APPLICATION OF VDC IN LEED PROJECTS: FRAMEWORK AND IMPLEMENTATION STRATEGY

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ABSTRACT

Virtual Design and Construction (VDC) generates multifaceted benefits in the Architectural, Engineering and Construction (AEC) industry. Stakeholders can achieve optimal balance between building performance and costs with the use of integrated, multidisciplinary, virtual building models. The VDC models provide project teams with valid and reliable sources to achieve project goals in a heterogeneous industry environment. This paper investigates the application of VDC in complex and high performance building projects, such as LEED projects. As a new business paradigm, LEED has attracted substantial investment in the North American building market. Owners, architects, engineers, and contractors are all striving to embark on facilitating LEED certification but oftentimes, they find the process confusing and cumbersome. The contributing factors are various but the technological and financial challenges are obvious. Focusing on the technological side, the authors believe that implementing VDC could help achieve compliance with the LEED criteria, and contribute to leveraging LEED project delivery. The framework for such an application is proposed. Implementation strategies are delineated and recommendations are given to the AEC professionals to encourage adoption of VDC in future LEED projects.

Keywords: VDC, BIM, LEED, integration framework

1. INTRODUCTION

The popularity of LEED in the building market reflects sustainability as an important trend in the architecture, engineering and construction (AEC) industry. To address and mitigate the impacts of buildings on the natural environment, LEED establishes a holistic framework to guide and evaluate more environmentally friendly practice with emphasis on several critical areas, which are referred to as the LEED environmental categories.

By following the criteria of LEED , a project is expected to achieve superior quality to conventional buildings in both performance and economic terms from a life cycle point of view. Such benefits have been well investigated by Kats et al. (2003). Nevertheless, LEED certification has posed substantial challenges to project teams, among which the increased upfront costs and the complexity of technological requirements are the most restrictive. Industry research such as that done by Mathiessen and Morris (2004, 2007) have attempted to demonstrate that “LEED is not necessarily more expensive”. To justify investments in LEED, owners may also need empirical evidence that LEED is technologically feasible, meaning the project can earn adequate LEED points to achieve a certain level of certification. Under some circumstances, how to maximize the project’s LEED scoring potential is critical in the owner’s decision-making on pursuit of LEED especially when the project budget is no longer a problem.

In light of recent boom in Virtual Design and Construction (VDC) / Building Information Modeling (BIM) technology, this research looks at the possibility of utilizing this technology to leverage LEED projects. The characteristics of the LEED rating system are explained, contributing factors in achieving LEED points are identified. The roles of VDC/BIM technology in the LEED project delivery are investigated, focusing on how such technology could facilitate compliance with the credit requirements and further facilitate achieving the desired LEED points. The major deliverable of this research is a framework established to navigate the project teams through the integration of VDC/BIM technologies in LEED projects.

2. BACKGROUND

The design and construction of building systems are complex and dynamic, unique to specific building types, geographical locations, functions and aesthetic requirements. Design approaches and construction methods evolve as technology advances. A wide array of computer software is available to help practitioners design and analyze buildings. VDC/BIM tools represents a relatively new paradigm but the terminology of "BIM", (as identified by Jerry Laiserin in his foreword for Chuck Eastman's BIM Handbook), has been in circulation for at least fifteen years, i.e. since the mid 1990s (Eastman et al. 2008). While "VDC" was firstly introduced in 2001 by the Center of Integrated Facility Engineering (CIFE) at University of Stanford (Kunz and Fisher, 2007). Both terms have come to indicate the use of parametric CAD models for analysis of various design, and construction problems (Khanzode et al. 2008).

The literature of research on benefits of using 3D/4D tools in commercial construction is abundant. Koo and Fischer (2000) investigated the feasibility of 4D for commercial construction. Research efforts have also focused on use of 3D/4D for specific trades such as precast concrete (Eastman et al. 2002). Studies on application of VDC/BIM in green building and sustainable construction are also popular. Laine and Karola (2007) described a new concept and interoperable software environment for management of thermal performance during the whole building life cycle. Schlueter and Thesseling (2008) proposed a prototypical tool integrated into BIM software, enabling instantaneous energy and exergy calculations to optimize a building design. Häkkinen and Kiviniemi (2008) discussed the potentials and problems of integrating building life cycle information with BIM.

