. All necessary fabrication information is encoded directly into the digital model. A proprietary method has been established enabling the direct translation of the digital model data into a programming language called G-code, used as a set of detailed instructions to control computerized machining tools. The fabrication instructions are interpreted by the CNC router, guiding the cutting head movement known as the tool path. The direct translation from a digital model representation to physical object ensures precision, consist quality and the elimination of interpretation errors commonly found in the traditional paper-based process using only printed drawing sets.

Construction logistics are also considered as each cassette is designed to be of manageable size, small enough for just one or two people to lift into place. In the process of cutting the plywood sheets, the CNC machine also inscribes

Figure 12 Cassettes Form Walls

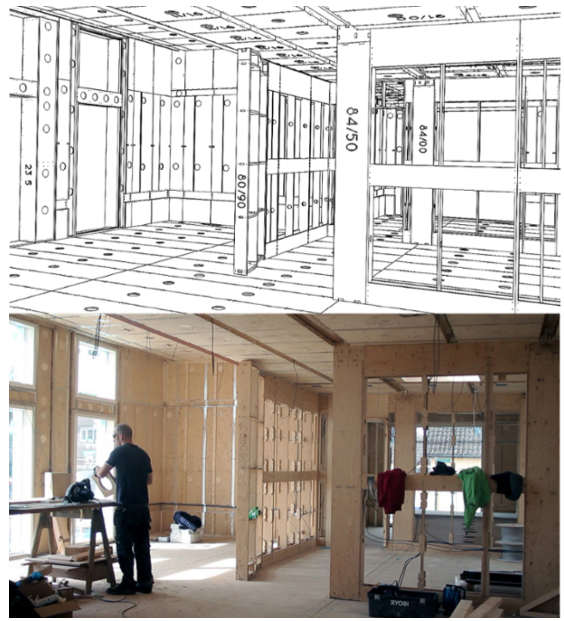

Figure 13 Digital Vs Real

Figure 14 Pump-in Insulation

a unique identification number for each piece as well as conveniently placed holes. The holes perform a dual purpose in that they are used as hand-holds for moving and positing the cassettes, as well as an access point through which loose insulation is blown into the cavity after assembly.

Sustainable Practices

Insulating the building envelope, cellulose fiber insulation made from 100% recycled content is pumped into the 275mm (10.8 in) cavity walls under pressure. The building process and tight tolerances during construction allow for a very energy efficient building envelope, meeting Passive House standards in terms of tightness and insulation values. Thermal performance is rated at a U-value of 0.14W/(m^2K). Additional environmental components, such as solar panels and heat recovery system ventilation, can be included in the design in order to achieve the full Passive House certification.

Facit Homes sources its plywood from a particular factory located in Finland and operated by a company named UPM. The benefit of using this engineered structural grade spruce plywood as the base structure opposed to more traditional timber framing goes beyond the conveniences of CNC cutting. A very low carbon footprint is achieved due to the processes of the Finnish

Figure 15 Spruce Structural Plywood

factory. The wood ply is peeled from the trees rather than sawn, producing very little waste. Furthermore, the company's mills are powered using by-product waste incineration. Highlighting the novelty of the approach, dubbed the RafCycle, the company states,

> UPM's customers in Europe can send their by-products for re-use as a source of energy in a combined heat and power plant which supplies heat and energy into the operation of UPM's paper mill… The purpose of conventional waste incineration is to reduce the volume and get rid of the waste, but UPM's power plant[s] burn solid fuels to produce heat and clean energy (Nyberg, 2014).

In addition to re-using waste wood, the RafCycle incorporates the re-use of recycled paper de-inking residue, paper and plastic rejects from the paper recycling process and self-adhesive label stock waste.

An additional benefit to creating such an integrated process package is that it can transcend geographical boundaries and scale to have a truly global reach. When the design, interface, fabrication & assembly instructions and specifications are combined in a single digital platform it can be easily transmitted anywhere in the world and be immediately put to use. Although the particular requirements of the design may vary, crafted specifically for a predetermined and individual site; the process remains unchanged, instilling the same operational benefits to each project. The true advancement is in the

Figure 16 Site Tools Minimal

underlying framework of the approach.

More time was spent developing the company structure and workflow to successfully deliver projects than on the basic technology. Facit's projects show how BIM and digital tools can be applied to meet challenging environmental targets with high-quality, bespoke homes. But perhaps the most exciting aspect is the new business model and new way of working that the technology is starting to define (Bell, 2013).

Figure 17 Hertfordshire House_Front Exterior

Hertfordshire House

Client	Celia & Diana
Completed	2011
Location	Hertfordshire, England
Project Type	Single Family Residential
Architect	Facit Homes, Bruce Bell
Manufacturer	Facit Homes
Builder	Alton Services MK Ltd
Area	2,153 sq ft (200 sq m)
Certification	Energy Rating A (92% Efficient)
Program	2 master bedrooms 3.5 bathrooms Study / Bedroom Lounge / Bedroom Kitchen Dining Pantry Utility Room

By responding to a local advertisement, Celia and Diana, the clients for the home to be built in Hertfordshire, England became participatory in the first on-site digitally manufactured home ever to be built. When the project was presented before the local planning department, the novel approach and low carbon nature of the project garnered praise and was granted approval by a majority vote.

Integrated Design

The design process leading to that critical point of being granted approval began as most any other. Through a series of discussions with the client and interpretation of the site, the program needs and ideas gradually took shape in the form of schematics and sketches. These early parameters were refined and molded into a working plan which then led to more refined details and prototypes in the design studio. The client expressed the desire to have a home that "…is hassle-free and economical to run; where every room and square meter of space will be used…A home that is flooded with light and sunshine; and one where we will easily be able to get outside to enjoy the garden" (Facit, 2014).

Figure 18 Hertfordshire House_Interior Lounge

The resulting design incorporated a careful integration with the site, considering elements such as symmetry, orientation, and surrounding contextual relationships. The chosen site fell within an area that had received AONB status, an acronym meaning Area of Outstanding Natural Beauty.

Defined by the National Association for AONBs as, “a precious landscape whose distinctive character and natural beauty are so outstanding that it is in the nation’s interest to safeguard them,” these areas represent only 18% of the of the countryside from England to Wales. The governing entity for the classification and management of such areas states the following (National Association for AONBs, 2014):

Figure 19 Hertfordshire House_Concept Sketch

The primary purpose of the AONB designation is

- To conserve and enhance the natural beauty of the landscape

Two secondary aims complement the purpose

- To meet the need for quiet enjoyment of the countryside
- To have regard for the interests of those who live and work there

In achieving these aims each AONB relies on

- Planning controls
- Practical countryside management

The helical piles supporting the structure help to minimize disturbance to the pristine site. The size of the house was kept relatively small, but allows for flexibility. The study and lounge, adjoined to the main living area, can serve a dual function as additional bedrooms. Diana says, “The house is designed

Figure 20 Hertfordshire House_Exterior Rendering

to work into old age for us, with the option to sleep and bathe on the ground floor if it becomes necessary, and easy disabled access via a ramp built into the rear decking" (Koones, 2014). It is this same type of forethought and integration that manifests throughout all aspects of the home and building systems.

Integrated Systems

Operating as a finely tuned system, large windows facing south admit plentiful sunlight, passively keeping the home warm throughout the winter, while solar shading reduces heat gains in the summer, allowing it to stay cool. The tightly constructed home effectively maintains the interior conditions, requiring only a small, low-energy boiler. The energy output required to heat the home is a mere 4 kW, equal to the that of just one radiator. In order to maintain a sufficient amount of air exchange without compromising the thermal efficiency, a heat recovery ventilation system was used. In such a system, the heat from the expelled stale air is captured and used to pre-heat the incoming fresh air, thereby minimizing the energy required to maintain a consistent temperature. The heating system is minimally used and acts only in supplement to the passive solar heating achieved by means of the large, double and triple

Figure 21 Hertfordshire House_Solar Shade

paned, windows and the generous skylights. A wood burning stove can also be used on rare occasion when needed for the coldest days.

