Integration of Well-defined BIM External Module with CAD via Associative Feature Templates

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ABSTRACT

Currently, building information modeling (BIM) is widely applied as a powerful tool to model and manage buildings and infrastructure. However, the BIM system only provides engineers with an overall view of the building, and the information generated cannot be consistently transferred to modular manufacturers who use computer-aided design (CAD) system as their major design tool. As a result, redundant communication is needed to discuss customer requirement and order details. In addition, human errors pose another barrier for information interoperability. In order to conquer this deficiency, a feature-based approach is applied to integrate BIM with CAD via an external module developed. Based on the developed module, the case study of a slider window is conducted, which proves the effectiveness of the proposed method and its potential impact on industrial practice.

Keywords: CAD, BIM, feature integration, associative feature
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1 INTRODUCTION

Nowadays, building information modeling (BIM) has become an irreplaceable tool in the architecture, engineering, and construction (AEC) industry. BIM software can provide architecture, engineering, and construction professionals an intelligent 3D model-based insight into the project. It can detect failure, conflict, interference and collision of the design, which can save the project time and overall cost with a more efficient plan, design, and construction capability. Compared with traditional computer-aided design (CAD) software (for example AutoCAD), BIM software can estimate the cost of the entire project and provide downstream stakeholders with product data, environment data, and lifecycle data [2]. BIM system helps professionals from the initial design stage till the final construction phase. Specifically, engineers and architects first prepare the schematic architectural model (overall building form) for the project owners. After any changes to the design requested by the owners are completed, the consensus design is ready to enter the detailed design model (e.g. with the color of an interior door). The 'detailed design and documentation' [10] is the 3rd level of details in the BIM system and it provides enough details to get the components ready for fabrication and manufacturing. Such kind of BIM model contains the precise dimensions, features of the component, and quantities and customization information. However, some more in-depth information such as a window's cross-section profile could still be missing. In fact, the BIM software only shows a 3D view of the items inside of a building but not the details for manufacturing, which will result in the lack of information during the manufacturing process after BIM documents are sent to factories. R&D engineers in manufacturing companies have to work with CAD software or even computer-aided engineering (CAE) software to model and analyze the products used in the building, and also have to synchronize the information between independent software, which drags down the efficiency dramatically. At present, there is a variety of commercial BIM software such as Autodesk Revit, BIMx, ArchiCAD etc., and CAD software such as NX, SolidWorks, Pro/Engineer etc. However, most of those tools just focus on either BIM or CAD and lack the ability to handle other aspects of the product information. Therefore, integrating BIM and CAD will not only play a key role in achieving digitalized building component manufacturing without an information granularity problem, but also enhance the ability of those manufacturing companies to rapidly respond to any design changes required by customers. In this paper, the BIM/CAD associative feature concept is proposed to manage geometric and semantic associations between BIM and CAD based on the associative feature regime brought forward by Ma and Tong [27]. In addition, the authors will introduce the application of a data sharing mechanism between BIM and CAD to validate the information consistency which used to be an issue before. By using the proposed feature concept, a BIM/CAD integration framework is developed, which can provide both forward and reverse integration [21], generate necessary manufacturing information, e.g. bill of material (BOM) for manufacturers, and support order driven production development. A case study of the design of a slider window using the prototyped BIM/CAD integration system will be shown to verify the effectiveness. The conclusion of this study comes as follows.

Nomenclature			
Temp	Temperature	**Loc**	Location
Cg	Color of Glass	**Trt**	Type of Roller Track
Ts	Type of Sash	**Tf**	Type of Frame
W	Rough Opening Width	**H**	Rough Opening Height
Hs	Sash left and right length	**Ws**	Sash top and bottom length
Pfw	Top and bottom frame part	**Pfh**	Left and right frame part
Pm	Mullion part	**Psh**	Left and right sash part
Psw	Top and bottom sash part	**Assem**	Assembly

Table 1: Nomenclature of the article.

2 LITERATURE REVIEW

Building information modeling (BIM) has become one of the most promising and effective technology in architecture, engineering, and construction (AEC) industry [3]. It is defined by the international standard as "a way to map and describe the information processes across the life cycle of construction works" [34]. After the early 80s, engineers and architects inside AEC industries shifted from hand drawing to CAD after the launch of 2D CAD software such as AutoCAD. By using 2D CAD software, drawings could be done more accurately and efficiently by using the computer compared to traditional hand drawing. Building information modeling was introduced to the industry to create models that "more closely represent the way buildings go together" [30]. BIM is now widely used in AEC industry with focuses on preplanning, design, scheduling, and construction. However its focus has also recently expanded to facility management [17,36], cost managing [32] , accident preventing [16], and etc. Recently, the integration of BIM and Geographic Information system (GIS) has become an important area of research because BIM and GIS help engineers to visualize buildings before construction through a 3D virtual model with analysis of geographic information [15,7].

BuildingSMART has developed standardized Industry Foundation Class (IFC) to accommodate information interoperability between AEC software [18]. It was designed to provide a standard building information language and to facilitate data transfer between BIM and other civil related software required by different stakeholders through the project [33]. However, some researchers [35,28] believe that despite using the open data exchange format such as IFC, data sharing between different architecture platforms is still a difficult task, which needs to be simplified. Therefore, to keep the data consistency and interoperability between BIM and manufacturing, other methods have to be used rather than just the traditional file transfer.