Implementing VDC/BIM in LEED projects is unique in that it requires application of 3D/4D tools with prescribed design and construction constraints in the sustainability arena. Krygiel and Nies (2008) indicated that BIM can aid in the following aspects of sustainable design:

- Building orientation (to select the best building orientation that results in minimum energy costs)
- Building massing (to analyze building form and optimize the building envelope)
- Daylighting analysis
- Water harvesting (to reduce water needs in a building)
- Energy modeling (to reduce energy needs and analyze renewable energy options such as solar energy)
- Sustainable materials (to reduce material needs and to use recycled materials)

These aspects are all captured in the LEED rating system, giving an opportunity for the project team to follow these guidelines in adopting pertinent VDC/BIM tools. According to Autodesk (2005), up to 20 points for LEED certification can be facilitated using BIM authoring and analyzing tools. Goldberg and Camlin (2009) briefly discussed popular BIM software for LEED and sustainable analysis. The next-step question, however, is "how to leverage LEED project delivery using VDC/BIM in an integrated and systematic manner". Biswas et al. (2008) outlined how a green building rating system such as LEED could be adopted into BIM to offer designers an environment with enhanced awareness of different sustainability factors. Barnes and Castro-Lacouture (2009) described a BIM-enabled integrated optimization tool catering to LEED decisions. This research intends to go further and propose a comprehensive integration framework for VDC/BIM technology and LEED project delivery.

3. METHODOLOGY

Integration of VDC/BIM technology with LEED project delivery is intuitive by nature. The answers to a pair of questions: 1) "What does LEED require?"; and 2) "What can VDC/BIM provide to help satisfy such requirements?" are fundamental to the framework development. Opinions of industrial professionals were garnered through a survey to help address these two questions. The second step is constructing the integration framework through mapping VDC/BIM functionalities to LEED constraints & requirements credit by credit, taking into account the unique feature of LEED project delivery. Popular VDC/BIM tools such as Autodesk Revit are reviewed to create the inventory of functionalities. LEED for New Construction 2009 is selected as the researched rating system, its credits are analyzed and interpreted into project specifications. The last step is to verify this framework with generic examples. Figure 1 illustrates the logic flow of this research.

