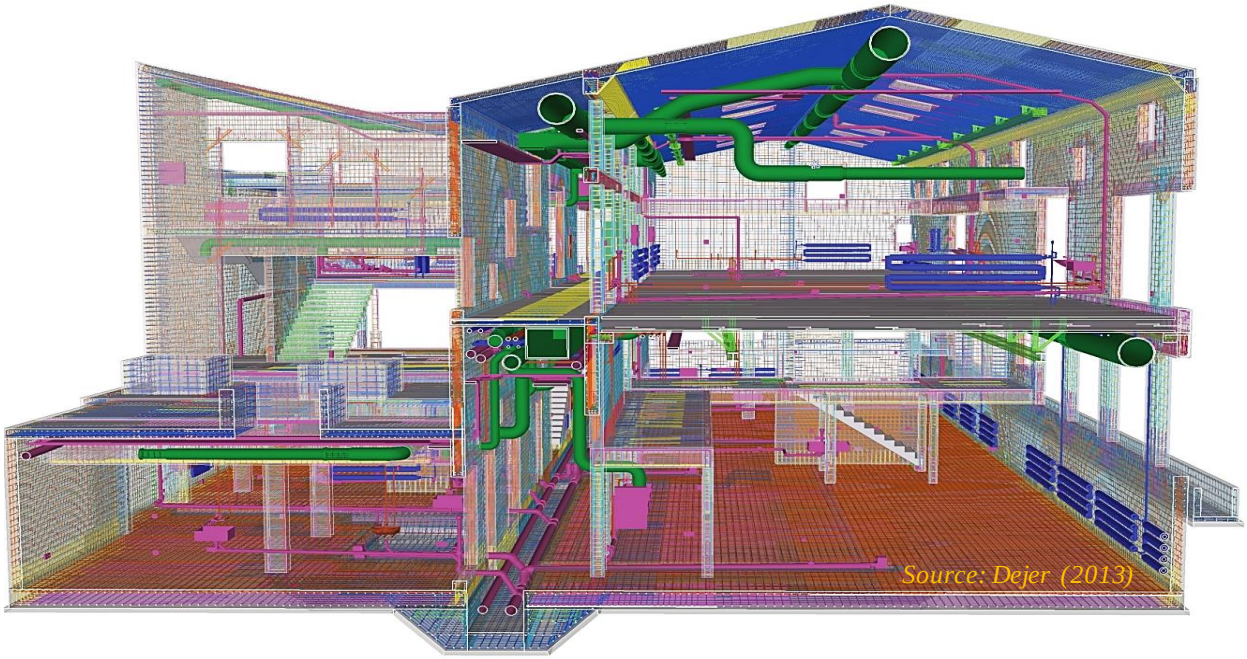
Adoption of Building Information Modeling in Small Size Home-Building-Businesses



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Abstract

Building Information Modeling (BIM) has the capability to help with all levels and types of building projects in the architectural, engineering, and construction (AEC) industry contributing to lower cost and time performance, and improved quality and levels of sustainability. Despite the potential benefits, the high initial investment required in adopting BIM practices presents a challenge for diffusion of this innovation in the industry. Main **initial investment areas** for BIM adoption in a company include: receiving consultancy, hiring of experts, training and retention of trained employees, and software license fees. Many **small size home-builders** are reluctant to adopt BIM practices due to lack of a business structure guaranteeing profitable business outcomes despite these high front-end investment costs. Driven by the small business management literature, this study proposes a number of practices for small home-builders to **economically and effectively create a business structure that supports BIM adoption and implementation for residential projects**. These practices were verified and refined via interviews with three small home-builders. Results suggest the following practices:

- Gain employees' support to implement BIM, and temporarily acquire external **coaching** or **consultancy** services at the beginning to put the BIM adoption process on the right track until relevant and practical BIM knowledge is possessed within the company;
- **Create** BIM expertise within the company via:
  - Hiring experts with the relevant BIM experience; or
  - Training existing employees by BIM experts in real-life projects; and
  - Promoting internal feedback practices and trust within the company.
- **Retain** and **motivate** BIM experts by:
  - Endowing them with adequate autonomy and task flexibility;
  - Imposing shared goals among them, and
  - Publicly recognizing noteworthy performance whenever applicable.
- Develop highly cohesive **BIM knowledge sharing networks,** bringing together diverse BIM users to economically search for and obtain valuable project- and business-related BIM knowledge driven by experience.

This study concludes that BIM can drastically increase employees' productivity and business profitability in the short-term. Moreover, BIM will be soon necessary for home-builders to compete in the residential market.

Table of Contents

1. Introduction 4

2. Overview 6

2.1. Innovative Features of BIM and Benefits 6
2.2. Challenges 14
2.3. Software 15

2.3.1. BIM Software for Residential Projects 15
2.3.2. BIM Software for Non-Residential Projects 17

3. BIM for Small Home Building Businesses 19

3.1. Initial BIM Adoption Setup 20
3.2. High Performance Work Practices (HPWPs) 22

3.2.1. Creation of BIM Expertise within the Organization 22
3.2.2. Retention and Motivation of BIM experts 23

3.3. Networks for BIM Knowledge Exchange 24
3.4. BIM Impact on Business Performance 25

4. Methods 26

5. Results and Discussion 28

5.1. Initial BIM Adoption Setup 28
5.2. Creation of BIM Experts 30
5.3. Retention and Motivation of BIM experts 31
5.4. Networks for Key BIM Knowledge Exchange with Other Home-Builders 33
5.5. BIM Impact on Business Performance 36

6. Summary and Conclusions 37

Acknowledgements 40

References 41

Appendix 48

List of Figures

Figure 1. BIM Component in Revit Software 7
Figure 2. 2D Plans Extracted from a BIM model in Revit Software 8
Figure 3. Bill of Materials Pulled Out from a BIM Model in Envisioneer Software to Produce the Cost Estimate and Which Can Be Used as A Point of Departure to Generate the Project Schedule 9
Figure 4. Project Scheduling Developed Using a BIM Model with Asta Powerproject BIM Software 9
Figure 5. BIM Model Where Architectural, Electrical, and Structural Systems Are Simultaneously Developed using Chief Architect Software 10
Figure 6. Wind Analysis (Left) in a BIM Model Using Autodesk Vasari Beta 3 11
Figure 7. Simulation of Building Construction Navisworks Software 12
Figure 8. BIM Model with Documents Attached to a Specific Pump for Maintenance in BIM 360 Glue Software 12
Figure 9. Virtual 3D Walkthrough of a BIM Model in Revit Software 13
Figure 10. BIM Pipeline – Option Management 17
Figure 11. Business Practices to Effectively Adopt BIM as an Innovation in Small Businesses of Home Building 20

1. Introduction

Although Building Information Modeling (BIM) has constituted a technological and team coordination breakthrough in the architectural, engineering, and construction (AEC) industry, it has been mainly adopted for commercial and/or large scale building projects while being mostly neglected by small or residential building project teams (NAHB, 2016). The main reasons include:

- Home-builders' unawareness of BIM, or their misunderstanding of BIM as a mere innovative and more sophisticated software producing fancy 3D models, thus ignoring the new multi-disciplinary collaboration processes among project parties for building design (NAHB, 2014);
- The high first investment for new software, training, and/or new hires to implement BIM (Nellis, 2012);
- Home-builders' perception that residential projects are simple in comparison to, e.g., commercial projects, and that BIM practices significantly improve project outcomes (e.g., time, cost, and quality) only if used in complex projects (Excelize, 2015; Fabris, 2010); and
- The severe crisis in the residential building market during the last decade (McGraw Hill, 2014) impacting business owners' ability to invest in innovative methods and technologies, along with the higher probability or bankruptcy of small businesses if profits are not quickly produced in such market (Robinson et al., 2006).

Nonetheless, BIM for residential projects is gaining popularity. The National Association of Home Builders (NAHB) conducted a survey where 15% of home-builders claimed to be very familiar with BIM, and another 30% would like to use it in the future (NAHB, 2014). BIM is attracting home-builders' attention promising a great qualitative leap in residential project outcomes including time, cost, quality, and sustainability (Fabris, 2010; Poirier et al., 2015). However, project efficiency does not necessarily translate into business efficiency.

A project is a temporary work with a specific goal (e.g., delivering a building to a client) to which resources are allocated (e.g., employees, software, and equipment); whereas a business is an ampler concept referring to all the activities needed to generate value or profit (e.g., marketing, project development, software acquisition, hiring, accounting, training, or networking) (Al-Debei & Avison, 2010; Lindsay et al., 2003). Creating a home-building business supporting BIM implementation in residential projects might require a high initial investment in new software, training, or hiring BIM experts. Therefore, although BIM promises greater efficiency in residential projects, it might take a while before small home-building businesses cover expenses from the BIM adoption process and start making greater profits.

To help home-builders confidently implement BIM in their small businesses, this study first analyzes BIM benefits and challenges in residential projects, and software; and second, examines the practices small home-building businesses should implement to create an appropriate business structure that supports BIM implementation in residential projects while enhancing business performance.

2. Overview

Eastman et al. (2011) define BIM as a "modeling technology and associated set of processes to produce, communicate, and analyze building models." The **modeling technology** should be capable of the following:

- Digitally developing building components in a 3D space;
- Assigning to the 3D building components both data attributes (e.g., materials, thermal and resistance properties, geometric dimensions, cost, or construction labor and equipment) and parametric rules determining how they interact with each other to avoid geometric incompatibilities (e.g., walls' height automatically adjusted to distance between floors);
- Allowing simultaneous design and integration of diverse building systems (e.g., mechanical, architectural, and structural systems);
- Enable specific functions to evaluate building performance in multiple aspects (e.g., structural and energy efficiency analysis, design consistency or clash detection, construction cost estimate, schedule and simulation, or maintenance costs) during its life cycle stages (i.e., materials manufacturing, construction, operation, maintenance, and demolition or deconstruction [GIT et al., 2010]).

3D models produced via the modeling technology above are referred to as **BIM models** since, besides representing a building in a 3D space, its components' multi-disciplinary data attributes (e.g., materials' thermal and resistance properties) allows simulation and assessment of building performance (e.g., energy or structural performance) during its life cycle before construction.

In addition, BIM requires an associated set of processes facilitating **multi-disciplinary collaboration**. This involves planning the timing of involvement of key parties (e.g., contractors, architects, engineers, and MEP subcontractors) during the design stage, and establishing information sharing processes among them (e.g., meetings for simultaneous architectural, structural and mechanical systems design) to create a BIM model integrating the necessary multi-disciplinary information to simulate building performance. The following subsections highlight innovative features of BIM in the construction industry, challenges for BIM implementation, and commonly used BIM software.

2.1. Innovative Features of BIM and Benefits

BIM was developed as a response to traditional AEC methods which were frequently unable to show the final product to the client before construction, or facilitate multi-disciplinary collaboration, especially during the design phase. Lack of effective multi-disciplinary collaboration in AEC projects repeatedly results in the inability to accurately predict building performance, or avoid redundant work and excessive errors in buildings' design and construction planning (Fabris, 2010). The main innovative features of BIM applicable to any type of construction project (e.g., residential, industrial, and commercial) that significantly enhance project performance as compared to traditional methods include the following:

Parametric Modeling: BIM models are made of building components that do not only contain data about their geometry, or materials' composition and properties, but also parametric rules that dictate how their geometry and position is to be adjusted according to the surrounding elements (Eastman et al., 2011). For example, specifications might impose that HVAC ducts have to be parallel to the roof, or that doors have to be at least one foot shorter than the floor height. An important consequence of parametric modeling is the capability of enabling tools such as clash detection to identify design incompatibilities within and among building components or systems. Consequently, change orders are significantly reduce later during the construction phase (Smith, 2014). For instance, Figure 1 below shows a building component following the parametric rules of the basic wall family which means that, the component height is to be adjusted to equal the distance between the floors where it is placed.