Back to the late 70s, the feature concept was introduced into computer-aided technologies which usually consist of CAD, CAE, computer-aided manufacture (CAM) and etc. for product lifecycle modeling [14,27,31]. In the traditional paradigm, the features were mainly used to represent low level geometrical shapes such as form features [5,29], like slot, hole, boss, and chamfer, used for product development [1]. Later, features were developed to interact between multiple platforms for data consistency through feature recognition [8]. For example, Mark and David [13] linked CAD and CAM by developing a method which could extract manufacture information from the form feature and arrange it in a high-level data structure for manufacturing process planning. Further, features can be categorized according to their various applications and engineering intents, such as machining feature, assembly feature, CAE feature, component feature, material feature, and functional feature. To achieve parametric configuration modeling, Ma et al. [25] used standard component library to represent all design object that has generic nature and can be expanded to include most mechanical component in a collaborative environment. The design of feature-object-based mechanical assembly library was introduced by Ma et al. [28] to enable different types and configurations of assemblies included in a common library framework.

Besides those established feature concepts, the associative feature proposed by Ma and Tong [21] can bridge the gap between knowledge-oriented tools and CAD applications for intelligent product development in which the information consistency should be well maintained. Due to this characteristic, associative features have been employed in many applications. Ma and Bong [23] used associated features to systematically explore collaborative engineering with reference to product lifecycle management (PLM). They defined a fine grain information access to support intelligent design and manufacturing in which the associative features were used to link engineering knowledge and product geometry. Xie and Ma [37] used associative features to solve the information interoperability issue and explored the universality of product and process model between chemical process engineering and mechanical design domains. Their developed feature model was designed to represent characteristics of multi-domain entities, while inter-domain sharing was supported by data mapping. Au and Ma [1] reported the application of garment pattern by using the associative feature. The virtual design features associated with parametric mannequins could solve the mass customization problems between the true measure of customers and regular size of cloth in the market. The associative optimization feature concept was proposed by Liu *et al*. [22] to complete information transfer between CAD and the structural optimization module. Cheng and Ma [6] proposed a new feature-based CAD modeling method to guide designers building CAD models that are valid to represent functional design considerations based on the functional feature and the associative feature. The associative assembly design feature proposed by Ma *et al*. [24] established the associations between part geometry and intermediate geometry which were used to define a part. Li *et al*. [20] proposed the associative CAE boundary feature to interpret the information in the CAD model and convert it into mesh and boundary conditions in CAE model. Incorporating fluid physics features and dynamic physics features, CAE boundary features also contribute to the feature model of an analysis view in multiple-view product development [19].

Based on the literatures, it can be concluded that the associative feature regime should be the right approach to integrate BIM and CAD applications. To the best of the authors' knowledge, there is no related research on associative feature-based modeling between BIM and CAD. Hence, it is significant to apply associative features to tackle the problems in BIM/CAD interaction.

3 STRUCTURE OF BIM/CAD INTEGRATION SYSTEM

The computer-aided applications such as CAD, CAE, and BIM, are developed for the special need of different areas in the industry. This results in the specification of one single function, but cannot automatically synchronize and exchange information between each platform due to the lack of synergy. For example, the technical files such as stress analysis report from CAE system cannot be interpreted by BIM system. In fact, those files have to be transferred into BIM system with a proper data format. Information from CAD cannot be transferred directly into BIM either. The CAD related files have to be converted or manually input by engineers. These issues reduce the efficiency in product development, hinder the design consistency and sometimes even break down the associations between two applications. BIM/CAD integration should not be just a simple combination of two platforms. It has to bridge the information of two systems efficiently, consistently and validly. Therefore, the associative features are applied in this work to interface BIM and CAD, which manage geometric and semantic associations between both applications and keep the information consistency. The framework of the BIM/CAD integration system is illustrated in Fig. 1.

In this system, there are four major players (stakeholders) including customer, architectural design firm, modular supplier and contract manufacture. Correspondingly, BIM, CAD, and ERP are the components at the system level. After architecture companies negotiate with customers about the final detailed model, the BIM model will be generated and the information will be extracted from the BIM files. Any important information such as quantity, feature, and parametric information will be excerpted and stored in a data set. Customization information will also be synthesized with extracted data to provide a shared database. Then the data set will be mapped into a well-defined CAD template. This external database is designed well enough to cover all types of products which can be made by the manufacturer. The detailed model and BOM can be exported by CAD software, which is essential for the manufacturing process. After verifying the result with standards and design requirements, the BOM is ready to be sent for manufacturing and the information provided by the CAD model can be updated in the BIM system. The BOM will then be sent to enterprise resource planning (ERP) system in which it will cooperate with scheduling and other enterprise data for manufacturing. Finally, the products will be delivered to the customers.

4 IMPLEMENTATION OF THE PROPOSED BIM/CAD INTEGRATION SYSTEM

The purpose of BIM/CAD integration is to make sure the consistency of the data during the product design, simulation, analysis, and manufacturing process. It is important to understand the differences between the two platforms and come up with a method to bridge the gap.

4.1 Element reorganization in BIM

Revit uses three important sets of entities in the 3D modeling system: model elements, datum elements, and view-specific elements [9] as shown in Fig. 2 (a). Essentially, from the engineering informatics point of view, they are in fact three classes of features that contain data structures and mapping graphs such as spatial relationships, component parameters, component geometry, engineering quantities and even building geographic information. The element types are also known as families, which represent the building component models within their corresponding categories. Each instance, also known as a detailed model, is an actual 3D model that is defined and controlled by its family [4]. This relationship is shown in Fig. 2 (b). Inside of the building information model, the hosts are the elements mostly built on the construction site such as walls, floors, and ceilings. The components are the attached elements associated with manufactured products that will be installed in a building such as windows, doors, and stairs. Fig. 2 (c) shows the detailed model of a slider window inside of BIM. However this model is lacking of details and could not sent out directly for manufacturing.