Figure 22 Hertfordshire House_Kitchen Detail

The energy requirements of the home are provided for by photovoltaic panels, including the energy used to provide hot water. Any surplus electricity generated is fed back into the local power grid. Optimal solar orientation was considered during the early design stage. Primarily illuminated by daylight, energy efficient LED and CFL lighting is used only as needed. Also contributing to savings are energy efficient appliances, working together with the other systems to decrease the overall energy load.

For the Hertfordshire House, no one element stands alone. All of the parts, pieces and processes work together to form the complete picture. It is the particular combination of design, siting, production, passive strategies, mechanical systems and build quality that makes the house exemplary. So too, the integrated process and strategy that Facit has embraced as a company and through the D-Process, challenge the status quo and represent true innovation for the industry.

SHoP Architects

Diversification, in the business sense, is "a risk-reduction strategy that involves adding product, services, location, customers and markets to [a] company's portfolio" (New Oxford American Dictionary). As a company continues to grow, it often diversifies into alternative revenue streams in order to withstand market fluctuation or new competition. It is a sound strategy, but is not without its challenges. Lack of expertise in new products or services can be a stumbling block in considering market realities, and success is far from guaranteed. From the outset, SHoP Architects embraced diversification through its management team. Intent on finding improved ways of building, SHoP was founded in 1996 by 5 principals: Christopher Sharples, Coren Sharples, William Sharples, Kimberly Holden, and Gregg Pasquarelli. The multifaceted team brought with them diverse backgrounds encompassing architecture, fine arts, structural engineering, finance, and business management. The practice has since expanded to 7 principals, beginning with the formation of a sister firm, SC | SHoP Construction, in 2007. Headed by Jonathan Mallie, SC offers valuable capacities in Construction Management, Building Information Modeling, Virtual Design and Construction and building envelope consulting. Completing the current makeup of principals, the addition of Vishaan Chakrabarti occurred in 2012, rounding out the firm's urban design expertise. Representing the firm's values is the following summary,

> We are neither ivory-tower elitists nor superficial stylists. We believe in both ideas and profitability. While we are well-versed in the ongoing development of architectural theories, our expertise and ambition extends beyond the discussion and design of buildings. We look at an entire project and consider the site, the cultural and economic environment, a client's physical needs and budget constraints, as well as construction techniques, branding, marketing, and post-occupancy issues. We use evolving computer-aided design technologies not only to produce innovative architectural forms but to streamline the design and construction process and create new efficiencies and cost-savings. Great architecture demands that design, finance, and technology work together - we're combining these forces in innovative ways to create a new model for the profession. Seventeen years ago we set out to prove that intelligent, exciting, evocative architecture can be made in the real world, with real world constraints. We believe our work presents a convincing argument that we were right (SHoP Architects, 2014).

A major component to their continued success is that they are a diversified team with a unified vision. Along with their supporting team of 160 employees, they have a strong track record of highly successful projects, including Barklays Center, Mulberry House, and Porter House Condos among others; and recently topped the list compiled by Fast Company being named the #1 most innovative company in architecture for 2014.

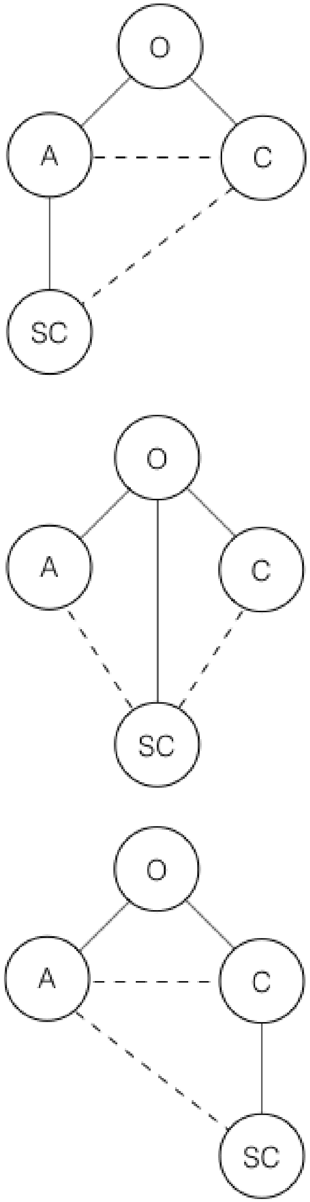

Figure 23 Organizational Variation

Catalysts for Collaboration

The swift rise from boutique firm to winning increasingly large commissions was not accomplished in isolation, but through a dedication to collaborative relationships throughout the industry and by leveraging appropriate technology to solve the problem at hand. In some cases, SHoP has also acted in the capacity of codeveloper, accepting additional risk but also enabling greater opportunity to affect change and alter the traditional process. SHoP principal Jonathan Mallie addresses the fact that on any given project, sometimes five, and sometimes hundreds of companies are needing to work together for better or worse; and effective collaboration is key. SHoP's diversified approach, branching out to better understand not only the Architecture, but also the Engineering, Construction and Development aspects of the industry, has better equipped them to implement the most effective strategies. Maintaining a broadened view, one phase of the process cannot be isolated from the others yet to come. How you make should inform how you design.

Project delivery is a key consideration to achieving integrated and performative architecture. There may never be a one-size-fits-all solution. Each project is unique and requires unique consideration.

Even so, the existence of contractual relationships does not inherently mean that the flow of information must be limited. The technological means by which tasks can be optimized and team members apprised of new project developments in easily comprehensible terms currently exist. As an example, the complex logistics involved in the design, manufacture and installation of nearly 12,000 unique and individual panels wrapping the Barclays Center was distilled down to be a manageable undertaking through a combination of various software platforms, allowing the process to be monitored and easily represented with a custom iPhone application. The organic form was designed and rationalized in Rhino, the supporting structure and panels modeled in Catia, and the resulting panels digitally unfolded and nested for manufacturing with Grasshopper. The curtain-wall fabricator in-turn hired SHoP to detail the panels in BIM. As a result, shop drawings were eliminated and the digital model output was used to directly control the CNC cutting and bending equipment. The precise nesting allowed the manufacturer to reduce the width of stock steel by slightly less than an inch, resulting in a six figure savings to the project overall. The panels were all pre-weathered in the factory prior to installation, requiring a series of 1,000 cycles each. The individually numbered panels were scanned by barcode and tracked

Figure 24 Barclays Center_Facade Panels

by simple color coding representation using the custom developed iPhone application. The daunting design was able to be realized economically and efficiently by using the application of appropriate technologies. Mallie states, “On Barclays, we learned that size doesn’t matter… What counts is sticking to one’s principles, digital process control and collaboration” (Post, 2013). With the contract structure aside, SHoP Architects, SHoP Construction, the curtain-wall fabricator, the general contractor and many others worked in an openly collaborative way, all contributing to the combined success of the project.

3DEXPERIENCE Platform

Further expanding their exploration in collaborative design, SHoP was selected to participate with Dassault Systèmes in testing their new 3DEXPERIENCE software platform. A leading force in technical business software solutions, Dassault describes the comprehensive nature of their product suites as follows:

> It provides software solutions for every organization in your company – from marketing to sales to engineering – that help you, in your value creation process, to create differentiating consumer experiences. With a single, easy-to-use interface, it powers Industry Solution Experiences – based on 3D design, analysis,

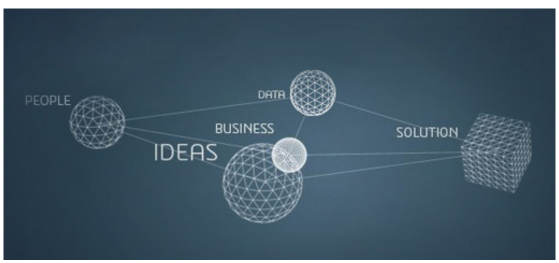

Figure 25 Connecting the Dots

> simulation, and intelligence software in a collaborative, interactive environment (Dassault Systèmes, 2014).