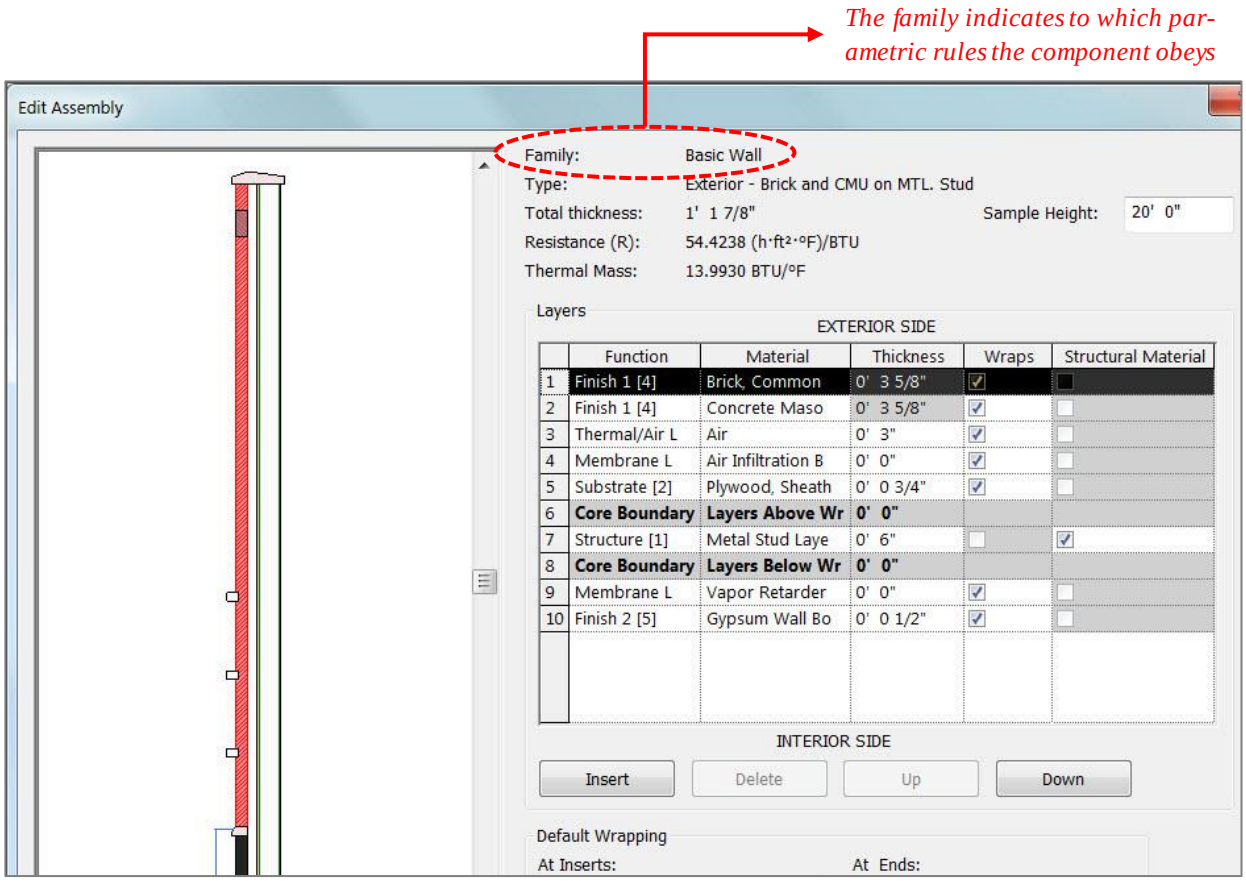

Figure 1. BIM Component in Revit Software. Source: Knittle (2014)

Specificity: All 2D site-specific drawings can be easily and automatically extracted from the BIM model ensuring that all 2D drawings are in harmony among them and with the 3D model (Indovance, 2015). Any change in the BIM model is automatically spread throughout all 2D drawings without the need to manually redraw them. Figure 2 below illustrates the ease to draw 2D plans from the 3D model.

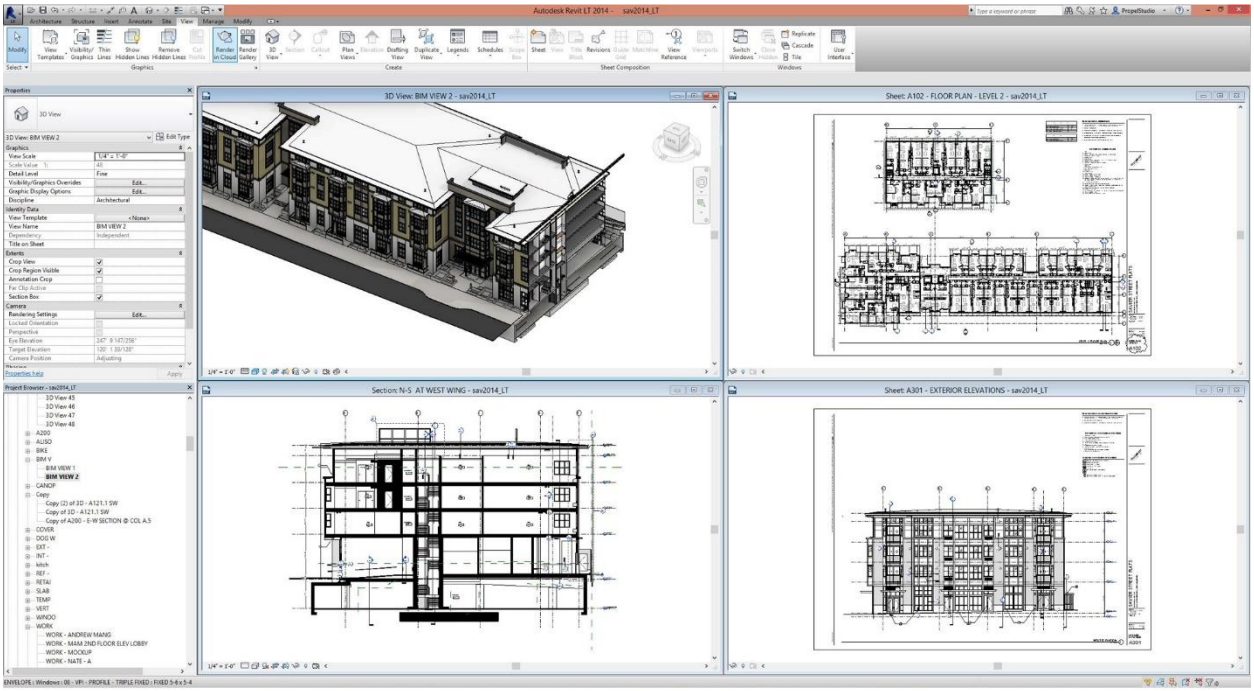

Figure 2. 2D Plans Extracted from a BIM model in Revit Software. Source: Autodesk (2014)

Automation of Construction Processes: Attached information to building components in BIM models allows the software to automatically count elements, and accurately calculate areas, volumes, and material quantities. This decreases material waste and enhancing productivity and can be used as a point of departure to generate the cost estimate and project schedule (Larson, 2011). In Figure 3, a list is extracted from the BIM model with the building components classified under different categories and with their respective material types, quantities, and units.

5D Models: Simultaneous development of a 3D design along with two more dimensions including cost estimate (Figure 3) and project schedule (Figure 4). 5D models allow a greater control over final project cost and time while design is being performed since any change in the BIM model can be instantly reflected into both project cost estimate and schedule. Thus 5D models facilitate adjusting design to meet clients' time and cost requirements (Eastman et al., 2011).

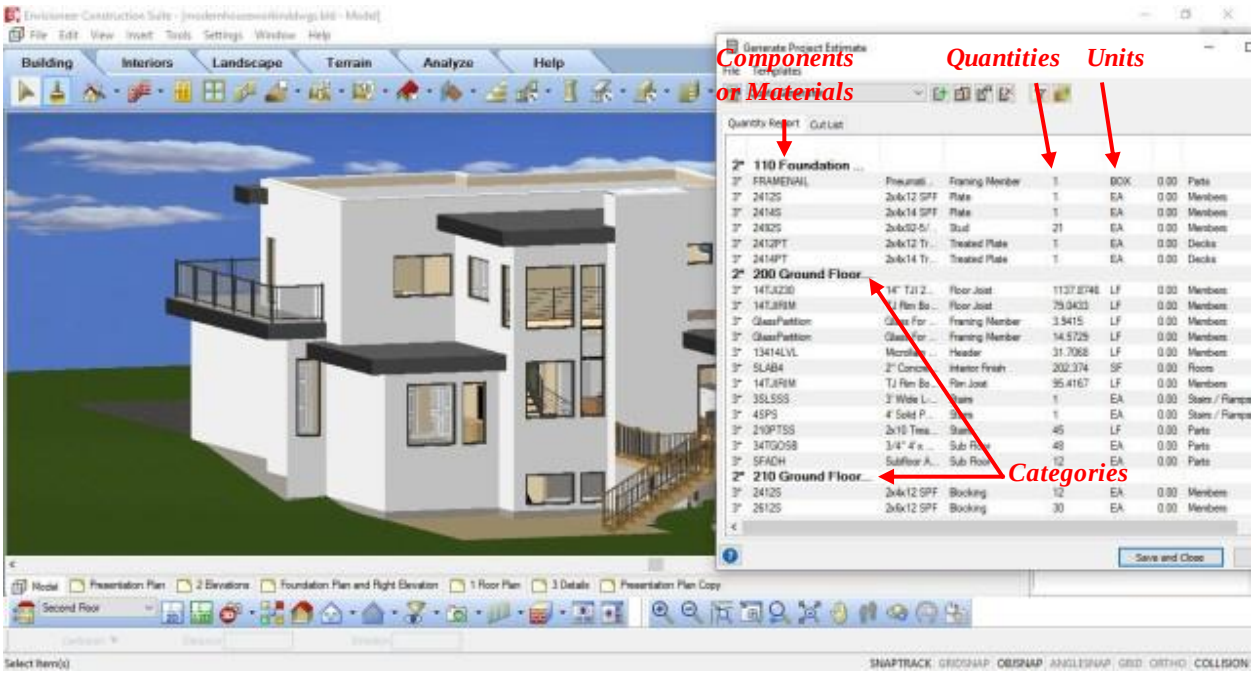

Figure 3. List of Building Components or Materials Pulled Out from a BIM Model in Envisioneer Software. Source: Cadsoft (2015)

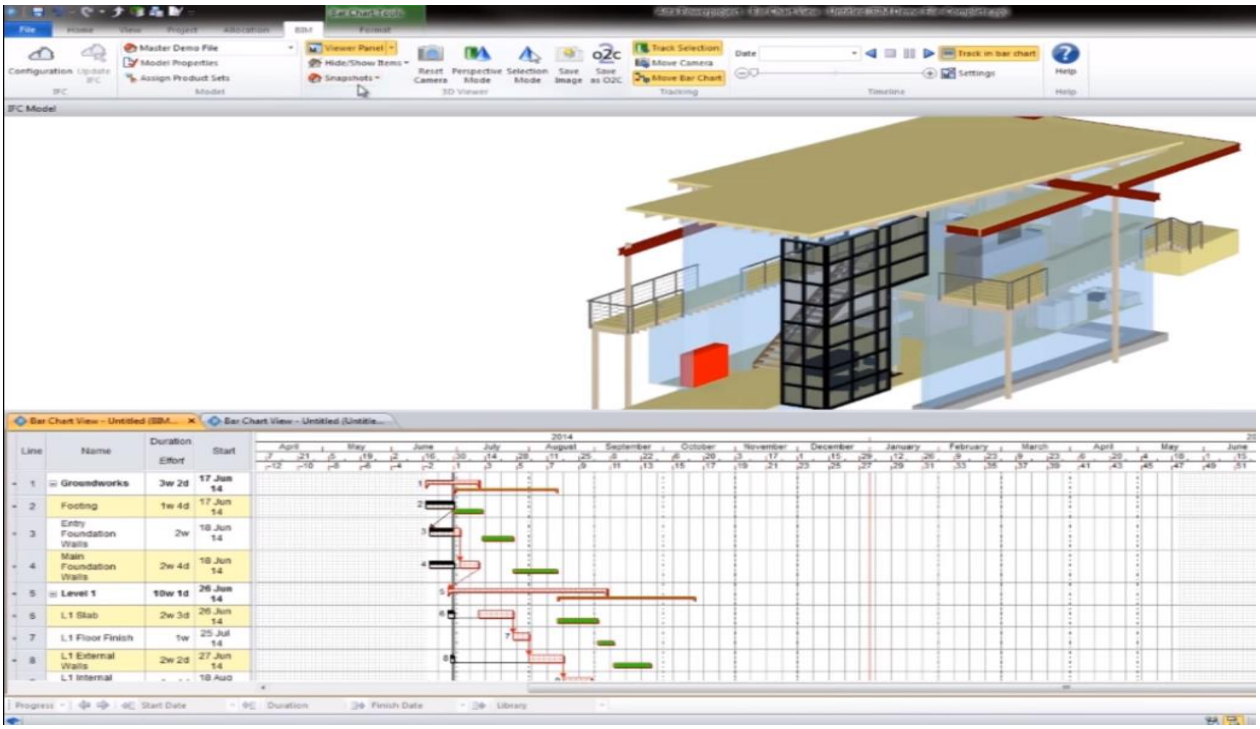

Figure 4. Project Scheduling Developed Using a BIM Model with Asta Powerproject BIM Software. Source: Asta Powerproject (2016)

Multi-disciplinary Design Collaboration: BIM models are designed simultaneously by multidisciplinary experts (e.g., architects, constructors, and structural, mechanical, energy and electrical engineers) in a shared software, thus they have instant access to each other's systems to effectively integrate their multi-disciplinary systems and task outcomes. An example of diverse systems designed together is shown in Figure 5 below.