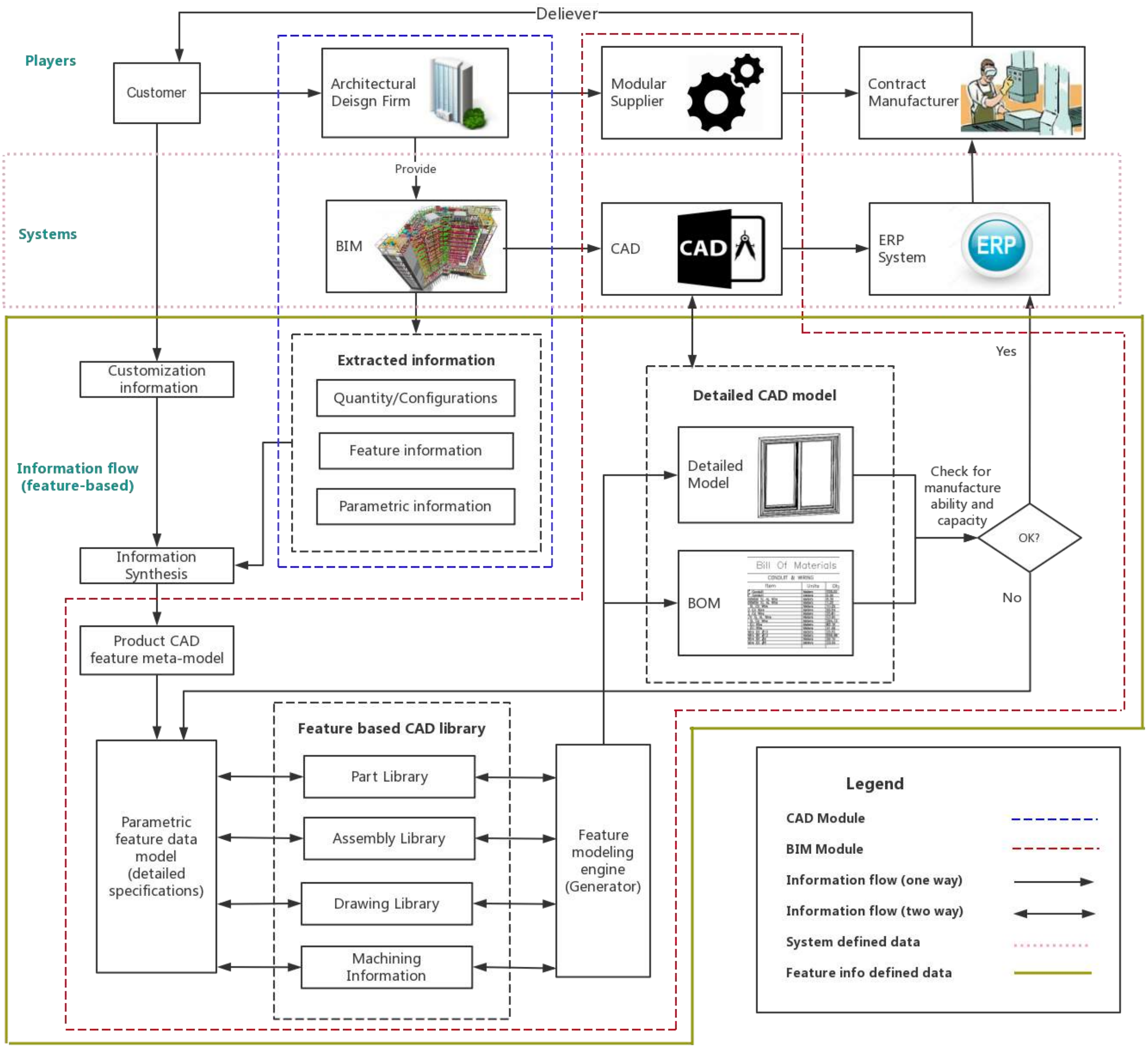
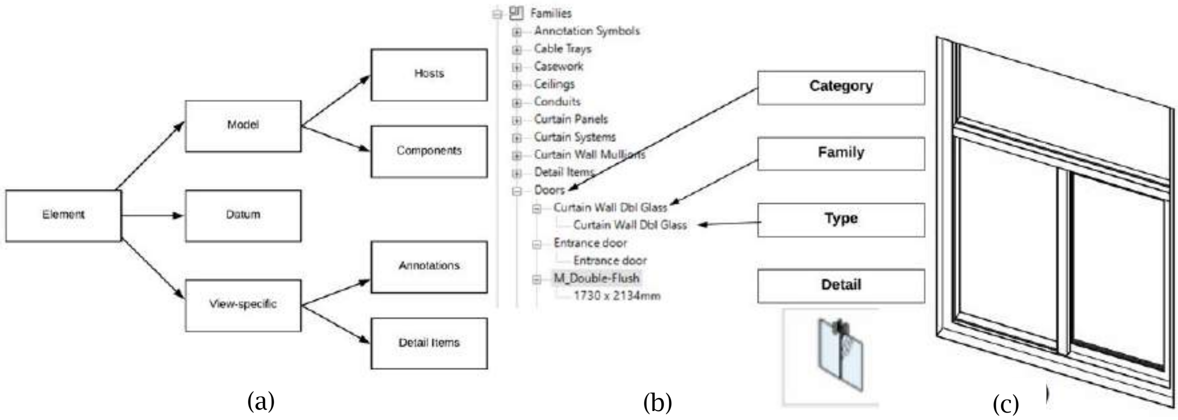


Figure 1: General framework of BIM/CAD integration.

Every family, sheet, 2D, 3D view and schedule are stored in the same underlying building information database. As engineers and architects working on drawings and schedule views, all these data and relationships are collected and integrated back to the project. Parametric design enables Revit to change anything at any time with ease. For example, when an engineer copies an existing window to a new location, the window will dimension equally as the previous model, and the relationship of spacing is also maintained. After the design phase, the schedule function can display the lists of any type of element in the project. It will extract properties information from the elements in a project and list in the data files.