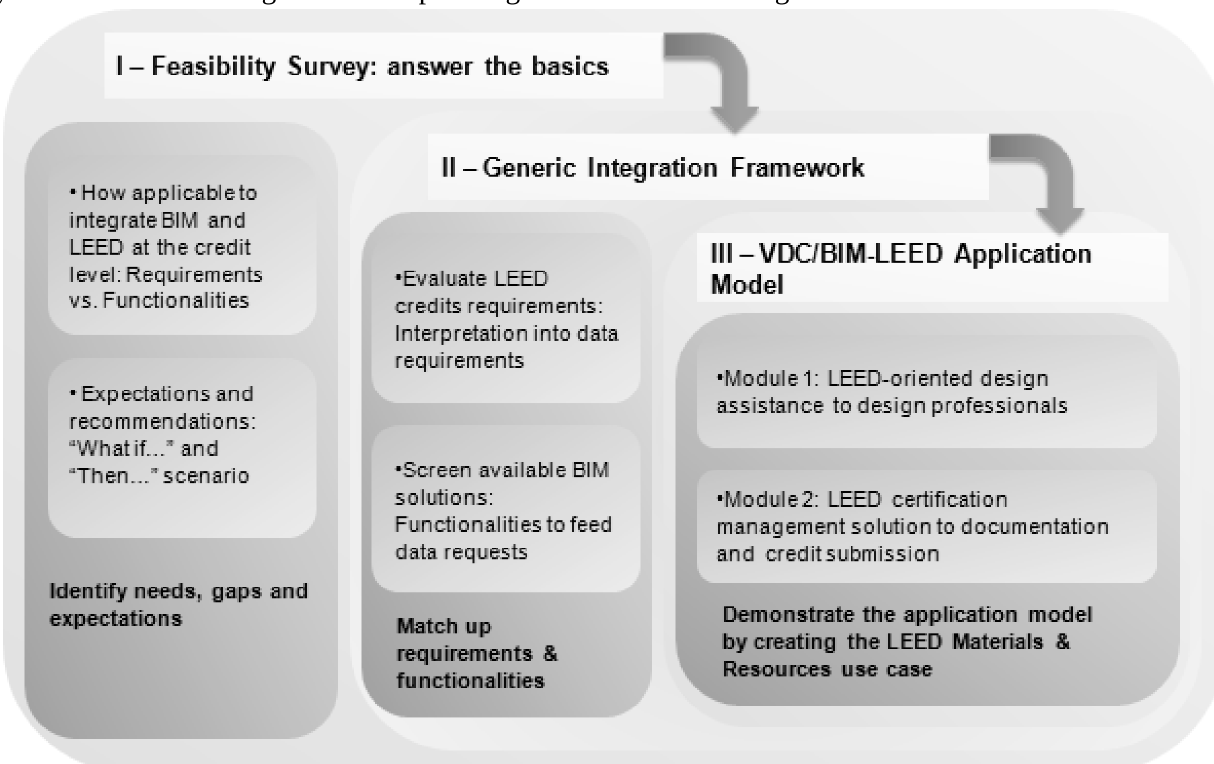

Figure 1: VDC/BIM and LEED integration workflow

4. RESULTS

4.1 Feasibility Survey

The purpose of this survey is simply to determine whether it is worthwhile to even look at the integration of VDC/BIM with LEED projects. The survey was deployed using the Zoomerang online survey tool (http://www.zoomerang.com). It was active from June 30th, 2009 to August 1st, 2009 posted at LinkedIn (http://www.linkedin.com, a business-oriented social networking website) to professional groups including BIM Architecture, BIM Expert, BIM and the AEC Profession, BuildingSMART, Club Revit, Collaborative BIM Advocates, Green Revit API, Group for Building Information Modeling and Revit Users. A total of 190 people accessed the survey, 64 finished it partially and 35 completed the questionnaire. The results of the survey were then imported into a statistical software package (SPSS 17) for analysis.

Two major issues were also explored in the survey, the benefits that VDC/BIM and LEED integration can bring and the degree of applicability of this integration at the LEED credit level. Table 1 and Table 2 summarize the responses to these issues respectively. The investigation of user perceptions of the status quo preliminarily benchmarked current BIM solutions and their applicability in LEED projects. In spite of the great potential of BIM, professionals were apprehensive about its value at the actual construction stage in the LEED project delivery. Quite a few desired functionalities to facilitate LEED certification such as GIS linkage and a more information-rich material library (building product model provided by manufacturers and material suppliers) are missing in current VDC/BIM software solutions.

Table 1: Perceived VDC/BIM and LEED integration benefits

Strongly Disagree 1	Disagree 2	Somewhat Disagree 3	Neutral 4	Somewhat Agree 5	Agree 6	Strongly Agree 7

Perception Statements	Mean Score
1.Current BIM can meet LEED requirements	3.53
2.Your company integrates BIM in LEED project	3.21
3.Current BIM is effective at the preconstruction stage	4.29
4.Current BIM is effective at the construction stage	3.88
5.Current BIM helps formulate LEED strategy	5.50
6.Current BIM facilitates generation & dissemination of design & contract documentation	5.71
7.Current BIM facilitates communication and information exchange project members	5.71
8.Current BIM facilitates generation and submission of submittals to LEED-Online	5.09
9.Current BIM helps reduce the upfront cost of pursuing LEED certification	4.82
10.Current BIM integration increases overall chances of achieving LEED certification	4.76

Table 2: Applicability of integration at LEED credit level

Not Applicable 0	Hardly Applicable 1	Somewhat Applicable 2	Moderately Applicable 3	Applicable 4	Highly Applicable 5

LEED-NC 2009 Categories	High Mean Score[a]	Low Mean Score[b]	Average Mean Score[c]
1.Sustainable Sites (SS)	3.34	1.94	2.68
2.Water Efficiency (WE)	2.78	2.44	2.6
3.Energy & Atmosphere (EA)	3.78	2.31	2.99
4.Materials & Resources (MR)	3.44	2.16	2.69
5.Indoor Environmental Quality (IEQ)	4.13	2.1	3.03
6.Innovation & Design (ID)	3.68	1.83	2.76
7.Regional Priority (RP)	2.32	2.32	2.32

Notes [a], [b] and [c]: Each LEED category has several LEED credits, and each credit has a mean score.

4.2 Integration Framework

The principle to integrate VDC/BIM and LEED certification is project delivery oriented. Project teams assume the following tasks in the course of attaining successful LEED certification:

1) LEED strategy: Project teams need to set up their goal about how many LEED points their project is targeted at and what level of LEED certification they are pursuing.
2) LEED credit interpretation: Team members assigned with specific LEED credits need to understand the requirements of the credits. Usually this means that they not only have to ensure the design or construction follows the guidelines spelled out in the LEED reference guide, but that also at the time when the LEED credit application is reviewed by USGBC, they can present relevant documentation to the review officials to demonstrate compliance with the requirements.