Various combinations of their product offerings comprise industry specific software solutions. For the AEC industry, Dassault currently provides two solution experiences: Lean Construction and Facade Design for Fabrication. Stemming from their sizable experience in the aerospace and automotive industries, where a high degree of control and coordination are paramount considerations, Dassault has worked to extend lessons learned and the benefits of industrialized processes to the AEC industry. Key components of the strategy include, BIM, feedback processes, and social network environments that foster a more holistic approach to design and construction. The Lean Construction 3DEXPERIENCE "provides a collaboration based project backbone that will enable centralized project and data management, construction simulation for better planning and execution, and the right information to be available to the right people at the right time" (Dassault Systèmes, 2014). What makes this cloud-based approach unique, and highly beneficial to the fragmented AEC industry, is the focus on centralized management for all aspects of the job, allowing a sense of tight team integration without the need to be in the same location or organizational structure. The aspect of integration over a distance

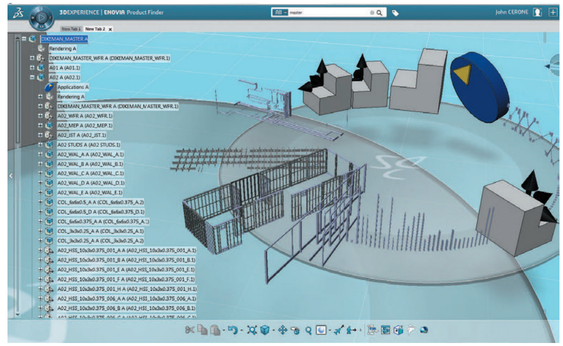

Figure 26 3DEXPERIENCE Project Navigation

Figure 27 3DEXPERIENCE Coordination

begins to align with Tombesi's description of "The Project-Firm" as referenced earlier in the literature review section of this document.

Figure 28 87 Dikeman_Exterior Rendering

87 Dikeman

Client	RH Associates LLC
Completed	Under Construction
Location	Brooklyn, New York (Red Hook Neighborhood)
Project Type	Modular, Multi-Family Residential
Architect	SHoP Architects, Christopher Lee
Design/Builder	SCIFAB (SHoP Construction + Island Exterior Fabricators)
Structural Engineer	AVRO Consult Engineering
MEP/FP	Engineering Solutions
Geotech Engineer	GZA
Civil Engineer	DS Engineering Services
Area	3,020 sq ft (280 sq m)
Program	<u>Unit 1 (Lower)</u> <u>Unit 2 (Upper)</u> 1 Bedroom 3 Bedrooms 1 Bathroom 2.5 Bathrooms

As a response to the recent devastation of the area affected by Hurricane Sandy in October of 2012, SHoP was asked to quickly design and fabricate a modular, 2-unit residence as a prototype housing solution. The program

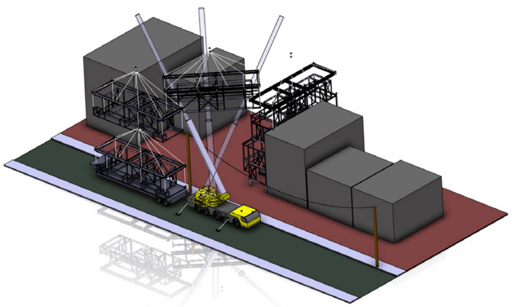

Figure 30 87 Dikeman_Exterior Rendering

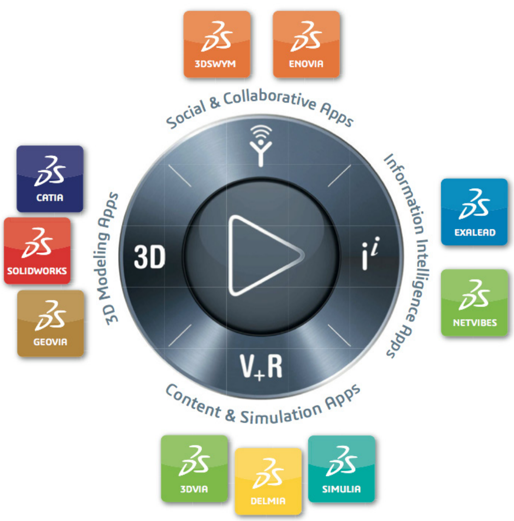

Figure 29 IFWE Compass

consists of a larger unit occupying the upper 3 floors with a smaller unit on the lower floor, each with private entrances. Modular construction allows the majority of the work to be done in a factory, reducing on-site assembly time to just 48 hours. The structure rests on a series of concrete micro-piles, raising the entire living area and building systems, reducing risk of future damage from flooding. SHoP saw the project as a challenge to propose an innovative solution as well as an opportunity to newly implement the cloud-based collaborative design and fabrication process of Dassault's 3DEXPERIENCE platform.

Integrated Design

The nature of the project required the close coordination of multiple parties in order to produce a high quality product in a short time frame while maintaining the budget. The team was able to dramatically reduce the time frame for design, engineering, fabrication and assembly of a high-quality residence. The cloud-based collaboration reduced the need for much of the back-and-forth typically required for clarification and documentation. Jonathan Mallie explains,

> …on the 3DEXPERIENCE platform, the modeling is on the Cloud and available to the factory floor immediately. The benefit of cloud-

> based collaboration is speed and efficiency. You're increasing productivity. You're getting to the end of the project quicker (Mallie, 2014).

Collaboration is built into the system to such a degree that it is nearly indistinguishable from the software itself. The hub of the working environment is the IFWE Compass (see figure), providing instant access to collaborative information sharing, analytic capabilities, simulation, and 3D modeling for all the members of the team. SHoP was selected to participate in the 3DEXPERIENCE "Lighthouse Program" to test the viability of the new interface and workflow capabilities of the platform prior to its official roll-out to all other customers in February of 2014.

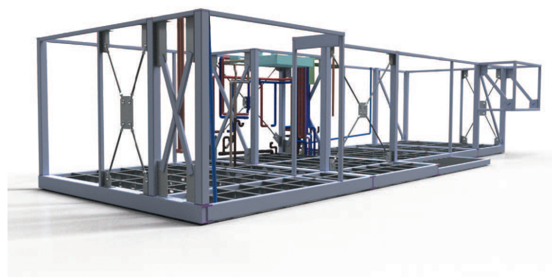

Figure 32 87 Dikeman_Module Structure

In the case of 87 Dikeman, the fast-paced schedule demanded instant access to the most up-to-date revisions from other team members and consultants. The design team was better able to understand the manufacturing constraints and logistics involved with the process of building the modules inside the factory. Images of the factory interior were able to be digitally mapped to the otherwise abstract 3D modeling environment, giving a sense of scale, coordination issues and space limitations. The design intent and assembly visualization were able to be readily communicated to the workers on the

Figure 31 87 DIkeman_Assembly Visualization


Figure 35   87 Dikeman_Module Joint Condition

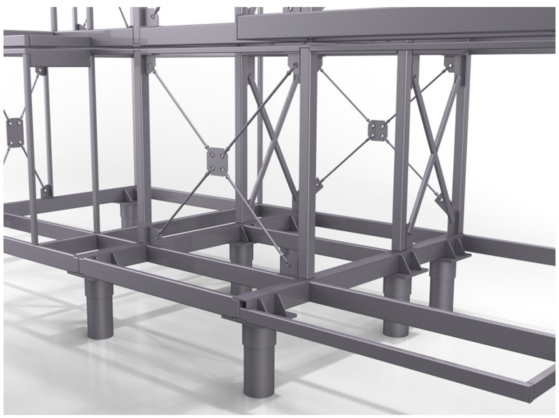
Figure 34   87 Dikeman_Raised Pile Foundation

shop floor without the time consuming process of producing shop drawings, assembly details and renderings. The same 3D model was used as the single version of truth for all involved. Having developed a system of prototypical details and connections, the pace of development was very rapid. Within just 1 week the structural system was fully designed, allowing an early extraction of quantities that fed into a the mill order and financial cost model. All the team members were able to access all of the related information through a singular streamlined interface. Set up along the lines of a social network, the project team could easily share thoughts, ask questions and view the work of others. In this collaborative framework, designers, engineers, fabricators and suppliers could all contribute meaningfully and efficiently to the final outcome beginning from the very early stages of the process.