(a) (b) (c)

Figure 2: Elements of Revit (b) Revit Families and (c) detailed model of slider window inside of BIM.

4.2 BIM/CAD associative features

The information from a BIM system, however, cannot be directly used to fabricate the windows and doors due to the complex geometry of the manufactured components. Prior to the manufacturing process, detailed 3D models are required to verify the possible interferences of the model, and a BOM can provide the required cutting dimensions for the raw materials as well as the information of all components required inside the products for the assembly line. The type and parameters of a BIM window or door feature can be extracted by using Revit application programming interface (API) or generated by Revit schedule feature, and then a data set of a separate window or door product CAD model will be produced. In order to achieve the automatic interpretation of the CAD result, a series of customized window features are defined so that it corresponds to customer's choices, such as the lamination material of the window frame or the type of glass used on the window. This set of feature properties could not be included in BIM due to its different focus compared to CAD software. In fact, the BIM system is only designed to embed objects, create visualization and input general information into a 3D special model [2]. How the proposed feature concept interacts with the other features in the integration system for a sample slider window is shown in Fig. 3.

4.3 A Well-defined external module CAD templates

Inside a window or door manufacturing model, components such as *frames*, *sashes* and *mullions* can be modeled according to characteristic parameters. Parametric modeling is used in external module CAD library with SolidWorks. This library uses a feature-object method and has the advantage that it is able to process different parameters with all type of configurations of assemblies included [26]. All the parts are grouped together and formed into series of typical *smart types*, e.g. *major/sub-types*, and stored as a supporting toolkit template file for the system [28]. CAD templates also cover associated child templates for drawing, assemblies, and BOMs. Each individual product also has its own relationship data file corresponding to only their own. They are well-defined and can be generated by running SolidWorks API functions. Based on the input from BIM data set, the requirement and customized specification data structures and associations are embedded into the templates with SolidWorks. The BIM/CAD associative features have been adopted to map the design-driven semantic parameters with constraints to build the CAD models based on data sharing [11]. When instantiated, the embedded functions then use BIM customer specifications to select and calculate all the required geometrics and analysis parameters according to standard design procedures and building codes. Most of the decisions and customization steps can be processed automatically.

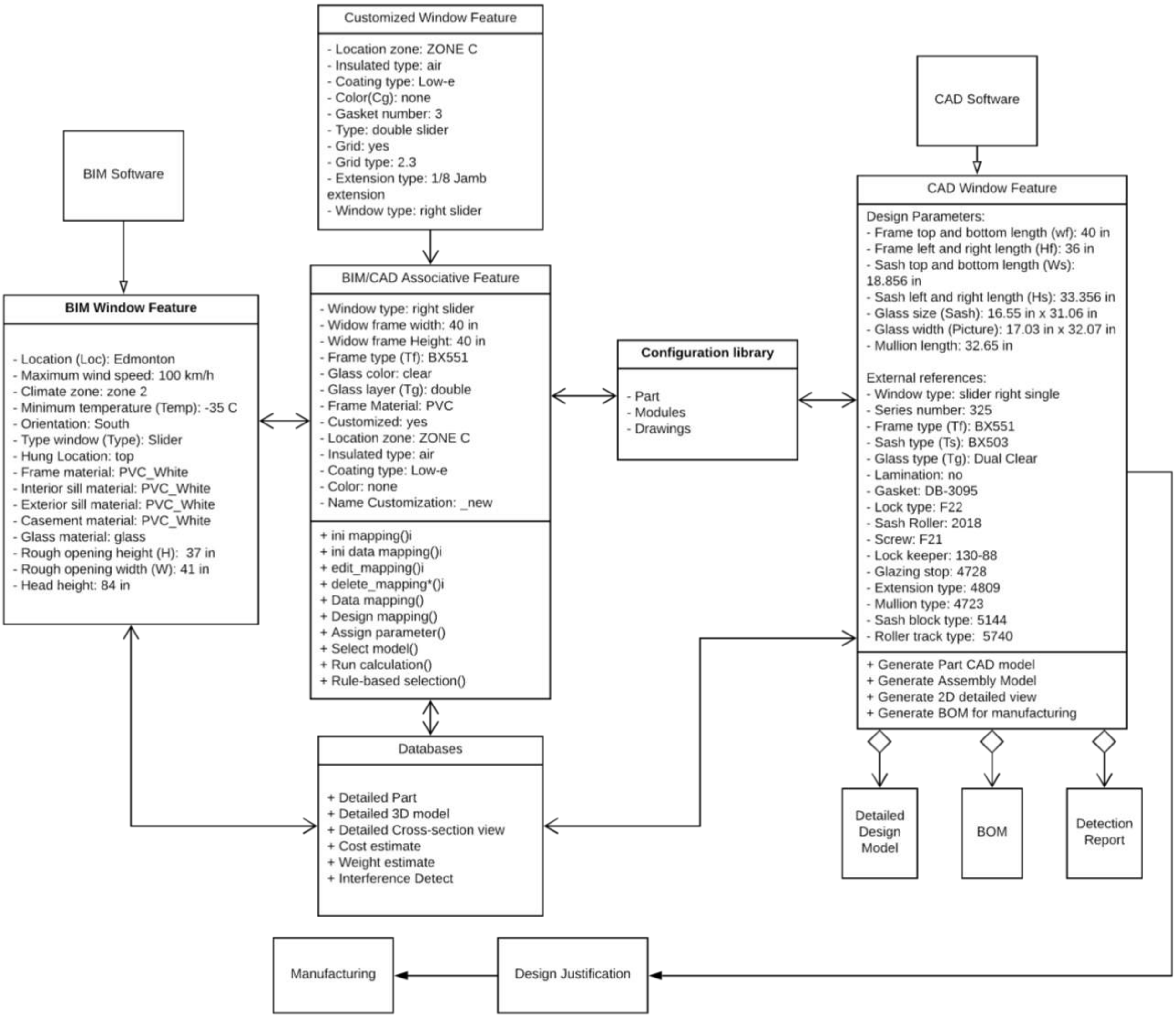


Figure 3: Semantic associations in BIM/CAD integration referring to window features.