The role of VDC/BIM solutions resides mainly in facilitating the project team to accomplish these tasks. The requirements of LEED credits should be matched up with the functionalities of VDC/BIM tools. Therefore, 1) Interpreting the LEED requirements and 2) Screening the VDC/BIM functionalities become two major tasks in developing the integration framework.

4.2.1 Interpreting LEED Credits

Each LEED credit entails either a descriptive or quantitative specification, which could be perceived as a request for particular project information. For instance, MRp1- Storage and Collection of Recyclables requires: "Provide an easily-accessible dedicated area or areas for the collection and storage of materials for recycling for the entire building. Materials must include, at a minimum: paper, corrugated cardboard, glass, plastics and metals" (USGBC

2007). This is a typical descriptive request. The key words in this request include “easily-accessible”, “dedicated area”, “recycling”, “materials”, “paper”, “corrugated cardboard”, “glass”, “plastics” and “metals”. The descriptive request often involves only “text” type keywords. In contrast, MRc3 – Material Reuse requires: “Use salvaged, refurbished or reused materials, the sum of which constitutes at least 5% or 10%, based on cost, of the total value of materials on the project”(USGBC 2007). This is a typical quantitative request. The key words in this request include “salvaged”, “refurbished”, “reused”, “materials”, “5%”, “10%”, “cost”, and “total value”. The quantitative request should at least include one or more “numeric” type keywords. Considering the fact that project teams will not receive the corresponding points unless these requests are met, LEED credit requirements are also a type of design or construction constraints.

To demonstrate the compliance with the credits requirements, the project team needs to prepare substantial documentation and present to the Green Building Certification Institute (GBCI) officials for review to determine if the specific LEED point will be awarded to the project team. The official review of GBCI is mostly paperwork based, rarely are field inspections done. The quality of the documentation thus becomes critical to a successful LEED certification. This clarifies why LEED documentation and relevant submittals should be deemed as necessary constituents of the LEED requirements.

There are 5 major environmental categories: Sustainable Sites (SS), Water Efficiency (WE), Energy & Atmosphere (EA), Materials & Resources (MR) and Indoor Environmental Quality (IEQ) in the LEED-NC 2009 rating system, plus 2 supplemental categories: Innovation in Design (ID) and Regional Priority (RP). Each LEED category consists of several credits with a certain number of points assigned. Meanwhile, the rating system mandates compliance with one or more prerequisites without any point attainable except for ID and RP.

Due to the diversity of building types, geoclimatic factors and owner’s project requirements, the LEED rating system allows a certain level of flexibility to the project team by providing compliance options for some credits. The compliance options constitute the requirements for the credit, and enable the project team to satisfy the credit with multiple choices. Depending on the level of complexity, one option may be worth more points than others. So the project team has to decide what tradeoffs to make when pursuing certain LEED points, based on factors such as cost, availability of resources and technology readiness, to name a few. Tables 3-5 demonstrates the LEED credit interpretation process when dealing with the LEED “Prerequisites”; Table 4 deals with “Credits without Options”; and Table 5 deals with “Credits with Options.”

In these tables, keywords (or ‘constraints’) of credits requirements and documentation/submittal requirements are highlighted in italic fonts. By identifying such keywords, the project team can easily understand what efforts are expected in pursuing the particular LEED point. These tables can also act as extended LEED checklists once the project team is ready to apply for the pursued LEED credits.

4.2.2 Screening VDC/BIM Functionalities

The functional and performance capabilities of different VDC/BIM solutions (termed as *Functionality Inventory* in this research) are relative and contextual since there is no single platform that will be sufficient to accommodate all project types. There are two major types of VDC/BIM tools in the market, depending on the functionality and intended application environment. One is called an “authoring” tool and the other is called an “auditing/analysis” tool. VDC/BIM authoring tools are often large and robust applications mostly used by design firms to create and compile most of the information contained in a building information model. While the auditing/analysis tools are typically designed to specialize in particular areas, and used by either design firms or contractors to perform energy analysis, sustainable design analysis, code compliance, construction cost estimate, constructability analysis and construction sequencing (Smith and Tardif 2009).