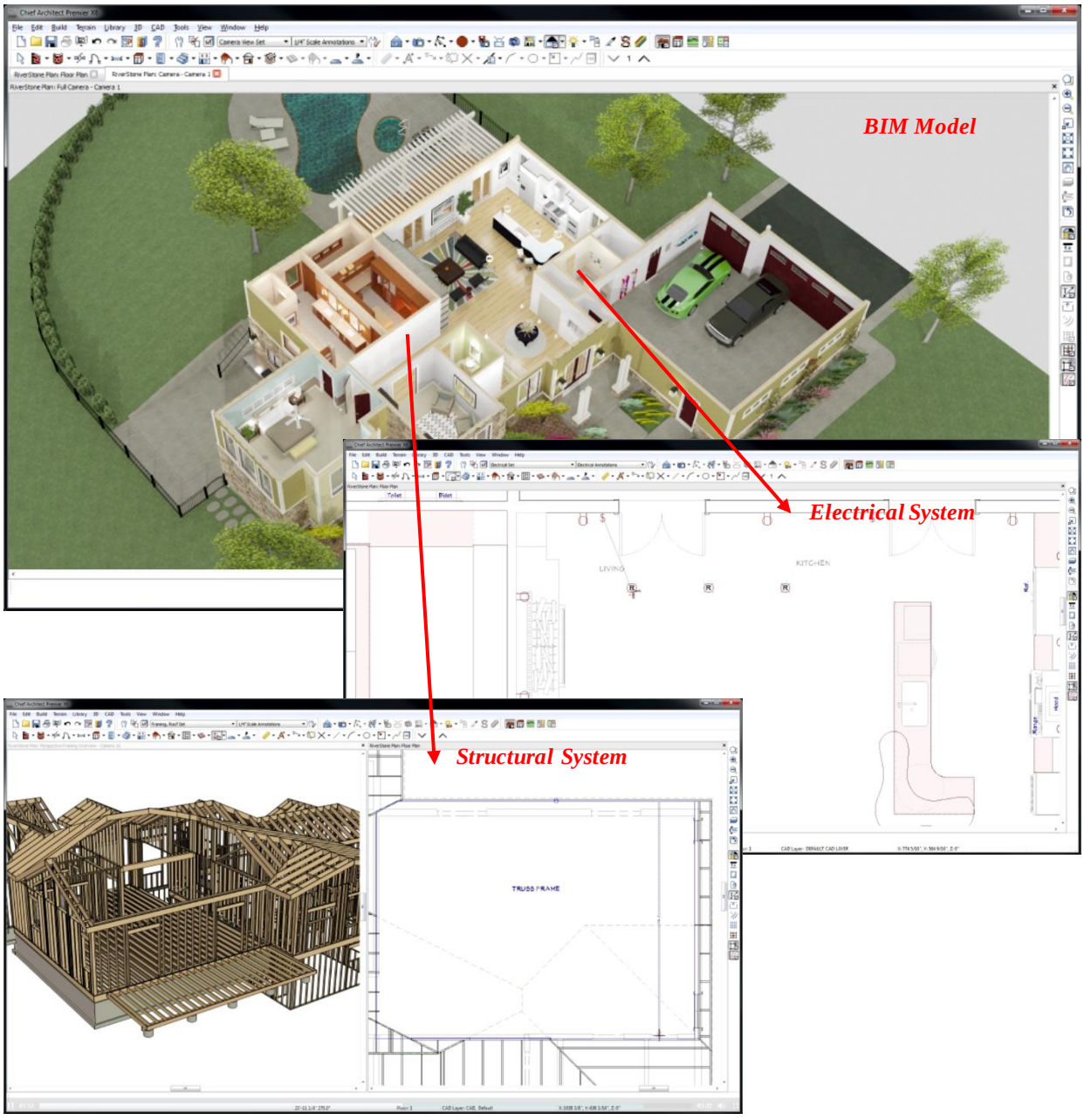

Figure 5. BIM Model Where Architectural, Electrical, and Structural Systems Are Simultaneously Developed using Chief Architect Software. Source: Chief Architect (2016b)

Building Performance Analyses: The collaborative processes involving all key multi-disciplinary experts allows pooling all necessary information to thoroughly evaluate BIM models' performance (e.g., structural, energy, or sustainability analyses) before construction (Azhar et al., 2011; Jalaei & Jrade, 2015). Figure 6 below illustrates a case where energy analysis is performed in a BIM software. This energy analysis takes into account wind direction and strength which requires previously integrating the structural model sustaining the building and the building envelope.

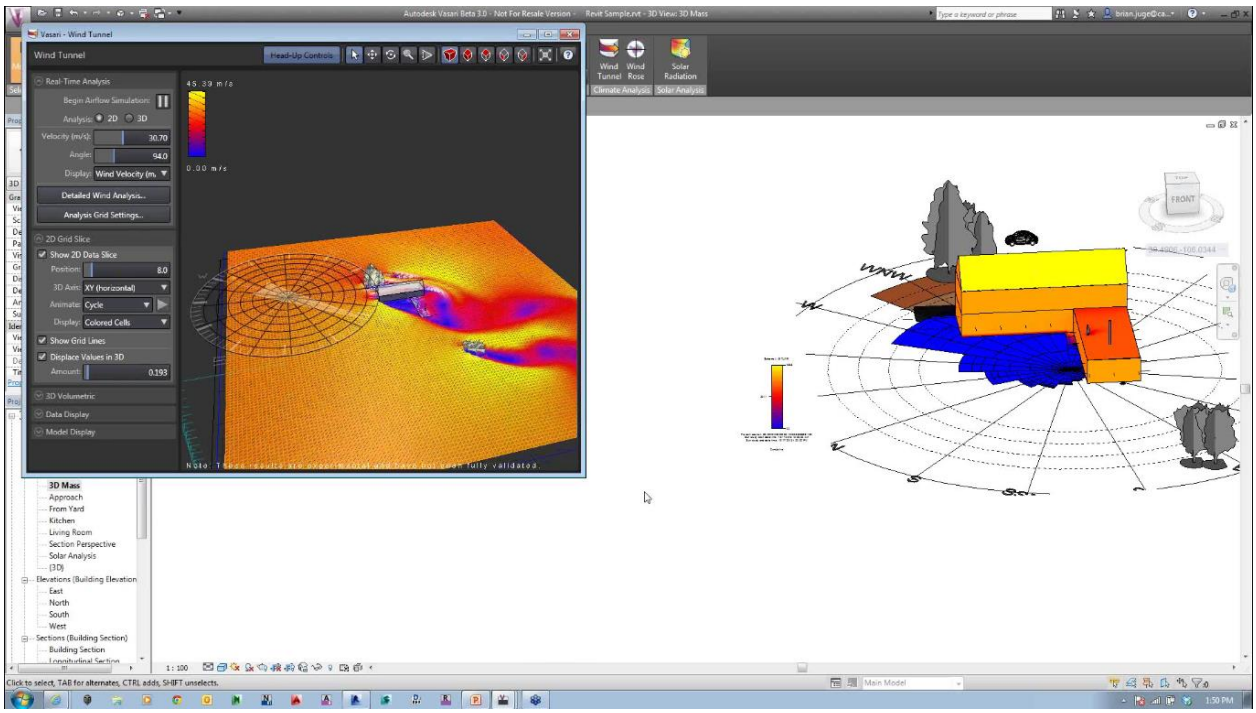

Figure 6. Energy Analysis in a BIM Model Using Autodesk Vasari Beta 3. Source: CAD1Webinars (2014)

Virtual Construction Arrangements: Construction sequences of complex designs can be tried virtually to detect constructability issues or assess the appropriateness of construction material and equipment layout on site (Figure 7) (BSRIA, 2013).

Facility Operation and Maintenance: BIM components hold data to simulate building operation, and provide guidance for building components' and systems' maintenance (Figure 8) which facilitates predicting building life cycle costs (Eastman et al., 2011).

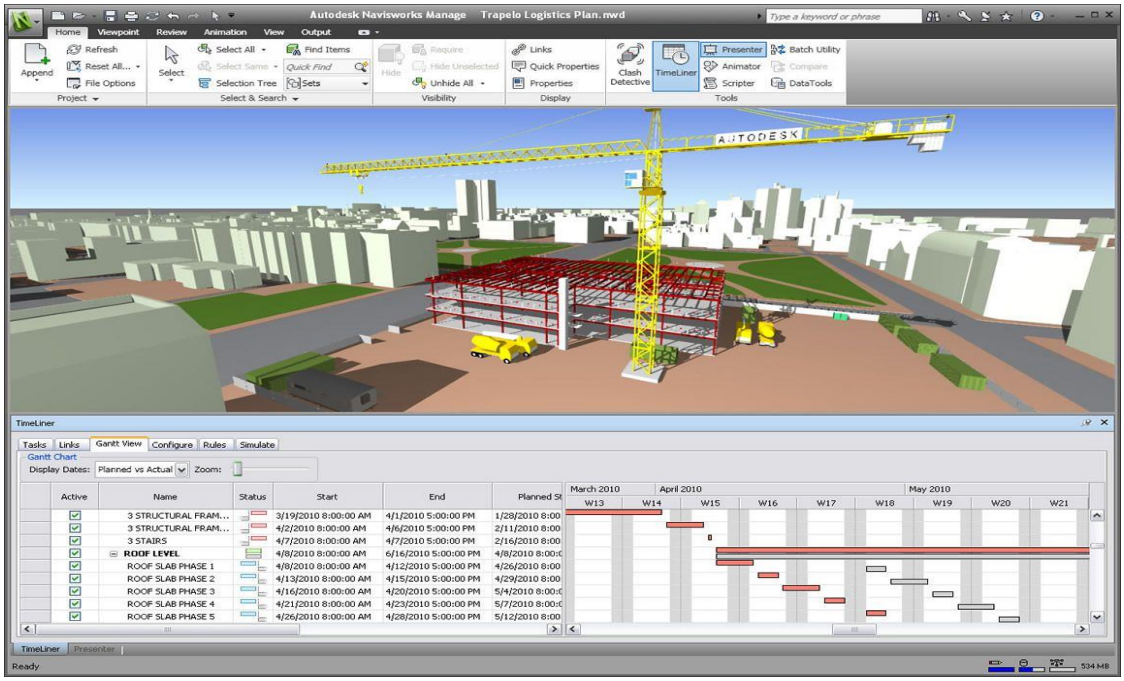

Figure 7. Simulation of Building Construction Navisworks Software. Source: Autodesk (2016c)

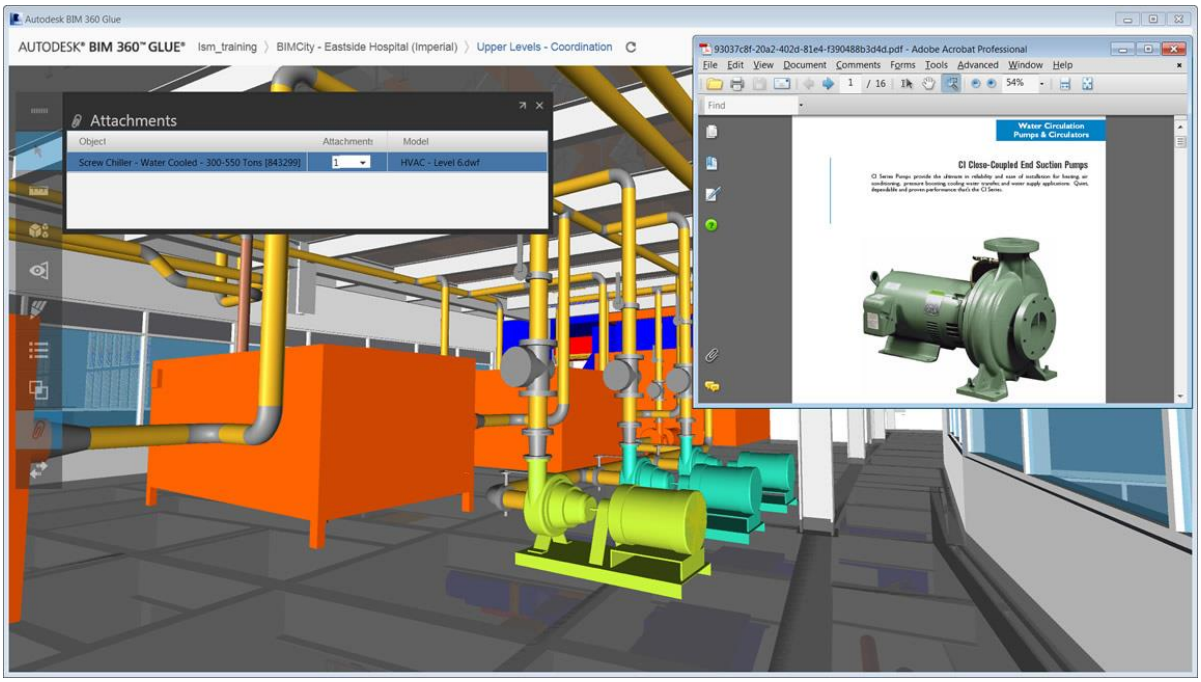

Figure 8. BIM Model with Documents Attached to a Specific Pump for Maintenance in BIM 360 Glue Software. Source: Grimm (2014)

Interactive 3D Walkthroughs: Clients can see before construction starts the final product through virtual walks throughout the building (Figure 9) (Smith, 2014; Sears, 2015). This BIM application might be key to increase project sales since clients tend to be more satisfied when they are able to see what they are paying for (Sears, 2015).