Reflecting on the process, Mallie envisions only iPads and digital screens on the shop floor, totally eliminating conventional shop drawings; and a digital submission of the 3D model to the building department for review and approval. However, as things currently stand, building department regulations and a limited user-base necessitate the continued use of physical drawings.

Integrated Systems / Modular Construction

The completed building would require the manufacture of 4 highly coordinated modules, all prefabricated at a factory in Long Island, New York. In order to minimize on-site work and assembly, the team modeled practically everything as it would be placed when installed. The typical practices of abstract representation was replaced with accurate placement of 3-dimensional electrical plates, floor framing, plumbing and HVAC equipment, for example. All of the coordination issues were worked through on-screen instead of in the field. The process was seemingly natural due to the virtual reality representation available when discussing with others.

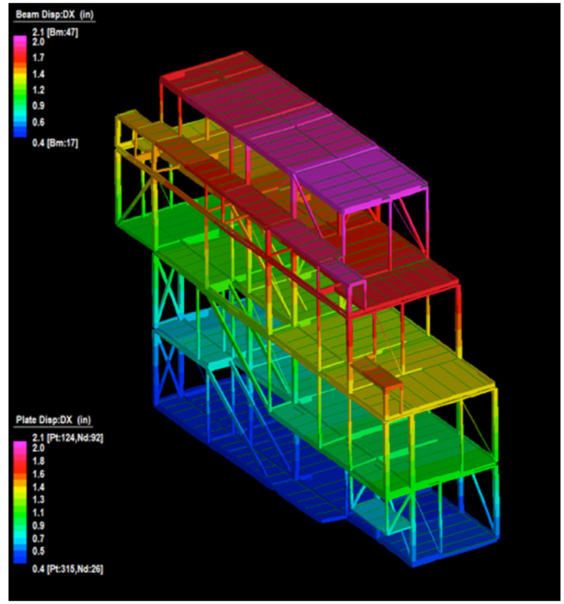

Figure 36 87 Dikeman_Structural Analysis

The highly collaborative workflow facilitated a highly integrated design, with an efficient structural system, compact and sustainable building systems, as well as greater precision and streamlined assembly. All parties were able to contribute their own particular specialized knowledge in a way that was most beneficial for the success of the project. Although working from various locations throughout the region, the team benefitted from a free flow of information, readily accessible via a consistent user interface distributed through the cloud. The complex IT infrastructure that would typically be needed to implement such coordinated efforts was nowhere to be seen.

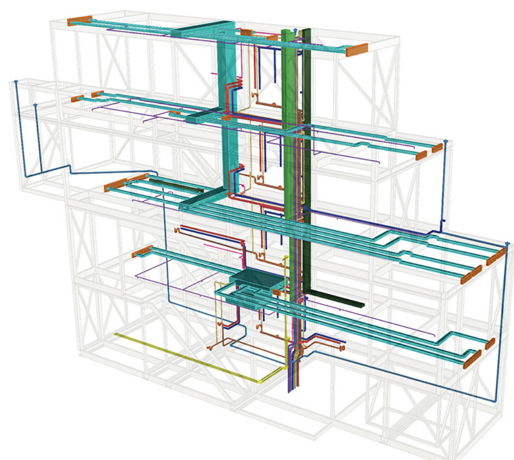

Figure 37 87 Dikeman_Systems Coordination

Team efforts were able to be focused on the challenges of the project more so than the intricacies administration. Sidestepping conventional practice, SHoP and the 3DEXPERIENCE offer a glimpse into a more integrated and barrier-free future for the AEC industry.

Lean Construction Parallels

Both cases illustrated herein exhibit strategies intended to make the process of design and construction more manageable while also increasing in quality. Such strategies are akin to the fundamentals of Lean Construction.

In the case of Facit Homes, the similarities of the driving principles behind the D-Process and those of Lean Construction are strikingly many. The D-Process used by Facit is likewise directed towards achieving operational stabilization. Controlling the variability by acting as the designer, fabricator and construction manager, a more seamless transition can occur from one stage to the next. Reducing the number of steps required to go from digital model to built reality, utilizing digital production processes, performing the production on-site, and exercising complete process oversight all contribute to a dramatic decrease in variability. Waste and Overburden are addressed simultaneously by practicing just-in-time delivery and production. Following the tenets of Just-in-Time (JIT) manufacturing and delivery, the precision cut panels that form the cassettes are produced on an as-needed basis, creating a "pull" system of production. Reducing the need to stock inventory on-site or to provide overly conservative contingencies, the pull system mitigates the need for additional on-site lay down space and unnecessary worker effort, expenditure, transportation and rework. If the schedule of construction is ahead or behind what was originally planned, the production rate can easily adjust to accommodate the changes in pace. When combined, the factors that constitute the D-Process allow for robust operational stabilization of a small team with low overhead and high output.

In the case of SHoP, the priority on supply chain management and multiparty integration is clearly evident. Much in the same way as one would develop a relationship with a preferred supplier, SHoP goes the extra mile to establish expectations and ensure a smooth transfer of information and work product. In regards to the fabricators, SHoP went one step further and created an integrated supplier by forming a project-specific entity, SCIFAB (**S**HoP

Construction + **I**sland Exterior **Fab**ricators). In this symbiotic relationship, each party is incentivized to provide the best service possible and anticipate each others' needs. The 3DEXPERIENCE platform allowed SHoP to more fully account for the fabrication constraints of the warehouse. Island Exterior Fabricators was able to provide immediate feedback on design considerations and make modifications as necessary, in turn becoming immediately available for the design team to continue developing other aspects of the project. By so doing, the team undoubtedly avoided costly and time consuming re-work involved in modifying the design to accommodate revisions. Working in a consistent software environment reduced the variability of deliverables, simplifying the exchange of information. The efficiency of workflow between the two entities reduced overburden in the relationship, leading to a reduction in wasted time, effort and expense. All factors considered, an operationally stabilized relationship is the intent and purpose of the Lean Construction methodology.

Collaborative Considerations

Examined individually, each case study presented here is highly fascinating and encompasses a multitude of noteworthy innovations and processes. Facit Homes and SHoP, employing the opposing organizational strategies of consolidation and diversification respectively, could not be more different from one another. Although when seen together, the two cases present commonalities and similarities at a fundamental level. They both rely heavily on the ability to leverage the specialized knowledge and skills of individual team members and collaborators.

At Facit Homes, the team has been selectively assembled over time, each member bringing something unique to the group. The company profile highlights each individual for who they are: their personalities, specialties and interests. Each contributes in a particular capacity, suited to their strengths. Architectural design, job-site management, digital production, process design and technology, fabrication and interiors, communication and business development are distinct areas of expertise in which one or more individuals meaningfully contribute. Success of each project, and of the company as a whole, relies on the interdependent nature of the team. Irrespective of what software is used or how the fabrication instructions are passed to the CNC router, one key to Facit's success lies not in technology but in the human realm. For Facit, the tightly knit team and their way of working together is at the heart of what they call the D-Process. The evidence illustrated in the case of Facit Homes is in support of hypothesis “b” in that as an integrated firm, an emphasis is placed on the relationships developed. This is reinforced by the following words of Bruce Bell,

> More time was spent developing the company structure and workflow to successfully deliver projects than on the basic technology. Facit’s projects show how BIM and digital tools can be applied to meet challenging environmental targets with high-quality, bespoke homes. But perhaps the most exciting aspect is the new business model and new way of working that the technology is starting to define (Bell, 2013).