In this research, Autodesk Revit and affiliated applications including Green Building Studio (GBS) and Ecotect, as well as other popular products such as GIS and Google Earth were reviewed. The functionality inventory of these products can be summarized as follows:

- Bidirectional Associativity: A change anywhere is a change everywhere. All model information is stored in a single, coordinated database. Revisions and alterations to information are automatically updated throughout the model;

Table 3: Prerequisite interpretation report of SSp1

Item	Description
LEED Category	SSp1: Construction activity pollution prevention
Credit Requirements Key Words	*2003 EPA construction general permit, local standards, National Pollutant Discharge Elimination System (NPDES) program*
Request Type	Descriptive
Proposed Data Type	Yes or No; Text
Submittal Requirements	*Site layout drawings; Confirmation of NPDES compliance; Narrative; LEED-Online template*
Submittal Data Type	Image; Boolean; Text

Table 4: Credit (without Option) interpretation report of SSc1

Item	Description
LEED Category	SSc1: Site selection
Requirements Key Words	*do not develop, prime farmland, lower than 5 feet above the elevation of the 100-year flood, habitat for federal or state threatened or endangered lists, 100 feet of any wetlands, undeveloped land that is within 50 feet of a water body, public parkland*
Request Type	Descriptive and quantitative
Proposed Data Type	Yes or No;
Submittal Requirements	*Confirm compliance with criteria; Narrative; LEED-Online template*
Submittal Data Type	Image; Boolean; Text

Table 5: Credit (with Option) interpretation report of SSc2

Item	Description
LEED Category	SSc2: Development density & community connectivity
Requirements Key Words	*Option 1: development density, previously developed site, minimum density of 60,000 square feet per acre net;* *Option 2: previously developed site,1/2 mile, average density of 10 units per acre net, 10 basic services, pedestrian access*
Request Type	Descriptive and quantitative
Proposed Data Type	Yes or No; Numeric
Submittal Requirements	*Option 1: Site vicinity plan; Site/Building area; Development density; LEED-Online template* *Option 2: Site vicinity plan; Site/Building area; List of business; Narrative; LEED-Online template*
Submittal Data Type	Image; Boolean; Numeric; Text

- Schedules: Schedules provide data-level view of the VDC/BIM model. Changes to a schedule view are automatically reflected in all other views. Functionality includes associative split-schedule sections and selectable design elements via schedule views, formulas, and filtering;
- Material Takeoff: This function is ideal for use on sustainable design projects and for precise verification of material quantities in cost estimates. As projects evolve, the parametric change engine helps ensure material takeoffs are always up to date;
- Interoperability: Interoperability enhancements enable users to work more efficiently with members of the extended project team. Users can import/export the building model between products with internal compatibility (e.g. between Autodesk CAD and Autodesk Inventor). With support for IFC, seamless information exchange between Autodesk Revit and other critical software application (e.g. Bentley, Vico and Tekla) in the project delivery could possibly be realized.
- Support Sustainable Design: Autodesk Revit supports sustainable design processes from the earliest stages. It exports building information, including materials and room volumes, to the green building extensible markup

language (gbXML). Energy analysis can be performed using Autodesk Green Building Studio web-based services, and building performance can be studied using Autodesk Ecotect software. Autodesk 3ds Max Design software can be used to evaluate indoor environmental quality in support of LEED IEQc8.1 (Daylight and Views) certification (Autodesk 2009).

With the LEED requirements interpreted into information requests, the next step is to match up these requests and the VDC/BIM functionality inventory. The LEED MR category will be used as an example. There are two categories of information requests: one for actual credit compliance and the other for demonstrating the compliance, which is the documentation/submittal. Tables 6 to 14 illustrate the process used to explore appropriate functionality for compliance and submittal requests respectively.

Table 6: Functionality screening for MRp1: Storage and collection of recyclables

BIM Solution	Functionality vs. Compliance Request	Functionality vs. Submittal Request
Revit	Site plan/Floor plan (2D/3D); Decals for recyclables;	Site plan/Floor plan; Area calculation (quantity takeoff)

Table 7: Functionality screening for MRc1.1: Building reuse – maintain existing walls, floors and roofs

BIM Solution	Functionality vs. Compliance Request	Functionality vs. Submittal Request
Revit	Floor plan by phases (demolish + new construction); Area takeoff by phases for structural components	Schedules/quantities report on structural components by phases

Table 8: Functionality screening for MRc1.2: Building reuse – maintain interior nonstructural elements