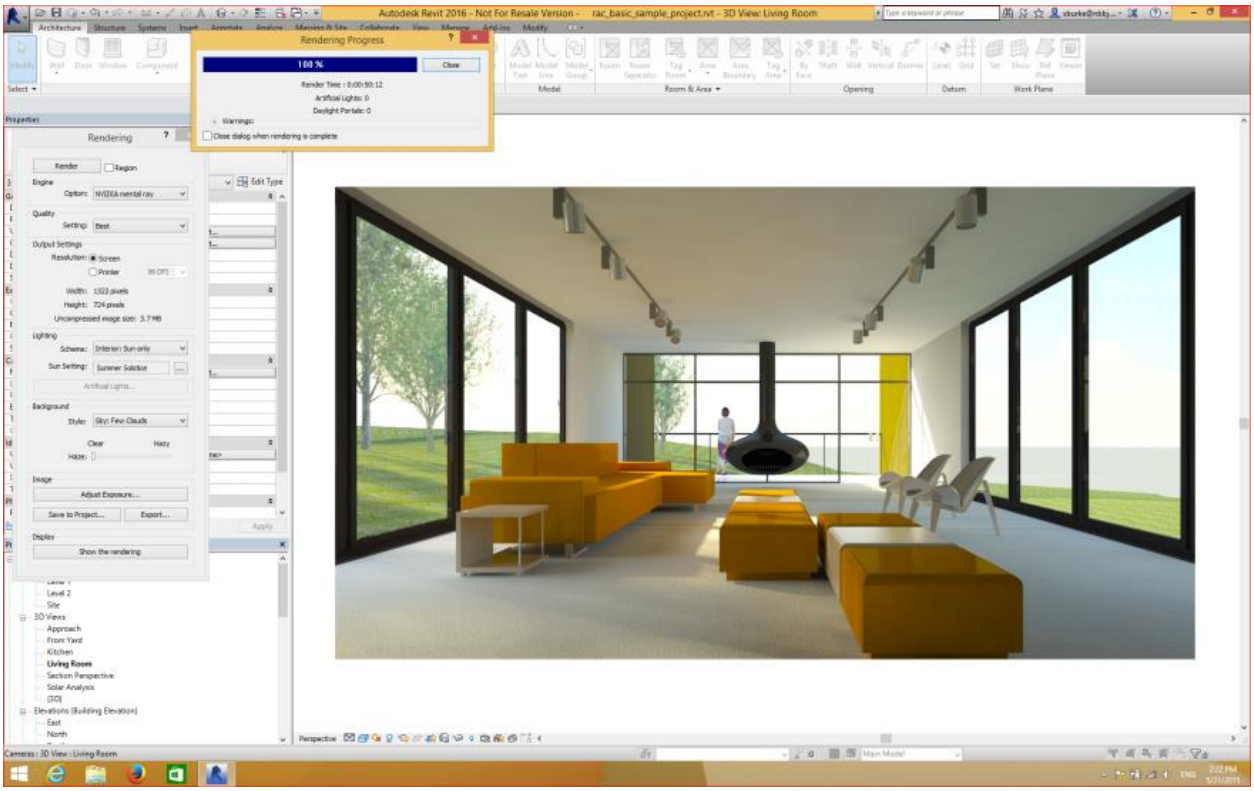

Figure 9. Virtual 3D Walkthrough of a BIM Model in Revit Software.
Source: Burke (2015)

2.2. Challenges

Although previous BIM innovative uses aim to improve residential projects' performance including time, cost, quality, and sustainability, BIM also presents some challenges:

Interoperability: Although geometry data can be easily transferred between different BIM software, exchange of data related to BIM elements' behaviors might not be possible. Ideally, all parties designing a product should be experts in and handle the same BIM software. In addition, data transfer between a 3D model and specific tools (e.g., structural analysis) within the same BIM software might not be trivial and require some additional expertise (Eastman et al., 2011).

Scalability: BIM models, depending on their size and level of detail, might end up containing thousands of BIM elements constituting huge loads of information that overwhelm computer memory size, slowing down software and reducing designers' productivity. To address this issue, designers can partition projects in different files and run BIM applications capable of spreading changes made in one file to the rest (Eastman et al., 2011).

Design Limited to Library Components or Time to Develop Library: Design might be limited to BIM software library components (Smith, 2014). Creating library components is time consuming since they require not only geometric data but also programing rules to guide their behavior; partially mitigating this issue, most BIM software typically comes with a standard library (Eastman et al., 2011). Although creating a library is initially time consuming, it eventually pays off by increasing productivity in future projects. When adopting BIM, it is recommended that small home-builders initially invest in creating a standard library within their software that satisfies their unique designs or style (Sears, 2015).

Client Initiated Setbacks to the Design Process: The BIM capability to quickly apply changes throughout the design and to show the final product to the client before construction starts via 3D walkthroughs, might encourage clients to keep demanding changes to check different design outcomes. Thus builders should limit or control clients' opportunities to demand new design changes (Smith, 2014).

2.3. Software

BIM software may refer to different concepts including BIM tools, platforms, and environments. "BIM tools" refer to specific tasks performed on BIM models such as parametric modeling, structural and energy analysis, and clash detection; "BIM platforms" provide an interface incorporating "BIM tools" that can take data contained in the BIM model to develop their tasks; and "BIM environments" manage data across multiple BIM models and is typically used by upper management to make sure that organizational practices and policies are implemented (Eastman et al., 2011).

Typically, builders first look for a "BIM platform" and then add "BIM tools" according to their needs. Most BIM platforms usually come with tools for, at least, designing a BIM model. However, some BIM platforms only perform construction management tasks such as cost estimating or scheduling, and require importing a BIM model developed in other BIM platforms. Below it is presented a list of popular BIM software with a brief description. They are classified between those specialized in residential projects, and those for non-residential projects which suit better larger or more complex projects.

2.3.1. BIM Software for Residential Projects

The most popular BIM platforms for residential projects include the following (Fabris, 2010; Eastman el al., 2011; Green 2016):

VisionREZ: Developed by Ameri-CAD in collaboration with Autodesk, this BIM platform is suitable for drafting residential projects, and is especially friendly with or easier to learn for those experts familiarized with 2D AutoCAD (BCG, 2016).

Vertex BD: Created by Argos Systems, Vertex BD offers a BIM platform to primarily design medium to large sized residential projects, but can also be used for commercial ones. This platform is capable to rapidly offer a number of different building design options based on a given set of standard building components or systems. (Argos Systems, 2016).

Envisioneer: Brought by Cadsoft, Envisioneer was primarily developed for home building and light commercial, and one of its main remarkable features is the inclusion of tools to guide energy efficient design (i.e., passivHaus package) (Cadsoft, 2016).

ARCHICAD 19 Solo: Recently created by GRAPHISOFT, this platform is only appropriate for homebuilders, and highlights its ability to simplify and speed the BIM process for the sole practitioner. It incorporates built-in tools for renovation and home expansion projects, and energy efficient design tools (GRAPHISOFT, 2016a).

SoftPlan: Mainly thought for residential projects, this software also offers the SoftPlan Remodel program for remodeling bathrooms and kitchens (Softplan, 2016). SoftPlan is an architectural design software offering a smooth simultaneous generation of design, construction documents, and bills of materials (Green, 2016).

Chief Architect: Similar software as SoftPlan above (Green, 2016) but also offers specific tools for kitchens, bathrooms, landscaping, and decks (Chief Architect, 2016a).

Vectorworks: Vectorworks Inc. offers this BIM platform, which is applicable to residential and commercial projects, and highlights the capability to 3D scan the physical location of the building instead of using the traditional field surveys; and an additional BIM tool (i.e., Energos) to support sustainability during the design process (Vectorworks, 2016).

Revit: Although this BIM platform offered by Autodesk is mostly used for commercial projects, it is also frequently used in residential projects where it is very appropriate for designing complex roofs and light-frame construction (Autodesk University, 2016).

StrucSoft Solutions' MWF: This software is an add-on for Revit suitable for residential projects (Green, 2016). MWF generates light gauge steel and wood framing, and offers optional CNC output to facilitate fabrication of framing elements (StrucSoft, 2016).

FreshBrix: Rather than for design drafting or construction management, this platform keeps builders and homebuyers connected before, during, and after construction via mobile devices if preferred (FreshBrix, 2016). Before construction, homebuyers have access to virtual tours, and design updates; during construction, they receive real-time updates and pictures; and after construction, they obtain a personalized database for home operation and maintenance (FreshBrix, 2016).

BuilderTREND: This platform is tailored for home-builders and remodelers and it is primarily an application for mobile devices; it does not include tools for project design, but rather imports a BIM model and allows construction, financial and customer management (BuilderTrend, 2016).

BIM Pipeline: This software is adequate for design options management, that is, having digitally built a set of standard BIM models, designers can manage the information held in the models to easily build up new BIM design options that automatically calculate the new cost estimate (Figure 11), allowing them to quickly offer to clients a variety of design options along with their cost and adjusted to clients' demands without the need to develop large portfolios. BIM Pipeline can also tie design options and cost estimate with sales and purchasing, and can utilize data from different BIM applications, e.g., Revit, Vertex BD, and VisionRez. (CG Visions, 2016a).

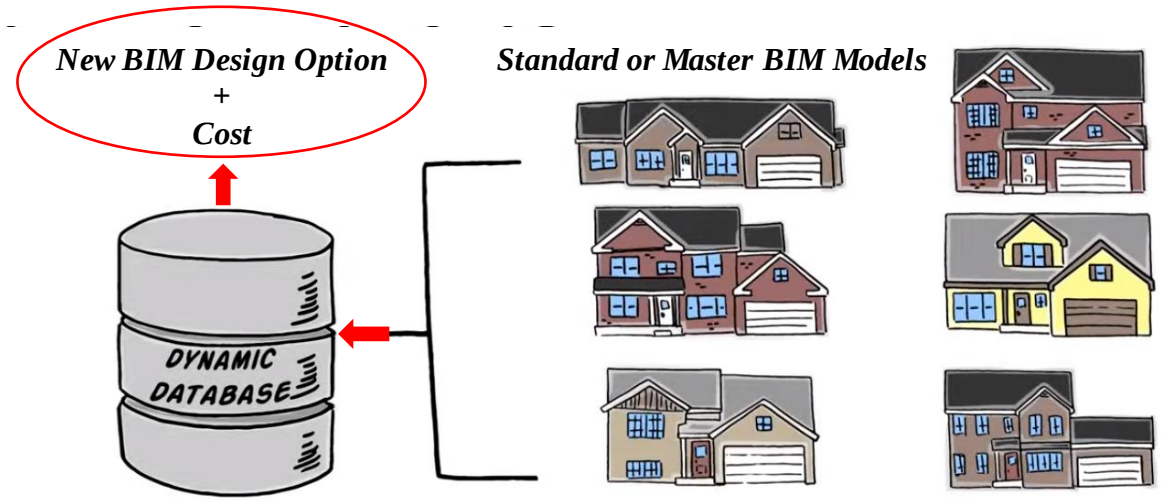

Figure 10. BIM Pipeline – Option Management. Source: CG Visions (2016b)

2.3.2. BIM Software for Non-Residential Projects

Although the software below could also be used for residential projects, their design and coordination tools and capabilities are so wide that they ae better exploited when used in larger and more complex projects than the residential ones:

Revit / Vectorworks: Both have been described in the previous subsection and are also suitable for commercial projects.

Bentley Architecture: Any type of project can be managed with this platform (e.g., residential, commercial, educational, retail, health care, and airport), however, it is mainly used for highly complex projects such as infrastructures needing very precise coordination among designers and critical information retention into the BIM model for future building operation and maintenance (Bentley, 2016).

Tekla Structures: As Bentley Architecture above, although Tekla can be used for residential projects, it works better for designing complex structures from large-scale projects such as stadiums, skyscrapers, bridges and factories (Tekla, 2016).

DESTINI Profiler: Beck Technology offers this platform emphasizing easy learning and use, and the ability of designers from different disciplines to easily assess outcomes (e.g., cost, time, and quality) and trade-offs from different designs to select the best design option (BECKTECH, 2016).

VICO Office: This platform requires importing a BIM model (i.e., preferably from ArchiCAD, Tekla, Revit, AutoCAD Architecture, or AutoCAD MEP) to accurately perform quantity takeoff, cost estimating, project scheduling, and production control (VICO Software, 2016).