In this context, the technology is an enabler, but not the primary consideration. High priority is placed on the company structure and way of working within an integrated firm organization.

SHoP Architect and SHoP Construction have a slightly different set of considerations. As a company with an international reputation and the opportunity to work on a wide array of project scales and project types, SHoP must be able to assimilate other organizations and form collaborative relationships on a regular basis in accordance with project needs and requirements. In order to ensure consistently high levels of quality in terms of design and execution, SHoP must ensure that they are getting the most out of those that they work with and that they themselves are able to contribute effectively. Establishing trusted partnerships and relationships with specialty contractors and consultants goes a long way to encourage empowerment, recognizing their talents and demonstrating consistent and quality follow-through. The technological implementation of the 3DEXPERIENCE platform was beneficial not only in the production of work, but more importantly in the way it allowed the entire team to freely communicate, thereby minimizing the barrier of physical separation and organizational structure. The case of SHoP construction is in support of hypothesis “a” focusing on the pragmatic workings of project management and technological coordination to accomplish precision and complexity within the constraints of schedule and budget. In a similar fashion, the following statement reinforce their commitments,

> We use evolving computer-aided design technologies not only to produce innovative architectural forms but to streamline the design and construction process and create new efficiencies and cost-savings. (SHoP Architects, 2014)

> …on the 3DEXPERIENCE platform, the modeling is on the Cloud and available to the factory floor immediately. The benefit of cloud-based collaboration is speed and efficiency. You’re increasing productivity. You’re getting to the end of the project quicker (Mallie, 2014).

Referring back to topic of integrated thinking, the essence is to approach a problem from a multitude of angles simultaneously. This multi-pronged approach is facilitated by the federated structure utilized by SHoP and their collaborative partners, but also by the integrated model of Facit Homes. The difference being mainly based on organizational structure.

5

PIECC CRITERIA ANALYSIS

In order to better understand the dynamics of team member contribution throughout the design and construction process, further investigation at the operational level reveals that a successful project is the result of more than the application of advanced technologies. The human element is a primary contributing factor to effective collaboration, project management and integrated team success. Any team relies on the contributions of its members, both individually and collectively. Typically, one member of the team stands out as the leader, helping to coordinate the collective efforts, in search of a predefined goal or objective. In terms of the PIECC framework, this individual would be termed the collaboration champion, also the being most important consideration for effective collaboration. The full list of considerations is illustrated for reference (see figure 38 and Appendix A).

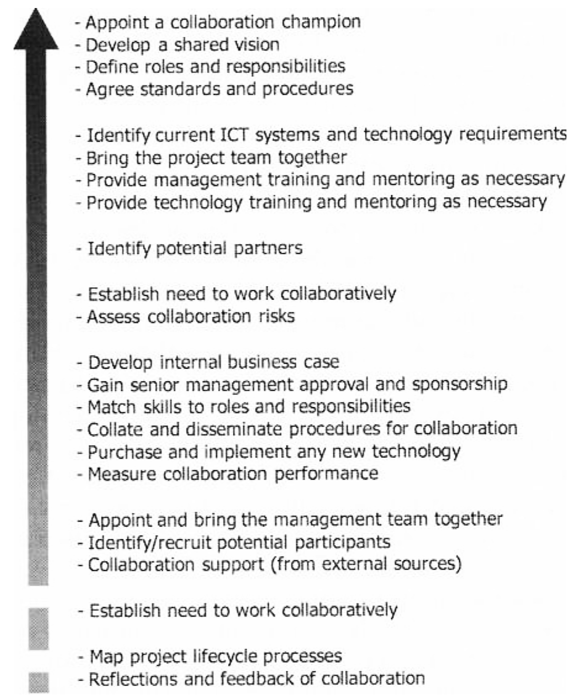

Figure 38 Order of importance of PIECC processes

Limitations

Both cases presented surely incorporate many of the PIECC processes, although not directly specified as such in the research. Therefore, a more subjective and abstract analysis is intended to address the respective over-arching approaches of SHoP Architects with VDC/BIM in the Cloud (VDC-C) and Facit Homes with Integrated Firm Organization (IFO). The data used in the analysis is subjective and solely a personal opinion based on the case study descriptions and literature review. The opportunity exits to further test the proposed hypotheses by collecting the views and opinions from individuals directly participatory in either VDC-C or IFO via the distribution of a similarly structured survey and analyzing the resulting data.

Analysis Structure

Comparing the approaches to the results of the PIECC framework referenced in the literature review, a weighted evaluation is presented. The evaluation criteria follow the structure of the workshop results and their corresponding rank from 1-5, 1 being most important and 5 the least, across the three categories as listed below.

Project

1. Poor morale and motivation
2. Lack of focus
3. Too much waste
4. Barriers to creativity
5. Managing risk and trust

Business

1. Breakdown of relationships
2. Cost+time inefficiencies due to waste of effort / repetition
3. Loss of value / quality
4. Lack of ownership / poor morale / loss of engagement
5. Lack of knowledge sharing and innovation

Technology

1. Poor communication
2. Lack of collaborative contracts and cultures
3. Lack of standards
4. Working in 3D-nD

The criteria rank is used to calculate a weighted scale on which the approaches of VDC-C and IFO can be scored. The weighted percentages to be used for each rank are as follows:

Rank #1 = 33%
Rank #2 = 27%
Rank #3 = 20%
Rank #4 = 13%
Rank #5 = 7%
Total 100%

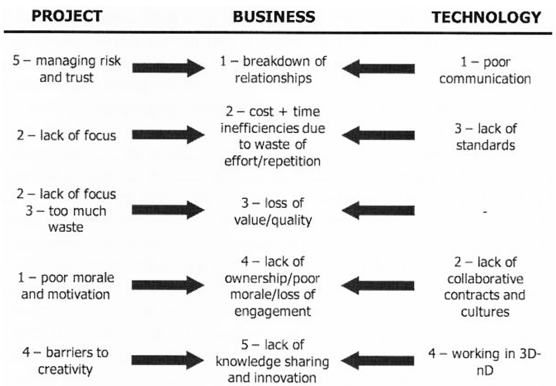

Figure 39 PIECC Workshop Task 1 Results Summary

The original results from the PIECC workshop went on to also indicate how the criteria might indirectly contribute to or influence those in other categories, represented by the arrows in figure 39. For the purposes of this analysis, the cross-contribution effects are not taken into consideration. Each category is evaluated independently and then combined to give an overall score. Each approach, VDC-C and IFO, is to be scored on a 4 point Likert type scale to gauge how well each addresses the various criteria where: 0=Not at all, 1=Minimally, 2=Average, 3=Strongly. The resulting scores are then totalled separately as weighted and un-weighted values.

Scorecard & Evaluation

As described above, subjective scores were generated for each of the two approaches and tabulated for analysis (see Appendix B). The results of the analysis are represented graphically (see figures 40 and 41) offering a distilled view of the comparison. The base scores and weighted scores for each of the 14 evaluation criteria were calculated in relation to both IFO and VDC-C and then averaged accordingly, resulting in 76 interdependent values on which to base the comparison. The totals for each category are summarized by the vertical bar graphs, also providing an overall average value that takes into account the results of all individual criteria as a whole.