5 CONSTRUCTION OF THE BIM AND CAD ASSOCIATIVE FEATURE FOR AN EXAMPLE SLIDER WINDOW

The sample slider window is designed with company profile and can fulfill the CSA-A440 standard. Location of the building (zone), level of the building, emissivity rate, color and specific customer requirement are considered to select the type, design, and dimension of the glass. The frame of the window is designed by the type of window inside the building model, and its dimension is decided depending on the opening on the wall inside the building model. The hardware of the window, for example, locking system, screws, hinges are then matched with the type of the window.

5.1 Profile design calculations

The relationships between the opening size of the wall and the length of frame PVC profiles are based on engineering considerations. Those relationships vary in different series of products due to the unique thickness and cross-section of each product type. In this work, this variation can be processed by the generic engineering calculation approach embedded in a program which can fulfill customer's requirements and design specifications. All of the calculations are controlled by BIM/CAD associative features and considered as constraints of the design. These relationships are saved as a sub-program aside of the main functions in which each sub-program will match corresponding series of the product. Each sub-program demonstrates the internal relationships and logics of a single product. The main program and sub-program are implemented in the Visual Basic (VB) programming language. The rough opening width (W) and height (H) are treated as input from the BIM model.

The calculation of the frame size is based on rough opening on the wall. The deduction is based on the thickness of water infiltration, glue and other material that may cause a gap between the window and rough opening. The width (top and bottom) of the frame can be calculated as

$$W_f = W - D_{fw} \tag{5.1}$$

The height (left and right) of the frame is given by the following equation

$$H_f = H - D_{fh} \tag{5.2}$$

The height of mullion can be calculated as the height of frame minus the width of the cross section

$$H_m = H - D_m \tag{5.3}$$

The height of the sash can be found as the height of the frame minus the gap left for the roller and hollow on the top

$$H_s = H_f - D_{sh} \tag{5.4}$$

The width of the sash is given by the following formula

$$W_s = W_f - D_{sw} \tag{5.5}$$

The length of the roller track should be determined from the width of the frame and gap left for installation

$$W_{rt} = W_f - D_{rt} \tag{5.6}$$

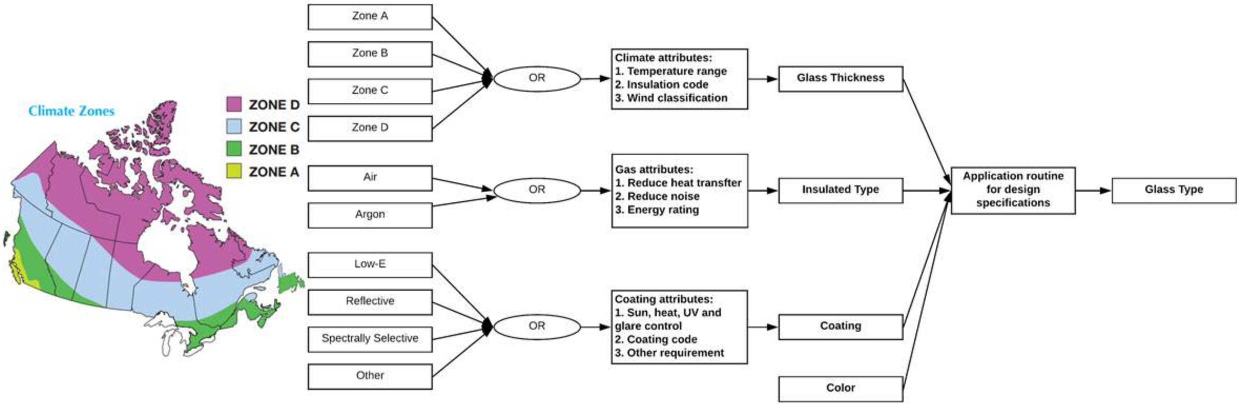
The pocket cover equals to the height of sash

$$H_{pc} = H_s \tag{5.7}$$

5.2 Design for specific glass based on geographic locations and climate attributes

As aforementioned, the program can generate a data model based on the parameters and geometry. However, there are some components on the inside of the windows that are rule based, such as locks and glass. Those are usually controlled by engineering rules, regulated standard and design experience. Customized window feature is introduced to help decision making in the integration system. These rule based paradigms are effectively implemented in VB code to make sure that the design adheres to the entire requirement and to ensure the information consistency.

Fig. 4 illustrates a logic structure of the customized window feature for the decision making on the glass selection. The location is based on geography information (climate zones) and will define the thickness of the glass. The insulated air will be inputted according to customer requirement to help minimize heat transmission between the interior and exterior. The coating which could either reduce heat transmission or reflect particular wavelength will be selected by customers as well. These three elements decide which type of glass will be used in the CAD model and this information will be eventually sent to the manufactory.



(a) (b)

Figure 4: (a) Climate zones of Canada and (b) Logics for choosing a glass according to customer requirements.

5.3 Parameter semantic map of BIM/CAD associative feature modeling

As previously discussed, BIM/CAD associative features collect parameters from the BIM and then combine them with customized window features required by customers for further processing by CAD. As described in section 5.1, all parameters are semantically connected to each other in the engineering calculation. In order to make sure all the parameters in the design are associated, the relationship between parameters has to be identified and well developed. Fig. 5 below shows all the relationships between parameters, customer requirements, CAD parts, and CAD assemblies. The corresponding nomenclature can be found in Tab.1. Changes in any parameters or customer requirements will have an impact on the whole design. All the relationships between parameters are saved in comma-separated values (CSV) files for each product.