Synchro Pro* / *Navisworks Manage & Simulate* / *AstaPowerProject BIM: After bringing in a BIM model, these platforms perform project scheduling and allow virtual project management with tools such as construction sequence visualization, or equipment and material layout on site (Synchro Software, 2016; Autodesk, 2016a; Elecosoft, 2016).

CostX: Developed by Exactal, Cost X performs quantity takeoff and cost estimate of an imported BIM model. CostX is remarkable for its ability to easily visualize any building component, system or section, and exporting the cost estimate to other BIM platforms overcoming interoperability issues (Exactal, 2016).

Many of the companies developing the above-noted BIM platforms offer a number of extra tools on their websites at an additional cost that home-builders may purchase. For instance, to complement the ArchiCAD BIM platform, GRAPHISOFT offers the BIMx tool for residential projects to generate virtual 3D walkthroughs for homebuyers (GRAPHISOFT, 2016c), EcoDesigner to facilitate green design, or Artlantis to communicate with city planning and other project approval departments (GRAPHISOFT, 2016b); or Autodesk offers additional tools to complement Revit BIM platform such as BIM A360 to support construction management in the field, or BIM Glue to enhance collaboration among team members before and during construction (Autodesk, 2016b).

In general, any BIM software specialized in 3D drafting also offers (1) 5D modeling, that is, the ability to develop cost estimates and project scheduling along with the 3D model, (2) options management or capability to develop design options based on a set of standard or master design options, and (3) the ability to link building components data to CNC machines to facilitate the manufacturing processes.

Other BIM software also exists that does not perform 3D drafting but takes the BIM model developed in other BIM software, and incorporates construction management applications in core areas (e.g., cost estimate, project scheduling, or construction simulation). This software typically has superior capabilities when compared to the same tools in BIM software that also offers 3D drafting.

None of the BIM software or platforms above can be deemed the best since each one has its own strengths and weaknesses, and frequently they offer different tools. Selection of the BIM software that best fits a home-building business mainly depends on projects' size and complexity. Consulting services exist to help select the best option for a specific business such as:

- Gehry Technologies (*www.gehrytechnologies.com*);
- IMAGINiT Technologies (*www.imaginit.com*); and
- CG Visions (*www.cgvisions.com*).

3. BIM for Small Size Home-Building-Businesses

Successful adoption and implementation of BIM in residential construction projects is required to achieve the numerous reported benefits. Therefore, a business structure for adoption and implementation is vital for small size home-building organizations. When compared to their larger counterparts, it is harder for small home-building businesses to adopt BIM because they benefit less from economies of scale (Ferris et al., 1998; Sels et al., 2006). For example, if one BIM software license is acquired for $1,000, then the cost per employee to purchase the license is much higher for a business with 10 employees ($100/employee) than for one with 100 (i.e., $10/employee).

Typically, home building businesses are small organizations that mainly perform construction activities and, less frequently, design services (NAHB, 2015c). However, BIM collaboration principles to develop a thorough and consistent design before construction, enables design-build residential firms to deliver residential buildings faster and at a lower price (NAHB, 2015a). Thus, it is possible that, as BIM adoption grows in the residential market, it will increase the number of residential construction firms offering design-build capabilities. On average, small single- and multi-family home builders specializing in construction only have 9 employees (NAHB, 2015c), whereas most small firms specializing in home design have less than 10 employees (AIA, 2012). Thus, small design-build residential firms probably have on average less than 20 employees.

Primarily based on a review of the small business management literature, which typically considers small firms those with less than 100 employees, the authors identified a number of practices to help small home-builders to economically and effectively create a business structure that can assist adoption and implementation of BIM as an innovation, ultimately improving not only project but also business performance. These practices can be classified under three main categories as illustrated in Figure 11:

1) Initial BIM adoption setup;
2) High performance work practices (HPWPs) for the creation, retention, and motivation of BIM expertise in the organization; and
3) Development of networks supplying BIM knowledge.

These practices are described in more detail in the following subsections.

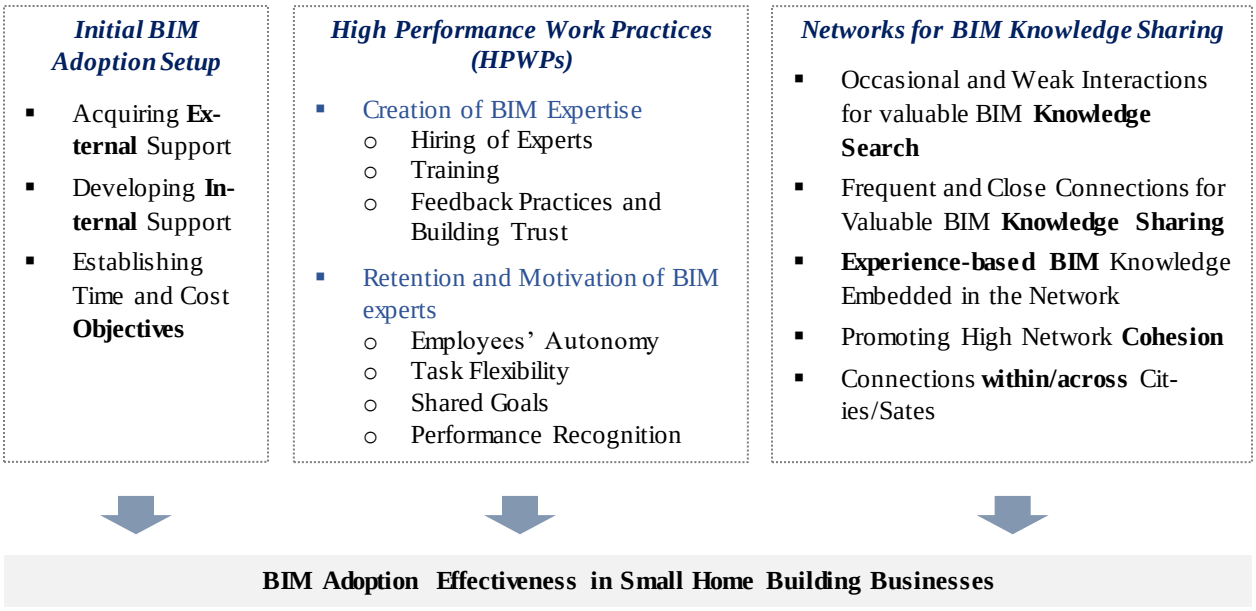

Figure 11. Business Practices to Effectively Adopt BIM as an Innovation in Small Businesses of Home Building

3.1. Initial Set up for BIM Adoption

BIM adoption requires new software and information sharing processes that are likely to redefine business capabilities and employees' relationships, roles and skills which need to be clearly described to increase employees' commitment to the BIM adoption process and improve business outcomes (Rue & Ibrahim, 1998; Terziovski, 2010). The following practices might give a vital initial impulse to set the ground for a smooth and fast BIM adoption process:

External Support: Hiring consultancy services for training, supplying advice, running BIM projects' start, or leading the entire BIM adoption process (Fabris, 2010; Smith, 2014). Some consultants emphasize services that are specifically developed for home-builders. When examined in detail, these services provide a good glance of important aspects to effectively start using BIM in small home building businesses (CG Visions, 2016a):

- Making a quick and precise decision about what BIM platform is best tailored for a specific home-builder, avoiding shifting to other BIM platforms in the future;
- Converting the company's sets of 2D plans into 3D models, and creating and planning a strategy to update a set of 3D master models;
- Establishing a strategy to generate and manage the numerous 3D structural and design options from the company's master models;
- Coordinating designers and trade partners in order to pay attention to the following:
    - Potential interoperability issues if different BIM platforms are used; and

    - Workflows that bring together all building systems into one consistent model to perform thorough building performance analysis such as clash detection or energy efficiency;
- Coordinating design with other parts of the company so design, sales, cost estimates, and purchase operations are integrated;

External help might also come from other small home-builders offering practical tips from their experiences in adopting BIM (Miller, 2012; Sears, 2015):

- At the beginning it might not be recommended to use BIM in all projects but only in small ones (around one million dollars) where if things go wrong, going back to former methods is easy;
- It may be appropriate to hire a BIM champion to lead BIM projects until employees gain enough confidence to take them over;
- Initially, it is advantageous to buy a library with standard BIM components and save excessive time to develop them; and
- Designers have to decide which level of detail is appropriate for each project since files above 50 or 100 MB might slow down software and productivity substantially.

Internal Support: Gaining internal support from both upper management and lower level employees is crucial when adopting BIM. Upper management support is important to obtain financial resources and freedom to make changes in software and workflow structures, and can be easily obtained if the BIM adoption process follows a thoroughly designed program (Nellis, 2012). This program should at least address the points described above, and, furthermore, this report will also recommend planning the implementation of additional practices as described in Sections 3.2 and 3.3.

Lower level employees' support is also vital since they will be the key to, while utilizing BIM, experimenting and adapting the new software capabilities and collaboration processes according to the company's culture and policies (Dearing & Meyer, 2011). Their support arises easier if their new roles in the BIM method are clearly defined (Terziovski, 2010), that is, their responsibilities regarding tasks to be performed, skills to be acquired or improved, and interactions with other peers (Chen & Klimoski, 2003).

Time and Cost Objectives: Ideally, small home-builders have to set up objectives in terms of cost and time for an effective BIM adoption process (Rue & Ibrahim, 1998). Nevertheless, it is very difficult to find home-builders in the market that have established clear and well-defined cost and time objectives. Many homebuilders may instead keep track of the cost and time outcomes from the adoption process. For instance, it might take around three months before employees proficiently handle BIM software (Sears, 2015); or BIM software and training costs can take up to $10.000 (Miller, 2012).

3.2. High Performance Work Practices (HPWPs)

One of the main concerns of small size home-building organizations when adopting BIM is to create BIM expertise and retaining it within the organizations. Retaining BIM experts is as important as attracting and hiring them, since they might be scarce and on high demand in the market due to their unique skills. During their stay in a small home building business, employees develop a knowledge about the organizational culture and policies, and other peers' skills and behaviors necessary to effectively implement BIM (Chen, 2005). Since such knowledge is probably ignored by other BIM experts in the market, retaining employees might be crucial to keep up good business performance.

A tactic to create, retain, and in addition, motivate BIM expertise is to develop specific practices referred to in the literature of small business management as high performance work practices (HPWPs). HPWPs require low financial resources, improve employees' skills and knowledge while decreasing their voluntary turnover, enhance their productivity, and foster their creativity and collaboration, ultimately improving business performance (Way, 2002, Sels et al., 2006; Messersmith & Guthrie, 2010; Mazzei et al., 2016). However, HPWPs might rise employees' work intensity and stress (Ramsay et al., 2000), or increase labor costs due to creating valuable unique employees that need to be compensated for their additional skills, and which could be attracted by other competitors in the market (Sels et al., 2006; Faems et al., 2005).

Based on the work from Way (2002), Sels et al. (2006), and Mazzei et al. (2016), HPWPs to create, retain, and motivate BIM experts to adopt and effectively implement BIM in small home building businesses are described in the following subsections.

3.2.1. Creation of BIM Expertise within the Organization

Hiring: Small home-building organizations can acquire BIM knowledge by hiring employees with BIM explicit or tacit knowledge (Nonaka & Takeuchi, 1995). Explicit knowledge is "academic, or theoretical knowledge or *know-what*" (e.g., BIM definition and overall functioning), is easy to share, and gained through books, education, or training. On the other hand, tacit knowledge is "practical, action-oriented knowledge, or *know-how* based on practice," it is harder to share, mainly acquired through experience, and frequently similar to intuition (Smith, 2001). Individuals with BIM tacit knowledge might be essential to efficiently implement BIM for the first time since their BIM experience in real life projects might be key to avoid naïve errors, and advice, orient and exploit other employees with mostly BIM explicit knowledge.

Training: Small home building businesses can also develop their in-house BIM expertise by training their own employees. Training might only develop employees' BIM explicit or theoretical knowledge. Consequently, initially their performance might not be effective due to missing tacit or experienced-based knowledge allowing them to better understand and interpret their explicit knowledge (Brown & Dugid, 2000). This problem might be mitigated if (1) their training is closely guided and supervised by employees that can provide them with the proper tacit knowledge, or (2)

their training involves real life projects where they can acquire tacit knowledge helping them to adequately understand and interpret their explicit knowledge.

Feedback Practices and Building Trust: Establishing feedback practices to reflect on, discuss, interpret, and assimilate BIM procedures and outcomes (Edmondson, 1999) are crucial to uninterruptedly grow employees' BIM applicable knowledge (Ruiz-Mercader et al., 2006) in a very economical way (Mazzei et al., 2016). For instance, home-builders could bring together their employees on a weekly basis via informal huddles or formal meetings to share their last BIM experiences. In addition, promoting trust among employees results in "psychological safety" by which employees do not fear embarrassment due to potential negative reactions from their colleagues when sharing any type of doubts, insights, comments, or suggestions, thus optimizing feedback practices (Edmondson, 1999). Thus building trust among employees is very important to increase the quality of their learning behavior.