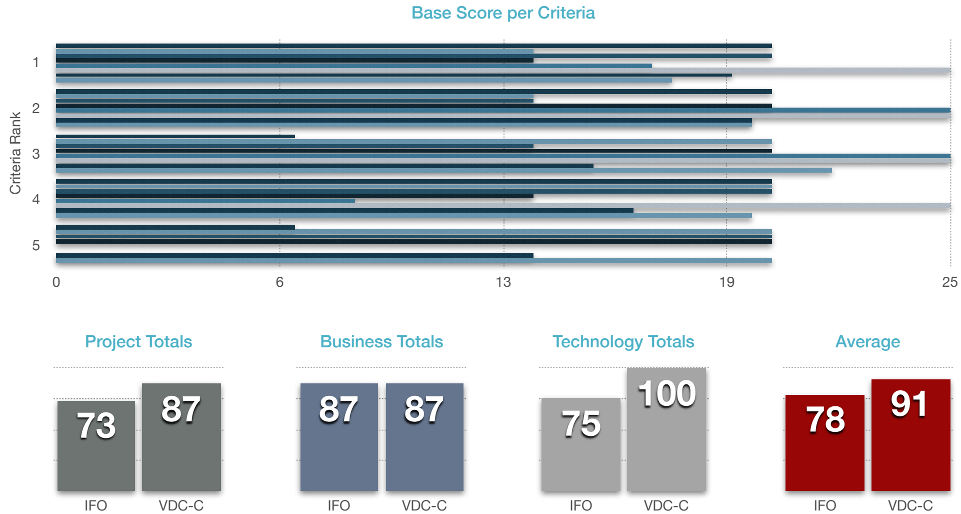

Figure 40 PIECC Base Score Summary

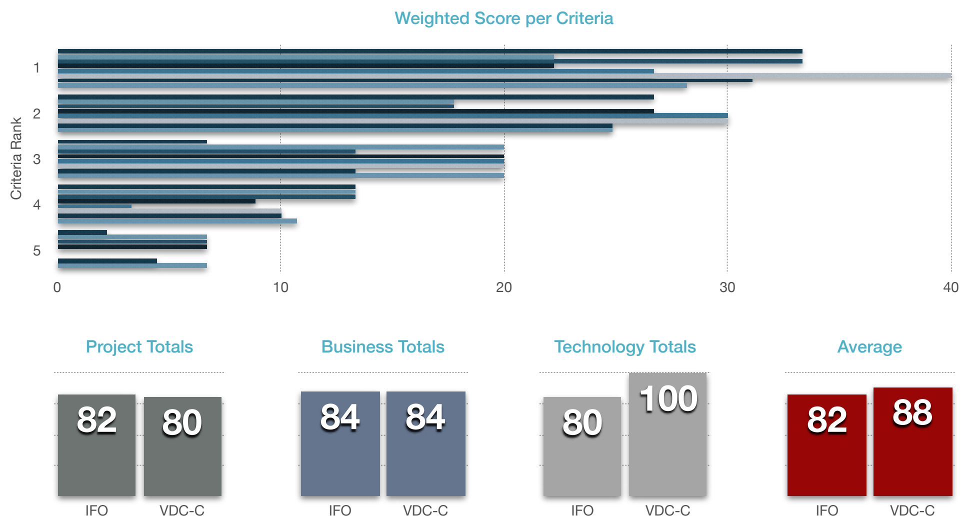

Figure 41 PIECC Weighted Score Summary

Base Scores

Interpreting the results of the base scores alone indicates a clear advantage for VDC-C in all areas except business, in which there was no variation between the two approaches. In terms of the project management category, there were two criteria dealing with IFO that scored very low (1 out of 3), those being “#3 Too much waste” and “#5 Management of risk and trust.” Reasons for the lower scores come down to the fact that an IFO does not automatically imply efficient operations. Waste is not one of the primary reasons behind forming and integrated firm. Typically it has more to do with expanding the capabilities and expertise offered in-house. Furthermore, operating as one entity also assumes additional risk should something go wrong. Relating to the category of Technology, IFO also scored low (1 out of 3) on criteria “#4 - Working in 3D-nD.” Although it is not ruled out of consideration for an IFO, it is not fundamental to its implementation, as is the case in VDC-C.

Weighted Scores

When examining the weighted scores, things become surprisingly balanced in both the categories of Project Management and Business. The relatively little importance placed on the low-scoring IFO criteria in conjunction with high marks received in those that are top ranked balance out with some of the more average scores attributed to VDC-C. Where VDC-C pulls away is in terms of Technology, as one would expect. Although only based on 4 criteria instead of 5 as with the other categories, technology is clearly the medium through which VDC-C operates. Where the differences occur are with technological communication of information and working in 3D-nD. Existing as a single platform, the barriers to information transfer and interoperability are essentially eliminated, also taking the top spot in terms of rank. However, this requires all involved to operate within its limitations, which may vary based on scope and discipline. The advanced coordination achieved through virtual design and construction, schedule simulations and model-based cost estimating are becoming increasingly useful, but also rank lowest in order of importance in the PIECC.

Overview

The general results of the analysis support hypothesis “a” in that VDC-C excels in terms of technology and project management, although with one exception. The base totals show a clear distinction in favor of VDC-C. However, the weighted totals for project management are much closer, giving a slight edge to IFO. This result is surprising given the prevalence of electronic communication already in use as a primary method. One would expect to see the more technologically based approach of VDC-C to excel here also, as it emphasizes a social component intended to lessen the impact of common barriers among separate teams.

Further information would be required to accurately address hypothesis “b” related to Business and IFO excelling at interpersonal relationships, morale and value. The dead-even tie between the two approaches when weighted or not may be due to a limitation of the data and/or method of analysis.

Opportunities for Further Study

The exercise illustrated herein was revealing in terms of the multitude of criteria affecting collaborative working in construction. The study definitely has room to expand in gathering data from a larger sampling of participants. Furthermore, the rather limited scoring scale from 0-4 proves difficult to ascertain any nuances in the results. A more broad scale from 1-10, for example, would allow for more accuracy in the resulting findings.

6

ASSESSMENT & CONCLUSION

Applying the findings from the analysis of the PIECC workshop in the context of the case study projects from Facit and SHoP, helps illustrate the research question in relatable terms. Is BIM/VDC in the Cloud a viable substitute to integrated firm organization in regards to effective collaboration and design for fabrication? That is yet to be definitively answered. Each strategy has strengths and weaknesses. The qualitative investigation herein seemingly leans in both directions. The case studies support both the hypotheses presented, while the PIECC analysis matches the approaches fairly evenly, with only a slight edge in favor of VDC/BIM in the Cloud based on its technology centric underpinnings.

BIM/VDC in the Cloud has great potential in terms of a technology and facilitating project management, but it is not the only cornerstone required for success. Integrated Firm Organization directly addresses the most important factors identified as morale, relationships and communication. Surely there is a place for both to coexist in the industry. In fact, I would venture to say that there needs to be both.

Concluding Thoughts

The initial direction of the research contained herein focused on the innovative technologies enabling greater efficiencies in the tectonics of construction and simplified collaboration. Further investigation revealed that to be only part of the Equation. Additional important and influential considerations based in humanistic relationships are vital to a projects success as much or more so than the technological methods. Innovation and technical advances are the results of effective collaboration with many talented individuals and organizations. Integrated thinking in design and construction must begin not at the building systems level, but at the team member level.

The examples and findings in this document are in no way a comprehensive representation. Many firms and industry professionals are beginning to rethink how things should be done. I'm certain that we have only seen the beginning of a fundamental change in the AEC industry; one that embraces alternative solutions and methods of practice.

Just as all projects are not the same, neither are all clients and colleagues. Some people thrive in the digital realm, something that is becoming increasingly prevalent in all aspects of design and construction. However, it will never fully substitute the human connection so vital to why we do what we do. As stated earlier, a shared vision as an industry is to create wonderful and inspiring places for ***people*** to be. The emphasis on that notion should proliferate through all our interactions so as not to lose sight of it.