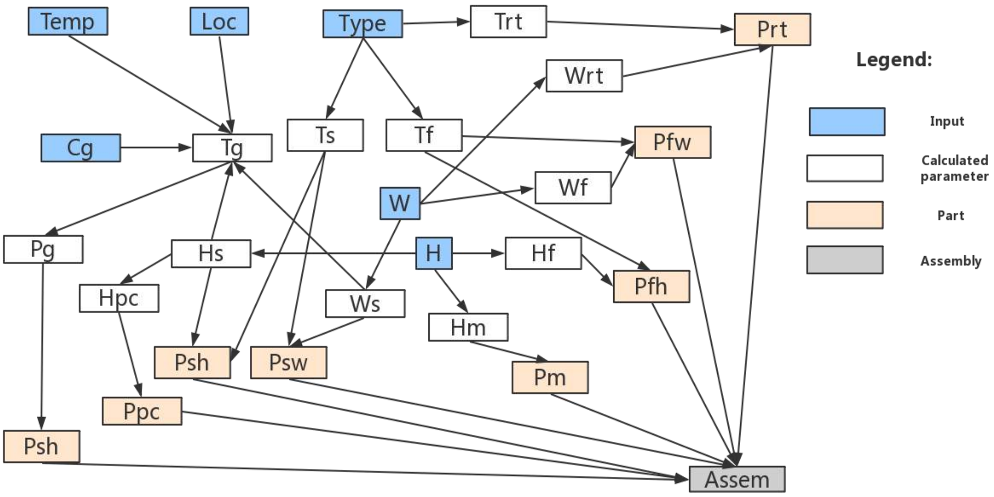


Figure 5: Parameter semantic map for a slider window.

The links between parameters and parts inside BIM/CAD associative features follow certain patterns according to its driven parameter, design procedure, and production limitation. In Fig. 5, parameters and customer requirements are colored in blue while parameters generated by BIM/CAD associative features have no filled color. Those parameters are directly linked to BIM parameters and elements useful for CAD model rebuilding. Yellow boxes indicate the CAD parts stored in a well-defined CAD library. After the relevant parameters are calculated, the CAD software will generate new parts and assemble them into the new CAD assembly.

5.4 BIM/CAD Associative Feature Program Development for Window

The pseudocode of the proposed system based on BIM/CAD associative features can be found in Fig.6. The input of this program contains sizing, quantity and classes information from BIM system within a CSV file, customer specific requirement for the window, and customer suffix for identification. The CAD library contains CAD CSV files with design logics of the product, CAD parts, assemblies, and drawing templates. This algorithm mainly serves two purposes. First, it can quickly calculate all essential parameters needed to re-model the existing CAD template by using all engineering relationships inside the corresponding CSV file. Second, it can regenerate new model and bill of material (BOM) with customized suffix and store them separately with the original templates. Once the program reads the rough opening size of the window, algorithm 1 is invoked to calculate all design parameters for different parts. In the map shown in Fig. 5, if the value of W and H change, all related and directly connected constraints, Wrt, Ws, Wf, Hf, Hs and Hm can be calculated by the engineering relationship and product deduction. Then those parameters are updated to the CAD software to reform the new part documents. The tool will rebuild the assembly file with all the new parts. The part, assembly, and drawing documents are stored separately.

6 DEMONSTRATION OF THE EXAMPLE PRODUCT DESIGN CASE

To demonstrate the application of BIM/CAD associative features, a software prototype which can design a slider window is developed. This software can read CSV files, map data with a well-defined CAD library and then regenerate CAD models for manufacturing. By employing the VB program language, this software achieves engineering calculations, design knowledge and data management in product development. In the integration system, Revit 2017 is used for collecting building information data while SolidWorks is used for CAD modeling. In this paper, the authors just use a slider window as a sample case to demonstrate the concept of the proposal and the general framework. However, this system can be easily adapted to other building components such as doors, elevators, and etc. because the associative regime is a generic regime to make this system valid regardless of the object of the model.

Fig. 7 shows the graphic user interface of the program. The CSV file generated by BIM can be automatically called by the software. The user of this software can then choose which window will be modeled based on the specific CSV file. In addition, the user can choose the unique suffix for a particular requirement. The type of glass will be assigned as the user chooses the different setting of the glass in the Customer Requirement combo box. The CAD model will be automatically generated by SolidWorks.

6.1 BIM data extraction

During the first phase of design in which the data is extracted, the window inside of BIM system contains basic parameters and model information. It also contains the appearance and the location of the window. Fig. 8 (a) shows the BIM model for a three-level house while Fig. 8 (b) presents the appearance of the window inside the house. Fig. 8 (c) demonstrates the property menu in which all the parameters and specification information are stored. The parameters of the window could be extracted from BIM system by using the schedule feature or BIM API. Fig. 8 (d) illustrates the sample CSV file which is exported from the BIM system with a rough opening size.

```
Algorithm 1:

Input:
    CAD_library:                'The library contains all parts, assemblies,
                                'drawings and etc. for all windows series.
    BIM_CSV (type_window,W,H):  'The CSV file exported from Building
                                'Information Modeling contains the type of
                                'window and rough opening size on the wall
    Customer_choice:            'The type of window a customer chooses from
                                'the BIM_CSV file
    CAD_CSV_library:            'The library contains CSV files of all the
                                'design logic for the windows
    Costumer_requirement:       'Other requirement from the customer for
                                'the type of glass
    Costumer_suffix:            'Customer suffix for easy identification

Output:
    New_model:                  'Model can be uploaded back into BIM
    New_drawing:                'Drawing (Bill of Material) for
                                'manufacturing and link with ERP
                                '(for the future work)

IF Solidworks IS running
    FOR each row IN BIM_CSV
        IF Customer_choice == type_window
            open assmebly_type_window FROM CAD_library
            open parts_type_window FROM assmebly_type_window
            Wrt,WF,Hf,Hm,Ws,Hs = Calculate(W,H, CAD_CSV_library(type_window))
            FOR each parts_type_window IN assmebly_type_window
                    FIND the first feature IN parts_type_window
                    IF first feature(parts_type_window) IS Boss-Extrude
                        length(Boss-Extrude) = Wrt,WF,Hf,Hm,Ws,Hs
                    ELSE
                        output error
                    ENDIF
            ENDFOR
            assembly = copy (CAD_assembly_type_window IN CAD_library)
            rebuild assembly
            drawing = copy (CAD_drawing_type_window IN CAD_library)
            rebuild drawing
            SAVE part, assembly, drawing with Costumer_suffix
        ENDIF
    ENDFOR
ELSE
    output error
ENDIF
```