3.2.2. Retention and Motivation of BIM experts

Employee Autonomy: Employees that can make their own choices without being disrupted experiment a greater sense of responsibility of the work performed (Campion et al., 1993), increase their motivation to exploit their skills (Elmuti, 1996), and increase their commitment to stay in the business (Mazzei et al., 2016). Small home building businesses might benefit from endowing individuals with BIM tacit knowledge with autonomy since they can rely on their BIM experience to make appropriate decisions. On the other hand, employees with lower BIM tacit knowledge (e.g., employees recently trained in BIM) should be given less autonomy and work under supervision due to their lower capability to accurately foresee the consequences of their decision-making which could hurt project performance.

Task Flexibility: Refers to the degree to which individuals can do others' tasks, and is a mechanism that can greatly improve team performance (Campion et al., 1993). BIM brings together experts from different disciplines which continuously have access to and learn from each other's task progress and outcomes. Eventually, this leads them to increase their common knowledge which enhances their ability to understand each other's information even if it comes from disciplines other than their own (Alavi & Leidner, 2001; Reagans & McEvily, 2003). Although possessing common knowledge, experts from distinct disciplines might not be able to perform each other's tasks; nevertheless, they can better influence each other's tasks by sharing comments, insights or feedback to effectively integrate their multi-disciplinary task outcomes and develop a consistent BIM model reducing design incompatibilities. Ultimately, the ability to influence other peers' tasks also increases employees' satisfaction and commitment to the business (Way, 2002).

Shared Goals: Shared goals (e.g., employees' share project targeted cost, time, and quality) pushes individuals to adopt a team-oriented behavior (Campion et al. 1993) whereby individuals are more prone to collaborate via open-minded discussions that produce solutions satisfying not only personal but also project or team interests (Tjosvold, 1999). In addition, it is easier that they identify

themselves with the business culture, values or standards (Dyer & Nobeoka, 2000), thus increasing their commitment and willingness to stay in the business.

Performance Recognition: Publicly recognizing employees' noteworthy BIM performance spreads their reputation throughout the business increasing their willingness not only to stay in the organization but also to work harder to keep performing well and preserve their reputation (Reagans & McEvily, 2003).

3.3. Networks for BIM Knowledge Exchange

Small home-builders need to continuously search for, assimilate, and exploit innovative BIM knowledge in the residential market to optimize their BIM performance and sustain competitive advantage (Zander & Kogut, 1995). Although the best way to take advantage of innovative BIM knowledge would be to create a Research and Development department that examines and experiments with it (Cohen & Levinthal, 1990), small home building businesses frequently lack of financial resources to support this type of departments (Mazzei et al., 2016; Sels et al., 2006).

An economical way to gain and effectively exploit innovative BIM knowledge is to develop a knowledge sharing network with other home-builders also utilizing BIM (Cooke & Wills, 1999; Wiklund & Shepherd, 2003; Gronum et al., 2012; Zacca et al., 2015). Frequently, small home-builders are not able to efficiently exploit the innovative knowledge that they possess, thus being prone to be part of a network where they share it with others to figure out how to best exploit it (Van de Vrande et al., 2009). When forming or participating in a BIM knowledge sharing network, home-builders should take into account the following factors:

Weak Connections for Valuable BIM Knowledge Search: Weak connections involve knowledge sharing without excessive detail. These connections are preferred when home builders simply scan new BIM knowledge and rapidly assess its potential value to their business without the need to dig into many details because it would be very costly (Gronum et al., 2012). For instance, such connections might occur in the International Builders' Show where multiple innovative BIM platforms might be presented, and home-builders only have time to scan their overall features and quickly evaluate their adequacy for their business.

Close Connections for Valuable BIM Knowledge Transfer: Once valuable knowledge has been identified, then highly close interactions involving knowledge sharing in deep detail, might be established between two businesses (Gronum et al., 2012). These interactions are very appropriate when knowledge being shared is experience-based or complex (Hansen, 1999). For example, two small home-builders sharing their last experiences utilizing innovative energy analysis tools with a specific BIM software might better share their insights with frequent face-to-face interactions so they can go back and forth rapidly sharing comments, opinions, and ask questions for further clarification.

Types of Embedded BIM Knowledge: Overall, explicit knowledge coming from books, training or education, is easily available to most businesses. Hence tacit knowledge acquired via experience and only found in people's brains, makes the difference and facilitates gaining competitive advantage (Wiklund & Shepherd, 2003). Therefore, home-builders should connect in their networks with other home-builders that can offer, for example, knowledge about how specific BIM software tools can help to enhance residential buildings' sustainability based on their experience.

BIM Network Cohesion: A highly cohesive network means that home-builders to which a small home building business is connected, are also connected among them (Chinowsky et al., 2008). In highly cohesive networks trust among network components arises since reputation is easily spread (Coleman, 1988) strengthening home-builders' interest in collaborating sharing valuable BIM knowledge to acquire or preserve their reputation in the network (Reagans & McEvily, 2003). An easy way to foster high cohesion within a network is, e.g., having monthly or quarterly meetings gathering all network members.

BIM Connections within/across Cities/States: Optimal business performance requires creating connections beyond close communities (Cooke & Wills, 1999) to avoid redundant knowledge and have access to new and diverse knowledge (Ahuja, 2000; Cohen & Levinthal, 1990). Hence small home-builders should consider building connections across their cities or states to have access to diverse and innovative BIM knowledge.

3.4. BIM Impact on Business Performance

Even though BIM tends to improve residential projects' time, cost and quality (Fabris, 2010; Poirier et al., 2015) if properly implemented, it might take up to two years before a small home building business covers expenses from the BIM adoption process (e.g., software, training or hiring) and starts making more profit than with former methods (Miller, 2012). The initial investment to adopt BIM might require small home-builders to request a loan, and later obtain a negative response from banks to finance other profitable investments while they are paying their debts; nonetheless, the fact of having more access to financial credit to comfortably adopt BIM is likely to drive them to successful BIM adoption and profit generation (Tsuruta, 2015). The main drawback for small home-builders requesting loans to adopt BIM would be downturns arising in the residential market (Opler & Titman, 1994), that is, if much credit is invested in BIM and then BIM is not accepted in the residential market as expected. However, it seems that BIM demand in the residential market will keep significantly increasing in the future (NAHB, 2015b).

4. Methods

The purpose of this study is to examine effective adoption of BIM in small home building businesses. So far the authors presented a review of the small business management literature to identify the key practices that can help home-builders create an effective business structure for BIM adoption. The key observations include the following:

- ***Initial BIM Adoption Setup:*** External help and internal support can greatly help to put on the right track the BIM adoption process since the beginning. External help might come from consultancy services (e.g., software selection and coordination with trade partners) or other home builders' practical tips based on their experience. Establishing accurate cost and time objectives for the adoption process seems very difficult;
- ***Creation of BIM experts:*** Home-builders can create BIM experts within their business via hiring or training strategies. The hiring strategy should acquire at least few experts with experience-based BIM knowledge, and the training strategy should train employees in real life projects and be led by experts with BIM experience. Also, feedback practices in BIM projects accompanied with trust engage BIM experts in an economical and high quality BIM learning;
- ***BIM experts retention and motivation:*** Endowing employees with autonomy and task flexibility, imposing shared goals, promoting feedback practices and trust, and publicly recognizing individuals' noteworthy performance whenever possible strengthens the likelihood of retaining and motivating BIM experts;
- ***Networks for key BIM knowledge exchange with other home-builders:*** Small home building businesses can economically obtain relevant and up-to-date BIM knowledge by participating in a network connecting home-builders using BIM. Interactions in the network should be occasional and weak when checking for potentially valuable BIM knowledge (e.g., International Builders' Show), whereas they should be frequent and close when exchanging detailed knowledge. Highly cohesive networks are preferred since they generate trust and easily spread reputation, encouraging network components to share their most valuable BIM knowledge; and
- ***BIM impact on business performance:*** BIM eventually increases both projects' efficiency and business profitability. However, it might take up to two years before greater profit is generated than with previous methods. Also, home-builders may have to request a loan to cover expenses for software and training which might affect their business performance.

To validate the findings above, the authors conducted interviews with three home-builders representing different small size organizations. When searching for home-builders implementing BIM practices within their organizations and willing to participate in this research, the authors observed that the majority of them offer not only construction management but also design services. The underlying reason might be twofold: first, the need of tight collaboration between designers and

constructors to fully exploit BIM practices has led many home-builders to incorporate design services or join design companies; and second, architects are leading BIM adoption in the residential market thus home-builders solely offering construction management without design services are very scant (NAHB, 2014).

The interviewed home-builders herein were found via a Google search of home-builders using BIM. Especially helpful were BIM software websites where home-builders commented their experiences using specific BIM software, and online construction magazines such as "Professional Builder" which offers a number of articles interviewing home-builders using BIM. The interviews followed the questionnaire shown in the Appendix, each took an average of 25 minutes, and were recorded and coded for research purposes. Later, a qualitative analysis was performed whereby home-builders' responses to the interview questionnaire were examined to verify and gain a clearer understanding of the literature review observations above.

5. Results and Discussion

The home-builders that participated in the study interviews perform both design and construction activities in their residential projects. The three home-builders are from different areas of the US including the West, Midwest, and Southeast regions. On average, they have 20 years of experience in residential construction and all of them currently use BIM for 100% of their projects. Two of them have around 50 employees, develop more than 200 residential projects per year, use Revit and Vertex BD, and have 5 and 13 years of BIM experience. The other one has 6 employees, develops less than 5 projects per year, utilizes Revit, and accumulates 14 years of BIM experience. Only one of them uses mobile devices (e.g., tablets and smartphones) with BIM applications on site. The three home-builders will be referred to from now on as home-builders A, B, and C. Their responses to the questionnaire in the Appendix are analyzed in the following sub-sections to enhance our understanding of the literature review observations. In addition, each sub-section includes some observations summarizing the main points.

5.1. Initial BIM Adoption Setup

When they made the decision to adopt BIM, all our interviewed home-builders immediately applied BIM for 100% of their projects. Making such a drastic change was not easy but the factors below were critical to effectively implement BIM since beginning.

External Help: To ensure successful BIM adoption, home-builder A utilized external consultants' services, whereas home-builder B a coach that would work with them one week per month during six months. Home-builder A said that *"We had some outside help to get us to do everything in BIM, it was literally the flip of a switch, and we just put the hard work in and the effort to make the switch. We went to BIM all the way for all projects… but we were not equipped internally to absorb everything in-house about BIM. There is a company in Indiana called CG visions that gave us that help."*

On the other hand, home-builder C did not require external help because he previously worked with BIM in another company and already had the experience to confidently adopt BIM. Possessing internal BIM knowledge is crucial for a business to effectively understand and adopt BIM, since human beings learn better new knowledge if they have stored related knowledge in their brains (Reagans & McEvily, 2003).

Internal Support: Employees' positive attitudes towards learning innovative software and collaboration processes brought up by BIM, make BIM adoption more effective in the business (Cohen & Bailey, 1997). All interviewees paid special attention to this as a key factor of internal support to adopt BIM: Home-builder A said that "*We look for people that love what they do and want to learn. If you have these things they will collaborate, it will be natural,"* home-builder B pointed that "*I have been very lucky I didn't have one person that didn't enjoy what he was doing,"* and home-builder C "*I want employees that have an internal desire to grow."*

Observation 1: *External* ***coaching*** *or* ***consultancy*** *services are good strategies to initiate the BIM adoption process, especially if there is a lack of internal BIM expertise. In addition, employees' positive attitudes (e.g., excitement with innovations or desire to grow) facilitate BIM adoption.*

Time and Cost Objectives: None of the interviewees claimed to be able to set up accurate cost and time estimates to switch from their traditional methods and adopt BIM. Although the cost for software is easy to estimate, they were not able initially to predict an accurate cost and schedule for creating BIM experts and other variables. Home-builder B commented that *"It was improvising a little bit, but we had a roadmap, and had short-term goals and stretch goals,"* and home-builder A asserted that *"we learned along the way, you kind of plug and play… and this doesn't work… and you fix this… and do that… and you figure out better ways. So some estimates were high and some were low, but we were able to adjust internally the things that needed to be adjusted in order to get the outcomes that we wanted."* Home-builder C emphasized that he firmly believed that the extra money spent to adopt BIM would come back later with greater benefits: "*The cost on training… I always thought as the amount of time that takes to train somebody would be offset by the time that would be saved by having BIM instead of having to redraw and rework two dimensional drawings. So I didn't have a technical spreadsheet of exactly how much training would cost, but I just knew that investing in BIM would be in the end productive and valuable."*

If Time/Cost Estimates to Plan BIM Adoption is Tough… Why Taking the Risk? Home-builders recognized that adopting BIM was risky to some degree but claimed that it was absolutely worth it. Home-builder B adopted BIM because he was fascinated with BIM productivity and accuracy outcomes. The other two home-builders saw BIM as the future in the residential construction market. Home-builder A shared that *"We chose to go to BIM because it is the future, a lot of other home-builders do not upgrade because of the cost and the fear of knowledge and learning, but that is our success. If you don't keep up with the times, you will be behind times and therefore you cannot succeed in the world that is progressing."* Similarly, home-builder C stated that *"If you don't pursue BIM, you're gonna be left in the dust because it's just the way it has to be… If you get stuck in one particular mindset or one particular software, no matter what field you're in, you are going to be left behind by the next technology."* Overall, it seems that our interviewed home-builders impregnate their small business with an entrepreneurial orientation which involves a "willingness to innovate to rejuvenate market offerings, take risks to try out new and uncertain products, services, and markets, and be more proactive than competitors toward new marketplace opportunities" (Wiklund & Shepherd, 2005).