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Appendix A

PIECC Framework

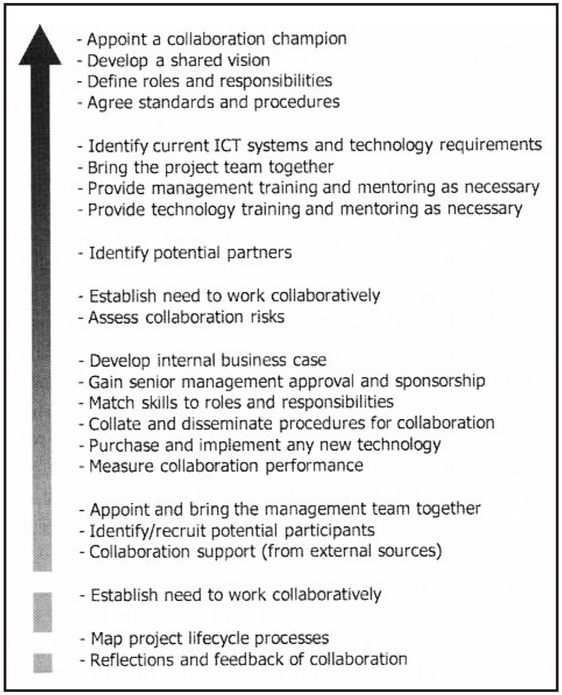

Figure 42 Order of importance of PIECC processes

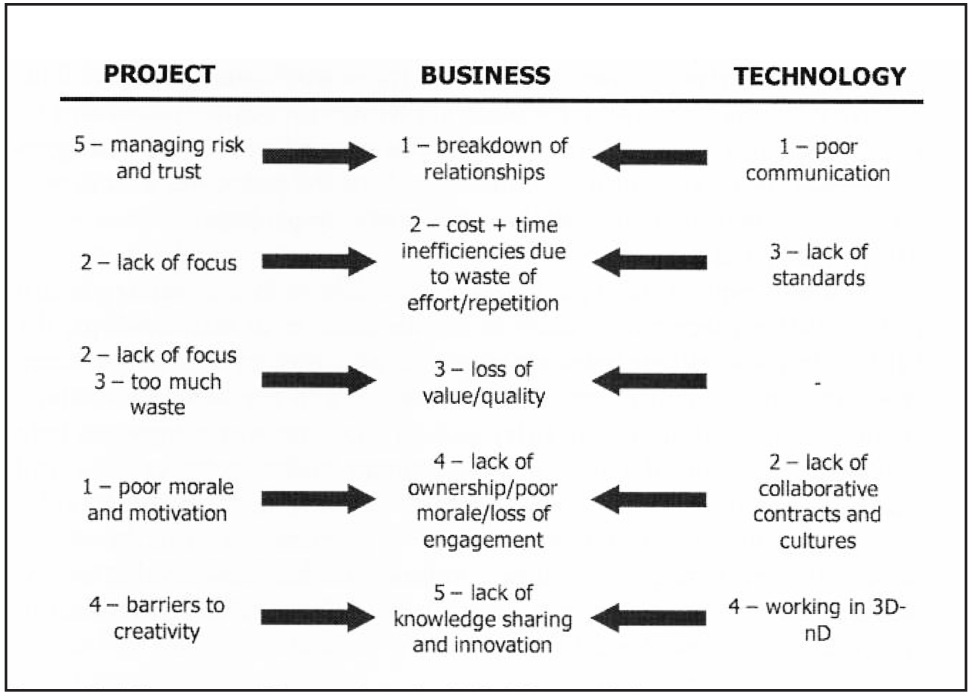

Figure 43 PIECC Workshop Task 1 Results Summary

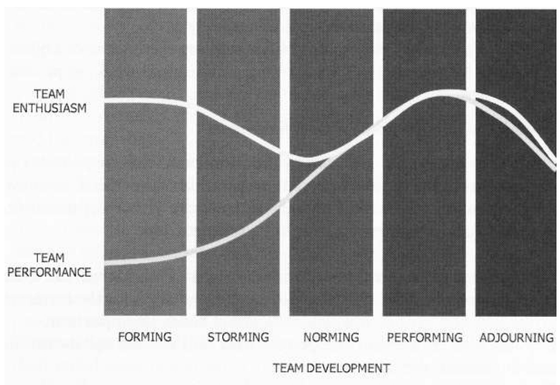

Figure 44 Tuckman's model_without PIECC

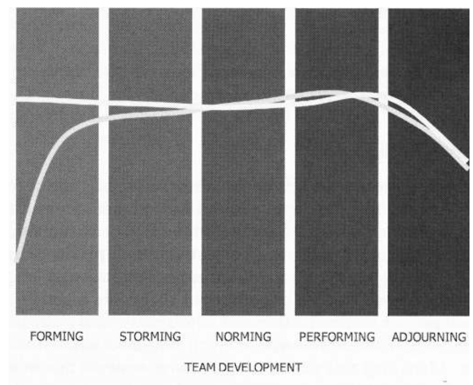

Figure 45 Tuckman's model_with PIECC

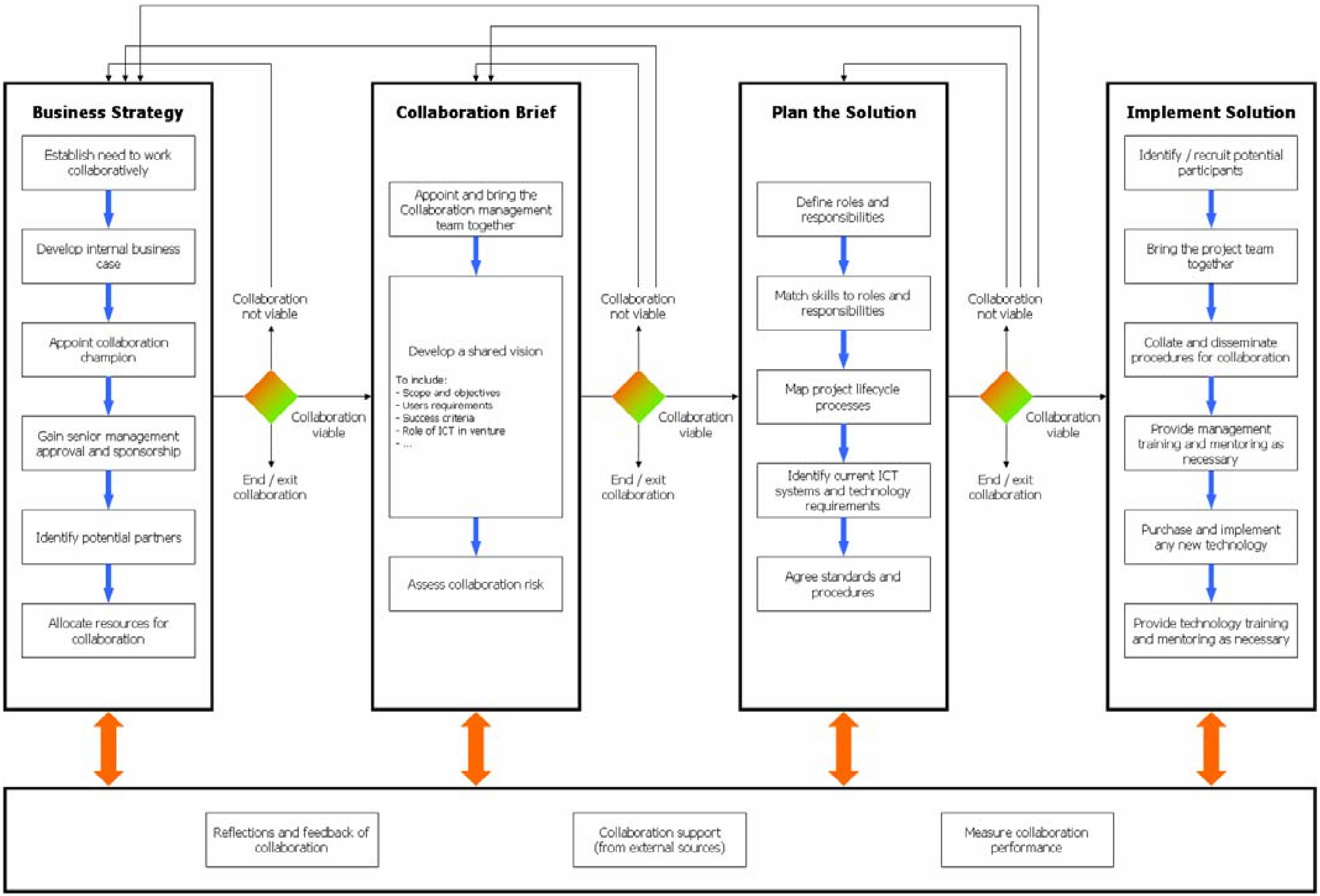

Figure 46 Final PIECC Decision-Making Framework

Appendix B

Data Analysis:

Integrated Firm Organization Vs . BIM/VDC in the Cloud

Adapted from the PIECC Workshop Findings

PROJECT

RANK	BASE WEIGHT	RANK WEIGHT	IFO VALUE	VDC-C VALUE	IFO BASE	VDC-C BASE	IFO WEIGHTED	VDC-C WEIGHTED
1	20%	33%	**3**	**2**	20	13	33	22
2	20%	27%	**3**	**2**	20	13	27	18
3	20%	20%	**1**	**3**	7	20	7	20
4	20%	13%	**3**	**3**	20	20	13	13
5	20%	7%	**1**	**3**	7	20	2	7
TOTAL					**73**	**87**	**82**	**80**

BUSINESS

RANK	BASE WEIGHT	RANK WEIGHT	IFO VALUE	VDC-C VALUE	IFO BASE	VDC-C BASE	IFO WEIGHTED	VDC-C WEIGHTED
1	20%	33%	**3**	**2**	20	13	33	22
2	20%	27%	**2**	**3**	13	20	18	27
3	20%	20%	**2**	**3**	13	20	13	20
4	20%	13%	**3**	**2**	20	13	13	9
5	20%	7%	**3**	**3**	20	20	7	7
					87	**87**	**84**	**84**

Project Criteria

1. Poor morale and motivation
2. Lack of focus
3. Too much waste
4. Barriers to creativity
5. Managing risk and trust

Business Criteria

1. Breakdown of relationships
2. Cost+time inefficiencies due to waste of effort / repetition
3. Loss of value / quality
4. Lack of ownership / poor morale / loss of engagement
5. Lack of knowledge sharing and innovation

TECHNOLOGY

RANK	BASE WEIGHT	RANK WEIGHT	IFO VALUE	VDC-C VALUE	IFO BASE	VDC-C BASE	IFO WEIGHTED	VDC-C WEIGHTED
1	25%	40%	**2**	**3**	17	25	27	40
2	25%	30%	**3**	**3**	25	25	30	30
3	25%	20%	**3**	**3**	25	25	20	20
4	25%	10%	**1**	**3**	8	25	3	10
					75	**100**	**80**	**100**

AVERAGES

IFO BASE AVG	VDC-C BASE AVG	IFO WEIGHTED AVG	VDC-C WEIGHTED AVG
19	17	31	28
19	19	25	25
15	22	13	20
16	19	10	11
13	20	4	7
78	**91**	**82**	**88**

Figure 47 PIECC Criteria Analysis Data

Technology Criteria

1. Poor communication
2. Lack of collaborative contracts and cultures
3. Lack of standards
4. Working in 3D-nD

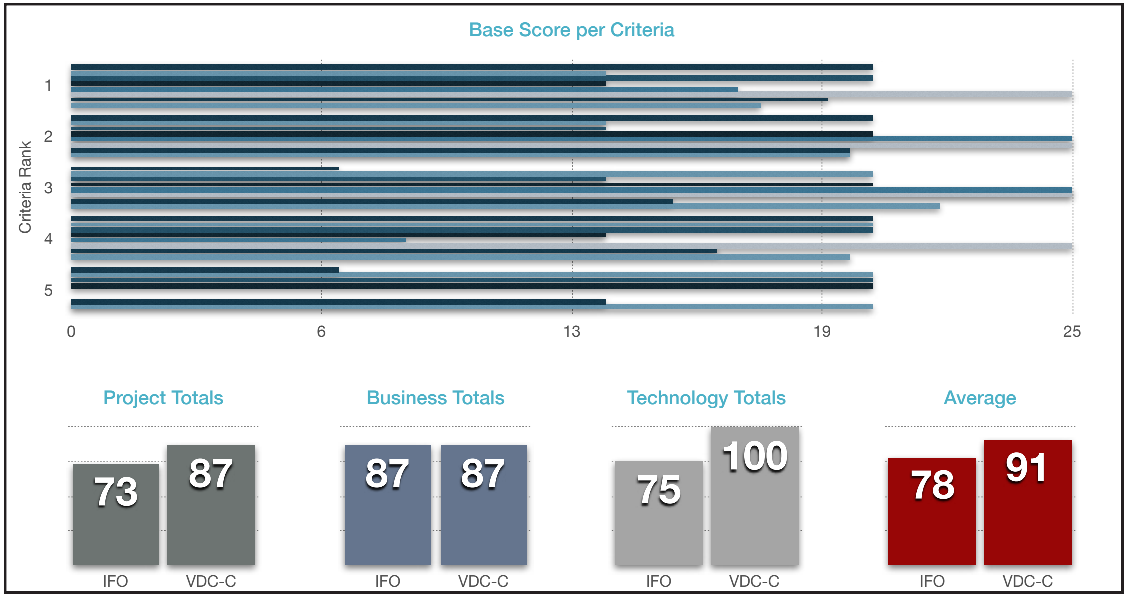

Figure 48 PIECC Base Score Summary

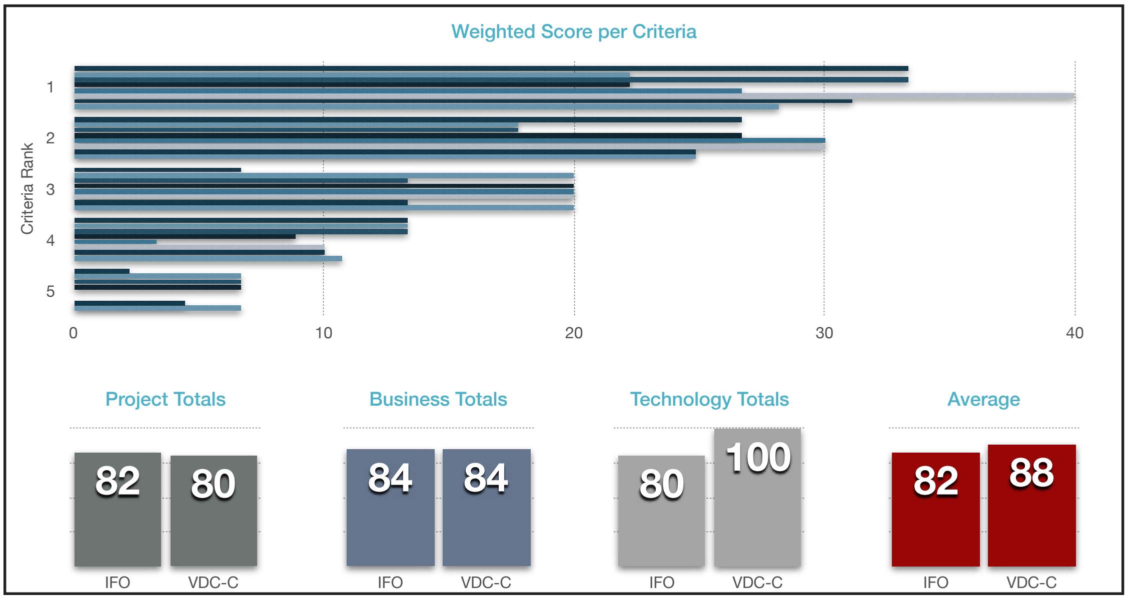

Figure 49 PIECC Weighted Score Summary