BIM Solution	Functionality vs. Compliance Request	Functionality vs. Submittal Request
Revit	Floor plan by phases (demolish + new construction); Area takeoff by phases for non structural interior components	Schedules/quantities report on non structural interior components by phases

Table 9: Functionality screening for MRc2: Construction waste management

BIM Solution	Functionality vs. Compliance Request	Functionality vs. Submittal Request
Revit	Floor plan by phases (demolish + new construction); Multi-category material takeoff by phases (volume +density factor)	Schedules/quantities report on multi-category material takeoff by phases (volume or weight)

Table 10: Functionality screening for MRc3: Material reuse

BIM Solution	Functionality vs. Compliance Request	Functionality vs. Submittal Request
Revit	Shared parameter* (tag material as reused); Material takeoff and pricing	Schedules/quantities report on reused materials; Pricing (material cost only) report

* Shared parameters are parameters that can be added to families or projects and then share with other families and projects. They give the ability to add specific data that is not already predefined in the family file or the project template.

Table 11: Functionality screening for MRc4: Recycled content

BIM Solution	Functionality vs. Compliance Request	Functionality vs. Submittal Request
Revit	Shared parameter (tag material as postconsumer or preconsumer); Material takeoff and pricing	Schedules/quantities report on recycled contents; Pricing (material cost only) report

Table 12: Functionality screening for MRc5: Regional materials

BIM Solution	Functionality vs. Compliance Request	Functionality vs. Submittal Request

Revit	Shared parameter (tag material as regional; zip code); Material takeoff and pricing	Schedules/quantities report on regional materials; Pricing (material cost only) report

Table 13: Functionality screening for MRc6: Rapidly renewable materials

BIM Solution	Functionality vs. Compliance Request	Functionality vs. Submittal Request
Revit	Shared parameter (tag material as rapidly renewable); Material takeoff and pricing	Schedules/quantities report on regional materials; Pricing (material cost only) report

Table 14: Functionality screening for MRc7: Certified wood

BIM Solution	Functionality vs. Compliance Request	Functionality vs. Submittal Request
Revit	Shared parameter (tag material as FSC certified); Material takeoff and pricing	Schedules/quantities report on regional materials; Pricing (material cost only) report

4.2.3 Integration Framework Summary

The integration framework is established on the basis of the LEED requirements interpretation and the VDC/BIM functionality screening. Table 15 is an excerpt of the framework in tabular format for the LEED MR category. Gaps pop up when no immediate solutions are available to achieve particular LEED credits.

4.3 Integration Framework Verification

To preliminarily validate the integration framework, a simple renovation project is modeled in Revit, with certain parts of the exterior wall is to be demolished. A sample application of the integration framework is conducted for LEED MR Credit 1.1: Building Reuse – Maintain Existing Walls, Floors and Roof. Figure 2 shows the recommended integration framework implementation process for LEED project teams. By designating “Existing”, “New” and “Complete” phases to the model, three interdependent wall schedules are created on the basis of which further calculation can be conducted. The formula to calculate the percentage of reused wall area is as follows:

$$Percentage = \frac{[(Exterior\ Wall\ Area_{complete}) - (Exterior\ Wall\ Area_{new})]}{(Exterior\ Wall\ Area_{existing})} * 100\%$$

In order to validate the results, a model based calculation (Table 16) is compared with the manual calculation (Table 17). The results from each method turn out to be consistent. But the model based calculation is much more straightforward since all the quantities are automatically generated. This can potentially prevent team members from making mistakes by omitting certain building components (e.g. forget to deduct window openings from wall area) when conducting a manual takeoff. While in an actual LEED project the calculations can be much more complex, the fundamental principles of these calculations are still applicable.