Figure 6: Pseudocode for the System.

6.2 Detailed model result

After the BIM data extraction is done, the detailed design of a slider window is produced. Fig. 9 (a) shows the detailed 3D model of the window. This model contains full design details and satisfies all design requirements. The CAD part models can also be integrated into BIM system and give engineers and customers a detailed view of the project. The collision detection feature by SolidWorks is able to detect collisions with all the components of the window when moving the sash, which guarantees that this model is feasible and accurate. A sample BOM can be found in Fig. 9 (b), which can provide manufacturers with specifications for production. The BOM is further extended to contain all the fabrication information such as the dimensioned cutting list which can simplify and accelerate the material preparation process and thus enhance productivity.

A time study is conducted by comparing the time used in each phase with traditional method and the proposed BIM/CAD integration system, respectively. The results listed in Tab. 2 prove that by using a well-defined CAD library in collaboration with the BIM system, the time could be saved by

98.5%. The whole process is seamless, making it human error free when creating the detailed CAD models, which also contributes to the modeling efficiency enhancement.

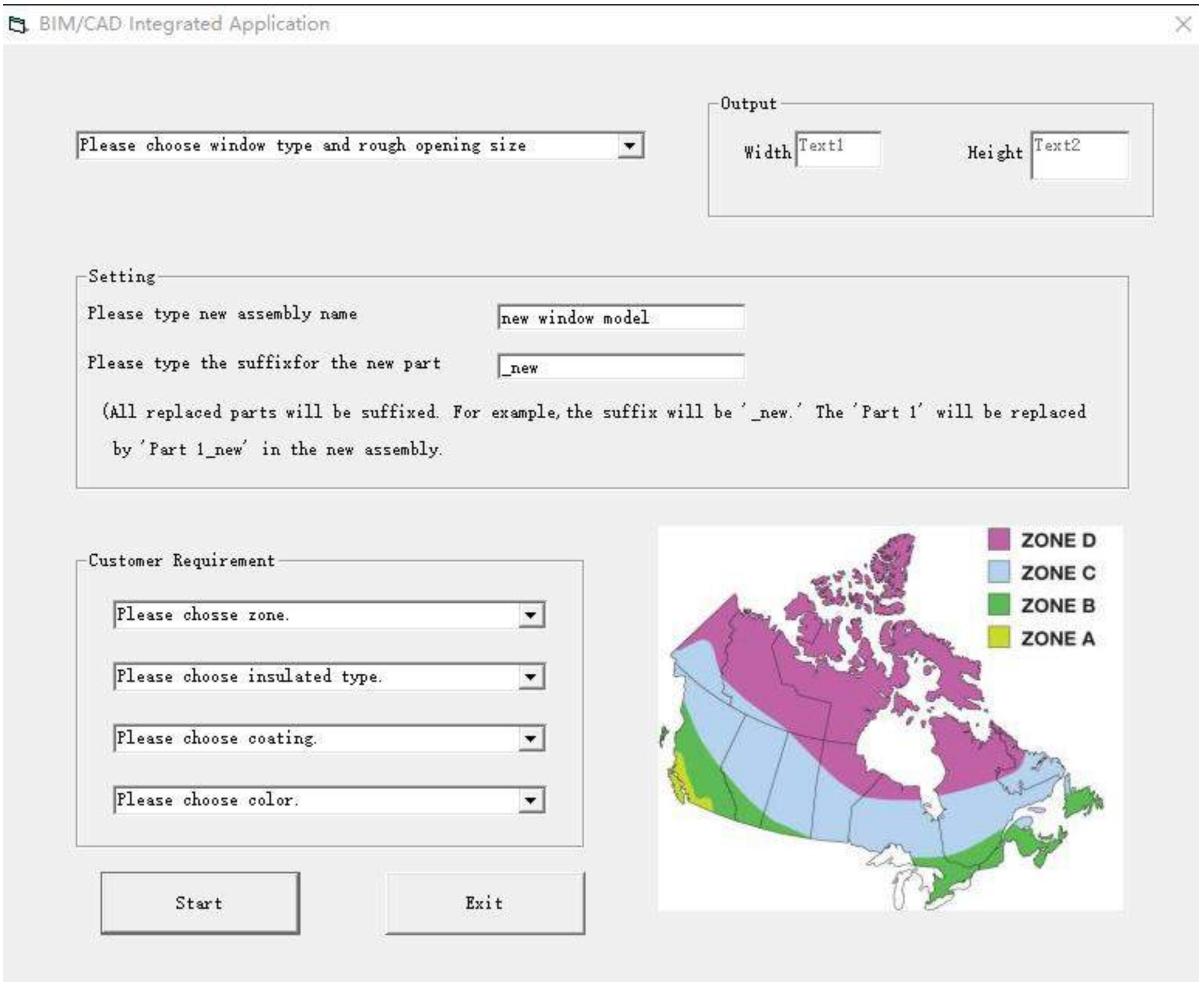
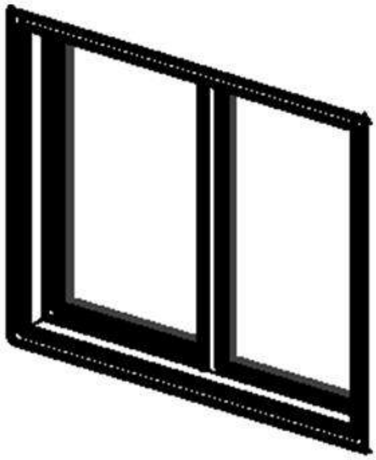