Observation 2: *BIM adoption might be* ***risky****, and estimating its cost and time is very difficult. However, home-builders believe that the risk is worth it due to first, BIM boosting employees'* ***productivity****, and second, the strong belief that BIM is the* ***future*** *in the residential market.*

5.2. Creation of BIM Experts

Hiring versus Training: To create BIM experts via either hiring or training within their business, home-builders A, B, and C have different approaches. Home-builder A prefers in-house training and said that *"I found that it is best that I train… Rather than hiring BIM experts I look for people that has an understanding of 3D software and then I train them."*

Home-builder B combines hiring with training: *"We are hiring a combination of people, some are experts at it and some other people that want to get in it but don't have prior BIM or Revit experience. At the beginning I temporarily hired an expert that trained all the employees together for 6 months, he would come once a month for one week… but now I have some people with BIM experience that teach the others, not only in BIM software but also in BIM collaboration processes."*

On the other hand, home-builder C prefers hiring BIM experts: *"I feel that I don't have enough time to train people, now I look for people who have experience in BIM. Also, now BIM and Revit are more prevalent, so it's easier to find people that have experience, not super easy though."* However, he asserted that would hire people without BIM experience and train them *"as long as they are technically experts [in 3D software] and have a BIM foundation."*

Effective Training: In terms of how to effectively train, home-builders A and B consider important training in real life projects. Home-builder A claimed that *"I first train employees on a BIM tutorial to allow them to understand BIM capabilities in our internal system, then I train them in an internal project."* And home-builder B asserted that when his employees are trained in BIM "*they actually build a home, using our projects, our whole concepts of floor plans, anything is done real time. I always use the analogy that you need some real bullets in your gun when you are testing software."*

Home-builder C observed that training is optimized when employees have a strong desire to learn and are excited about BIM: *"The cost of training is pretty high, that's why it is important to know that they are excited about BIM and technology, because they need to be studying and trying it at home as well. It's not just come in and try to figure out during the work day, they need to practice it at home and have an internal desire to grow."*

Training Cost and Time: Training cost and time are burdens that home-builders are willing to assume because they ultimately pay off. Home-builder A said that *"Training takes between 3 and 4 weeks before the employees are productive and become an asset to me… Training costs between $100 and $110 per hour… It's expensive up front, but the yield on the back is very good."* Home-builder C commented that *"training is costly, between $1,500 and $2,000 per month at least. That's why it is better to hire people with a BIM foundation. The learning curve is steep in the beginning and then the steep is off... So in the beginning the steep curve could be 3 weeks which are stressful and with hard learning… afterwards it becomes easier."*

Hiring Cost: Although new hires with BIM experience do not require training, they typically have a higher salary that compensate their valuable expertise. Home-builder B said that "*BIM employees*

are paid more based on experience… Sometimes they may be making a certain pay scale and it may stay consistent until a different skill set has been reached." Likewise, home-builder C highlighted that *"if you hire someone with BIM expertise that you don't need to train, this new hire would have a higher salary than another new hire that doesn't have BIM expertise and you need to train."*

Observation 3: *Either hiring or training BIM experts, or a combination of both are effective strategies to create BIM expertise. The* ***hiring*** *strategy should not only capture employees with theoretical BIM knowledge but also with BIM experience since they have practical tips to avoid naïve errors that might hurt projects' performance. New hires with BIM expertise avoid training cost and time but require a higher salary than trained employees. The* ***training*** *strategy should involve real life projects and be led by experts with BIM experience.*

Feedback Practices and Trust: Home-builder A admitted having formal feedback practices to support continuous BIM learning: *"Our BIM experts manage their own schedules and jobs but they do collaborate with each other. If they have questions or issues, we have a weekly meeting where we discuss issues and BIM development, and we incorporate new ideas if they are fruitful to our BIM environment."*

On the other hand, home-builders B and C promote informal practices naturally emerging from collaboration. For instance, home-builder B indicated that *"Our BIM experts work together, and learn from each other about the software, company information flows, and company's products."* In addition, all home-builders observed that high levels of trust among their employees facilitate collaboration and subsequent learning.

Observation 4: *Feedback practices (e.g., formal weekly meetings where employees share and discuss their last BIM experiences), economically* ***grow*** *employees' BIM knowledge, and* ***spread*** *and* ***exploit*** *valuable* ***BIM knowledge*** *created within a business.*

5.3. Retention and Motivation of BIM experts

Employees' Autonomy: Home-builders A and B give very high levels of autonomy to their BIM experts, thus they do not interfere in their design solutions or construction methods as long as they have enough experience and respect the company's culture or standards. Home-builder A claimed "*If there is someone brand new, I'm going to be very watchful… but after that person has been here for a while and knows enough, then their autonomy in scale from 1 to 5 would be more than 4.5."*

Similarly, home-builder B said that *"We want people to take ownership of BIM projects, so on a scale from 1 to 5, I would say they have 5 of autonomy, but the rules of the game are our company and architectural standards, and guidelines for planning,"* and also highlighted that "*Our group*

of BIM experts collaborate with each other but only one of them becomes the project manager of each project and owns the job from conception to putting the home on site."

On the other hand, home-builder C prefers to tightly supervise designers' task outcomes to make sure they meet the company's standards.

Task Flexibility: All home-builders agreed with the importance of task flexibility, that is, having experts from different building systems (e.g., architectural, structural, or HVAC) influencing or giving input into each other's tasks. Moreover, they talked about it as something naturally arising in BIM processes due to close collaboration.

Home-builder A pointed that "*We have to check the heart of the structural engineer plans and have them work with our software to incorporate what they are looking for into the design."* Home-builder B said that *"We are doing a lot of work where we are designing the home structure along with the HVAC system since we want to have better airflow, travel, path, a better ease of placing, so collaboration has escalated a lot."* And home-builder C asserted that *"We don't want to have any issues in the construction phase, so we try hard to hire structural or mechanical engineers who use BIM and Revit… that way we can coordinate their models with the architectural model, it's easier."*

However, close collaboration allowing task flexibility in BIM projects is not always easy, as home-builder A commented, *"The industry as a whole is not up to date on technology or 3D software so some of the outside sources that we currently use don't allow us to have a full integration in our system… But that would be something that we would love to do."*

Shared Goals: All home-builders claimed that goal sharing is beneficial. Imposing shared project goals in terms of project targeted cost, time, and quality, promotes tight collaboration in BIM projects because employees ensure that their task outcomes are compatible and contributing to project goals. Home-builder C pointed that goal sharing is beneficial because *"Once the model is being created, the designers and technicians make changes together understanding how, for example, the elevations, roofs or specific sections are affected when you move a wall. The design is much more coordinated."*

Public Recognition: Only home-builders A and B claimed formally and publicly recognize BIM experts with noteworthy performance. Home-builder A highlighted that *"We have an internal BIM competition, here in our office, and the whole company is able to be involved. There is a rating system for three BIM aspects: design, collaboration processes, and construction field readability. Employees get graded from all their peers… and at the end of that, there is a tangible gift which is also some sort of recognition that is company-wide."*

Similarly, but not strictly focusing on BIM-related performance, home-builder B stated that *"We have seven core values in our organization and every month you can nominate any employee from the company for a particular core value. So if you see somebody or hear somebody or are told someone did something well in a particular core value for a specific month you nominate that*

person, and that nomination is sent by email throughout the organization, and displayed in our inter-office set of TVs which are running updates all day long."

BIM Experts Retention: Home-builders A and B asserted that so far they did not lose any BIM expert that was either hired or trained. On the other hand, home-builder C admitted that his BIM experts typically stay for three or four years and then go to other competitors: *"I'd like to retain my employees though. We do a lot of retail and high residential… they go to other competitors because they're looking for different type of projects."*

Home-builders A and B are very similar in that they strongly implement all the practices described above which might greatly help them to motivate and retain all their BIM experts. On the other hand, home-builder C places weaker emphasis in providing employees with higher levels of autonomy or public recognition for noteworthy performance, which, according to the literature review performed earlier, are vital to preserve BIM experts' commitment to stay in the business and perform well to keep their reputation.

Observation 5: *Home-builders are more likely to* ***retain and motivate*** *their BIM experts if they offer high levels of* ***autonomy*** *to employees with enough BIM experience, facilitate* ***task flexibility*** *via tight collaboration, ensure that all BIM experts understand and* ***share projects' goals*** *(e.g., targeted cost, time and quality), and set up, if possible, a system to formally and publicly* ***recognize*** *BIM experts' noteworthy performance.*

5.4. Networks for Key BIM Knowledge Exchange with Other Home-Builders

Connections with Other Home-Builders: Home-builder B shared that developing a network is important because *"If I get stumped, I hope that I can have a connection that I can reach out and say, would you spend a few minutes talking to me or one of my team members about a BIM issue?"*

Home-builder C revealed that he has a well-established and solid network bringing together different BIM users and not just home-builders to share BIM knowledge: *"I'm a part of a BIM user group here at [city name] and there are engineers, builders, and architects who use BIM. We collaborate and discuss BIM issues."*

Likewise, home-builder B described a network that is not limited to solely home-builders but also other types of BIM users: *"I try very hard to do networking either via Linkedin, or via software providers such as Autodesk, CG Visions, or BuilderMT. Also, our company is part of a group of home-builders of the NAHB, and we try to get knowledge from them as well."* Furthermore, he emphasized the convenience of connecting to commercial general contractors *"We have a lot of big commercial general contractors here in town that have done an awesome job with BIM, and virtual design and construction. We, as small home-builders compared to the size of projects that they do, we can look up to them and ask them questions."*

On the other hand, home-builder A pointed that he does not take part in any network because there are very few BIM competitors in his city.

Observation 6: *Small home-builders can easily and economically gain valuable BIM knowledge from* ***knowledge sharing networks*** *with other BIM users. These networks should embrace not only other small home-builders but also other* ***BIM users*** *such as architects, engineers, or commercial general contractors.*

Weak / Strong Connections for BIM Knowledge Search / Exchange: Home-builder C claimed that he and the BIM users in his network are closely connected since they meet *"once a month in person. We meet face-to-face. It's a formal meeting in downtown [city name] and we meet with pizza and beer."*

Home-builder B pointed that he interacted very frequently with some BIM users in his network when started BIM adoption; however, now his interactions are overall weak because of the scarcity of BIM users in his city/state: *"I exchange knowledge once every 6 months because there are very few BIM home-builders. In the beginning, during the training, there is a lot of collaboration with your software vendor, then you make questions after the initial training to follow up. But after a while, you kind of just dig in and keep plugging along."*

Observation 7: ***Monthly close interactions*** *(e.g., formal face-to-face meetings with PowerPoint presentation) might suffice to take advantage of valuable BIM knowledge possessed by other BIM users in the network. However, when adopting BIM for the first time, the learning process might require* ***daily or weekly interactions*** *with other BIM users due to multiple doubts or problems arising. Having BIM experts in the network that can be* ***reached out at any moment*** *might be very helpful to quickly address specific BIM issues that unexpectedly arise.*

Types of Embedded BIM Knowledge: Home-builder C mentions that the BIM users in his network share BIM knowledge related to software techniques, tools, workflows, uses in the field, and solutions to specific issues based on experience: *"We discuss new techniques in the BIM software, how to use BIM in the field in construction, and specific issues… If we're having a technical issue, usually if you talk to other people that have experience in that in using BIM, often times they know how to fix it… Some of them have interesting BIM tools that share with us free of fees. Also, in our meetings usually a couple of the guys are presenting about different features or the newest things that they have learned such as how to optimize workflows."*

Home-builder B coincides with C in that he shares BIM solutions to specific design or construction issues based on experience in his network. However, he also exchanges knowledge related to BIM implementation at the business rather than at the project level such as planned portfolio, or number of projects and employees: *"We discuss processes and how your process works compared to another, talk about your planned portfolio, how you manage it and keep it current… There is a lot of discussion about BIM processes, people, and number of both residential projects and employees. If you have a specific problem, a challenge that you cannot figure out, then you reach out a specific home-builder and ask specific questions since maybe they had the same problem and came up with a solution."*

Although home-builder A is not involved in a knowledge sharing network, he admitted that other home-builders are interested in getting knowledge regarding the BIM software system within his company: *"We have worked with developers and we have an integrated system that ties five software together… So we have a proprietary system right now that is very good. Since five years we've been BIM technology leaders and there are other companies that are coming on board with what we are doing, we don't look outward but other people look inward."*

Observation 8: *The valuable* ***BIM knowledge*** *shared in networks is mostly* ***experience-based*** *and can be either* ***business-related*** *(e.g., planned portfolio and its management, or the number of both residential projects and employees) or* ***project-related*** *(e.g., BIM software techniques, tools, workflows, uses in the field during the construction phase, or solutions to specific issues).*

Network Cohesion: Only home-builder C has a highly cohesive network since all the BIM users in his network attend the same meeting monthly; therefore, all BIM users with which home-builder C interacts, also interact among them. Home-builder C commented that *"in this network I perceive that all BIM users are motivated to share their best BIM knowledge, there is a strong trust between us. Also, there are some BIM users that have better reputation and share more valuable knowledge than others."* Therefore, it seems that highly cohesive networks where members interact closely face-to-face facilitate trust generation and reputation, facilitating valuable BIM knowledge spillover.