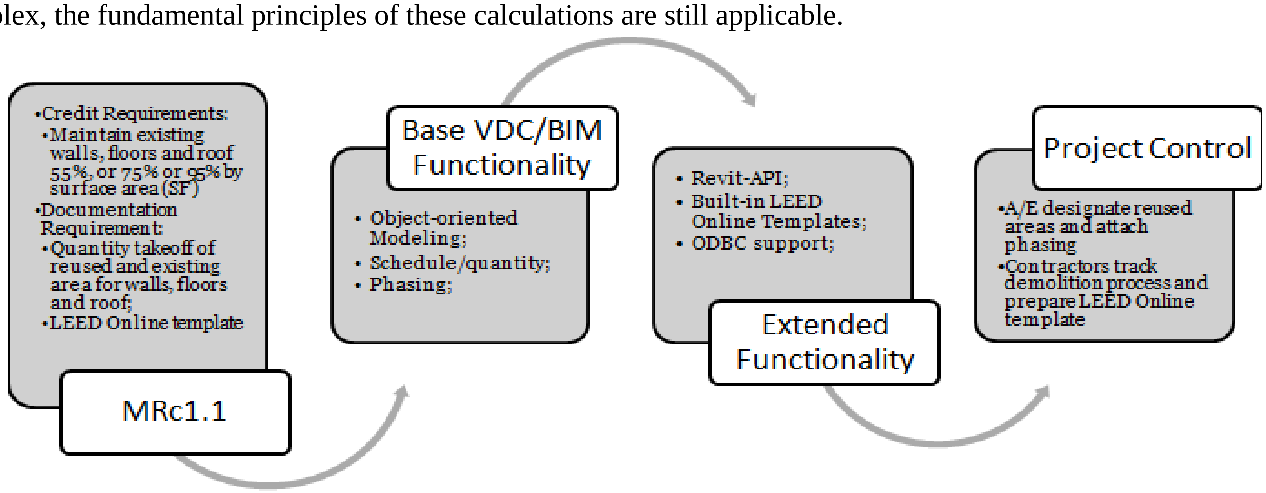

Figure 2: Integration framework implementation process

Table 15: Integration framework summary

LEED - NC 2009	Autodesk Products	Non – Autodesk Products	Notes
MRp1	Revit: Site plan with area designation		
MRc1.1	Revit: Floor plan + Material takeoff by phases (Demolition and New construction)		Compute Area
MRc1.2	Revit: Floor plan + Material takeoff by phases (Demolition and New construction)		Compute Area
MRc2	Revit: Floor plan + Material takeoff by phases (Demolition and New construction)		Compute Vol. or Weight
MRc3	Revit: Shared parameter (Reuse) + Material takeoff and Pricing (material cost only)		Compute Cost
MRc4	Revit: Shared parameters (Post-consumer and Pre-consumer) + Material takeoff and Pricing (material cost only)		Compute Cost
MRc5	Revit: Shared parameter (Regional or Zip code) + Material takeoff and Pricing (material cost only)	GIS linkage/ Google Map	Compute Cost
MRc6	Revit: Shared parameter (Rapidly Renewable) + Material takeoff and Pricing (material cost only)		Compute Cost
MRc7	Revit: Shared parameter (FSC) + Material takeoff and Pricing (wood products only)		Compute Wood Cost only

Table 16: Model based calculation for MRc1.1 – Building reuse

Model Calculation			
Building Shell/Structure	Existing Area (SF)	Reused Area (SF)	Percentage (%) Reused
Structural Floor	4504	4504	
Exterior Wall	2478	1952	
Roof Structure	5003	5003	
Total	11985	11459	95.6%

Table 17: Manual Calculation for MRc1.1 – Building reuse

Manual Calculation					
		Building Shell/Structure			
	QTO	Structural Floor	Exterior Wall	Roof Structure	Total
Existing	Gross Area (SF)	4500	2700	5004	
Existing	Opening Area* (SF)	0	222	0	
Existing	Net Area (SF)	4500	2478	5004	11982
Reused	Gross Area (SF)	4500	2100	5004	
Reused	Opening Area* (SF)	0	165	0	
Reused	Net Area (SF)	4500	1935	5004	11439
	Percentage (%) Reused				95.5%

5. CONCLUSION

This study identified a unique opportunity for integrating VDC/BIM technology in LEED projects to facilitate the pursuit of LEED certification. Due to the significance of sustainability in mitigating a building's impacts on the natural environment, LEED is gaining strong momentum in the U.S. market. However, there are substantial challenges posed to the project teams and the technological complexity of LEED rating system is one of the major barriers to smooth LEED project delivery. As the first step of a continuous investigation in the sustainability oriented VDC/BIM application, the study proposes an integration framework that lays out the foundation to future endeavors. The fundamental contribution and the major deliverable is a holistic approach to match the functionalities of current VDC/BIM tools with the LEED credit compliance and documentation requirements that are critical for LEED certification. Future research on the application model based on this integration framework is recommended. Investigations of cost implication of implementing VDC/BIM and LEED integration will also be valuable.

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