Figure 7: Graphic user interface of the software.

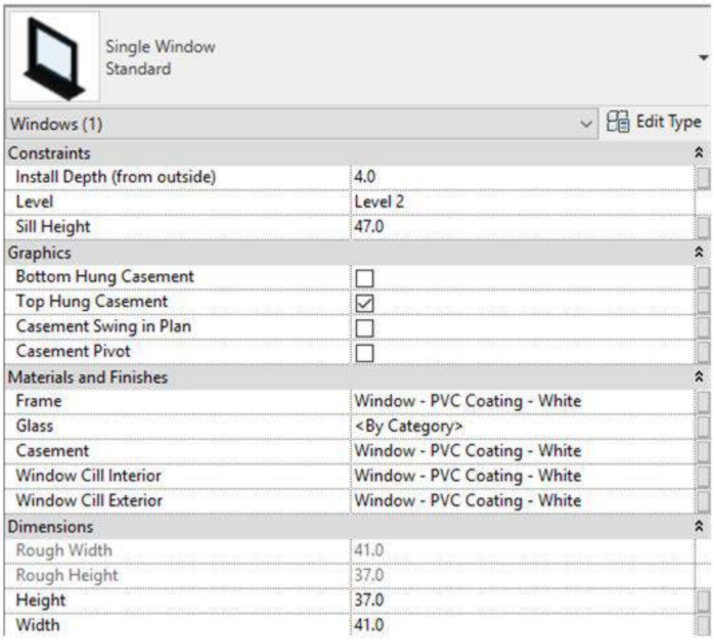
Time (min)	*Record Data from BIM*	*Redesig n*	*Rework on BOM and Drawing*	*Validation*	*Total time*
Traditional Method	1	300	100	4	405
BIM/CAD integration system	0	1	1	4	6

Table 2: Time study for comparing the traditional method and the proposed method.

(a)



(b)



(c)

Window Schedule 2

Family	Width	Height
450series	1500	1800
460series	1600	2600
470series	1700	3600
480series	1800	4600
490series	1900	5800
500series	2000	5600

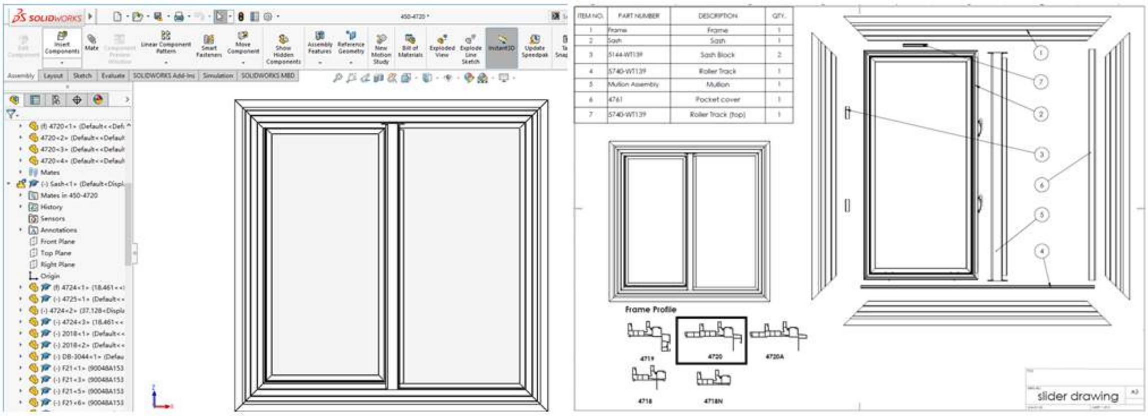
(d)

Figure 8: BIM data: BIM model, (b) window model in BIM, (c) property menu of a window in BIM and (d) CSV file export from BIM system.

7 CONCLUSION

This paper explores the mechanism of BIM/CAD integration based on the concept of *associative feature*. An overall mapping framework for BIM and a well-defined external modular CAD library has been suggested. This framework can represent the cycle of parametric and knowledge-based product design, CAD modeling, change justification, validation, and manufacturing. Through a case study of a slider window, it is evident that the associations between the BIM system and CAD model can be established. The BIM/CAD associative feature is an effective method to bridge the gap between BIM and CAD system. A prototyping system has been implemented to show the effectiveness of the proposed method. It should be noted that, the proposed method is not limited to the shown case; it can be applied in other scenarios such as the design of components in modular construction.

In practice, the parametric development of building components is highly demanded with the trend of customization according to the various requirements from the customers. Actually, this BIM/CAD integration system is very suitable for order-driven manufacture in which the adaption to sudden changes in parameters or features of the product is vital. In the future, this BIM/CAD interacting mechanism can be potentially merged into an enterprise resource planning (ERP) system to facilitate lean manufacturing.



(a) (b)

Figure 9: (a) New detailed design model (b) BOM generated by SolidWorks.

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