Observation 9: ***Highly cohesive networks*** *(i.e., those where members to which a home-builder is connected are also connected among them) promote* ***trust*** *generation and* ***reputation*** *spread, pushing network members share their* ***best valuable BIM knowledge****. Highly cohesive networks can be created, for example, via monthly meetings bringing together all network members.*

Connections within/across Cities/States: Home-builder B said that he searches for home-builders with BIM knowledge out of his state primarily because he cannot find them closer. On the other hand, home-builder C's network includes BIM users from different cities but all of them within the same state. Since BIM is still relatively new in the residential construction market, it is likely that home-builders connecting with other BIM users in the same state are still sharing on-redundant and innovative knowledge. Thus they do not need yet to make an extra effort to establish connections across states to find new innovative knowledge. In addition, connections across states are typically harder to maintain because of geographical distance, hence, home-builders would only pursue them if they are critical.

Observation 10: *In the beginning, BIM knowledge sharing networks embracing only BIM users within the* ***same state*** *might be enough to provide BIM innovative knowledge. However, when knowledge spread in the network starts to be* ***redundant****, expanding connections* ***across states****, although might be harder to maintain, might be key to find* ***innovative*** *BIM knowledge.*

5.5. BIM Impact on Business Performance

Home-builders highlighted that BIM enormously increases employees' productivity resulting in higher business profitability in the short term. They shared very diverse BIM factors directly influencing productivity mainly including improved information flows and coordination, facility to replicate building pieces and manage a large amount of design options, employees' role expansion to develop more tasks simultaneously, and facility to detect design errors. Moreover, any home-builder need to request a loan to finance BIM software and training

Home-builder A focused on software influence on coordination and information management: "*BIM has allowed us to work seamlessly through multiple software. So internally has helped us in a lot of ways: in the flow of information to the field, we can replicate building pieces and parts with no cost, we can manage these items, and we can plug and play… Also, there is something called option management tool to effectively manage all our design options in our BIM software that has been very helpful in our industry."* Similarly, home-builder C asserted that *"The BIM technology allows you to have less coordination issues in the field and during the construction phase. So even it takes longer to model an element, that extra time spent modeling that element will come back to you in savings during construction… In addition, if they [employees] build a 3D model, often times they'll see the problems easier on the screen with BIM than with 2 dimensional lines for floor plans and then separate two dimensional lines for elevations."*

Additionally, home-builder B complemented what the other interviewees said bringing up employees' improved roles: *"So the roles are far expanded and upgraded than just a person drafting lines in a piece of paper or on the screen. They are digitally building a home, and they are digitally accountable for the accuracy of the structure and the building materials. So I think that makes a better employee, makes a more productive employee. Another aspect is that one person is now doing the modeling and takeoff versus having two people for each of these tasks."*

Observation 11: *BIM greatly improves* ***employees' productivity*** *and* ***business profitability*** *in the short term due to improved information flows and coordination, facility to replicate building pieces and manage a large amount of design options, employees' role expansion to develop more tasks simultaneously, and facility to detect design errors.*

6. Summary and Conclusions

The purpose of this study is to examine business practices that can help small home-building organizations to effectively adopt and implement BIM. In summary, these practices include the following:

✓ ***Initial BIM Adoption Setup***

- **External coaching** and **consultancy services** if there is lack of internal BIM expertise, and employees' **positive attitudes** (e.g., excitement with innovations or desire to grow) are key factors to ensure that the BIM adoption process takes the adequate path since the beginning.
- Currently, **cost and time estimates** to adopt BIM in small home-building businesses might not be precise, thus making BIM adoption risky to some degree. However, home-builders believe that taking this risk is worth it because BIM drastically increases employees' **productivity** and will probably be a key factor in the future to sustain competitive advantage in the residential construction market.

✓ ***Creation of BIM expertise:***

- Either hiring or training BIM experts, or a combination of both are effective strategies for BIM adoption.
- The **hiring** strategy should capture employees with experience-based BIM knowledge since they have valuable practical tips to avoid naïve errors, and guide new hires or trained employees with mostly theoretical BIM knowledge.
- The **training** strategy is optimized if employees are excited about BIM, trained in real life projects, and led by experts with BIM experience.
- New hires with BIM expertise avoid training cost and time but require a **higher salary** than employees trained in BIM.
- Regularly promoting **feedback practices** (e.g., weekly face-to-face meetings) where employees share, discuss, interpret, or search for BIM knowledge is an economical and effective way to grow employees' BIM expertise, and spread and exploit valuable BIM knowledge created within a business. The quality of employees' learning in feedback practices is optimized if there is **trust** among them.

✓ ***Retention and motivation of BIM experts:***

- BIM experts with enough experience should possess high levels of **autonomy**, that is, be able to make important decisions without managers' interference.
- Collaboration in BIM projects should be tight enough to promote BIM experts' **task flexibility**, that is, experts in different building disciplines (e.g., architectural, structural, or

mechanical systems) should be able to learn from each other's disciplines and give input into each other's tasks.

- Managers should ensure that all BIM experts understand and **share projects' goals** (e.g., targeted cost, time and quality) since they will be prone to participate in open minded discussions facilitating an integrated design free of errors.
- Formally establishing a system to **publicly recognize** BIM experts' noteworthy performance not only increases their commitment to stay in the business but also motivates them to keep performing well to preserve their reputation.

✓ ***BIM knowledge sharing networks:***

- Small home-builders can **easily and economically gain valuable BIM knowledge** if they create a network connecting diverse BIM users. These networks should not only include home-builders but also other types of **BIM users** such as architects, engineers, or commercial general contractors.
- BIM knowledge sharing networks can provide both **business-related** (e.g., planned portfolio and its management, or number of both residential projects and employees) **and project-related BIM knowledge** (e.g., software techniques, tools, workflows, uses in the field during the construction phase, and solutions to specific issues) based on **experience**.
- **Monthly interactions** might be enough to take advantage of BIM users' knowledge within the network as long as the interactions are **close (e.g., formal face-to-face meetings with PowerPoint presentations)**. However, when adopting BIM for the **first time**, the learning process might require **daily or weekly interactions** due to multiple doubts or problems arising. Also, connections that can be reached out at any moment are helpful to address BIM issues unexpectedly arising.
- Highly cohesive networks, that is, those where members to which a home-builder is connected are also connected among them, promote **trust** generation and **reputation** spread, and predispose all network members to share their **best valuable BIM knowledge**. For instance, monthly meetings bringing together all network members would easily result in a high cohesive network.
- Initially, BIM knowledge sharing networks where all members belong to the **same city or state** might provide innovative BIM knowledge. However, over time, knowledge circulating in the network might become **redundant**, and connections **across states** might be needed to search and obtain **innovative BIM knowledge**.

Furthermore, regarding BIM impact on small home building businesses, the researchers observed the following:

- BIM improves employees' productivity, subsequently incrementing **business profitability** in the **short term**. In addition, BIM will be a key tool in the short term for small-home builders to be **competitive** in the residential market.

- Some of the main factors enhancing **productivity** comprise improved information flows and coordination, facility to replicate building pieces and manage a large amount of design options, employees' role expansion to develop more tasks simultaneously, and facility to detect design errors.

The practices described above are applicable to home-builders with either both, design and construction services, or only the latter. Although not all observations in this study are applicable for the many sole practitioners in the residential building market (NAHB, 2015c), they can greatly benefit from those regarding an appropriate initial BIM adoption set up, and participation in networks to gain BIM knowledge.

This study contributes to the body of knowledge by depicting the key business practices in small home building businesses to support effective adoption and implementation of BIM in residential projects. It was discussed herein hiring and training strategies to create BIM experts; however, most colleges in the US are starting to incorporate BIM courses in their construction management and architectural programs. Therefore, soon it will be easier to hire newcomers with a robust BIM foundation and costly training will gradually disappear.

BIM software constitutes the last technological breakthrough in the architectural, engineering and construction industry. As with other technologies such as smartphones that abruptly emerged, and rapidly and inexorably spread, BIM software will be adopted by most home-builders in the following five years. Therefore, home-builders need to understand and start implementing the key business practices that will allow them to adopt and effectively implement BIM software and collaborative processes to gain and sustain competitive advantage in the residential market.

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Appendix

Interview questionnaire:

1. ***General information:***
   - What type of projects does your business perform?
   - What is your experience in residential construction (years)? How long have you been using BIM? In what areas of the US do you usually develop your projects?
   - What is your business annual revenue and number of residential projects?
   - How many employees do you have in your business?
   - What BIM software and hardware do you use?
2. ***Initial BIM Adoption Setup:***
   - ***Key External/Internal Factors:*** What are the key external (e.g., consultancy services, external coaching, client demand in the market) and internal factors (e.g., employees' attitudes, collaboration culture) to adopt BIM?
   - ***Main Objectives for Effective BIM Adoption:*** When you adopted BIM, what were your main objectives (e.g., how many BIM projects initially, when to use BIM for all projects) and budgets (e.g., cost for training-hiring-software)?
   - ***Actual vs Planned Performance Tracking:*** Do you keep track of actual vs planned performance (i.e., objectives/budget in the previous question) to assess BIM adoption?
3. ***HPWPs for the Creation, retention and motivation of BIM experts:***
   - ***Hiring:*** When you decided to adopt BIM, did you hire BIM experts? What hiring criteria did you follow to get BIM experts (e.g., experience)? Did they require a higher salary?
   - ***Training:*** When you decided to adopt BIM, did you train your own employees? How many employees? How much did it cost? How long? Has their salary increased?
   - ***Hiring-Training Combination:*** Is it better to hire BIM experts or to train your own employees? Or a combination of both (e.g., hired BIM expert leading and advising trained employees?
   - ***Employee Autonomy:*** To what extent do your employees have autonomy in BIM projects, that is, they can make important decisions without you interfering (i.e., scale from 1 to 5)?
   - ***Goals, and decision-making power sharing:*** Do you and your employees share goals, or power in decision-making in BIM projects?

- ***Task Flexibility:*** Do your employees enjoy to some extent task flexibility? E.g., since BIM requires tight collaboration among all parties to develop a 3D model, would electrical engineers be able to give their input into the mechanical system (and vice versa)?
- ***Feedback Practices and Trust:*** Do you implement feedback practices (e.g., opportunity for employees to interact while they work together to exchange feedback and learn)? In a scale from 1 to 5, how much trust there is among your employees?
- ***Public Recognition:*** Do you publicly recognize specific employees' noteworthy performance?
- ***Business Capacity to Retain BIM Experts:*** How is the voluntary turnover rate from your BIM experts (either hired with BIM expertise or trained in BIM) in your business (%)?

4. ***Network development to absorb external BIM knowledge:***
   - ***BIM Knowledge Sharing Networks and Connections' Strength:*** Do you keep connected to other small home-builders to exchange BIM knowledge? How frequently do you share BIM knowledge with them (e.g., occasionally with some of them to check if there is anything interesting, or very often to share specific BIM knowledge)? How do you typically share this knowledge (e.g., face-to-face, phone call)? In what context (e.g., informal meetings, lunch, conferences, builders' show)?
   - ***BIM Knowledge Searched in Networks:*** What type of BIM knowledge do you usually search when connecting with other small home-builders (e.g., BIM experience in past projects, software capabilities, client concerns/demand, BIM library components)?
   - ***BIM Knowledge Sharing Network Features:*** How wide are your connections with other home-builders for BIM knowledge sharing (e.g., within/across US cities/states)?
5. ***BIM impact on business performance. Which are the key business parameters at the business level affected by BIM.***
   - ***Performance Factors:*** What business performance factors have been significantly impacted by BIM adoption? E.g., subjective factors such as personal, economic, sustainable, or enduring; or objective ones such as business profitability and growth.
   - ***Initial Investment:*** Did the initial investment for BIM adoption require you to request a loan? How did this affect your business performance (e.g., not getting loans for other profitable projects)?
6. ***What BIM uses would you highlight that help you to improve project efficiency with respect to traditional methods?***