WEB-ENABLED MODEL-BASED CAD FOR THE ARCHITECTURE, ENGINEERING AND CONSTRUCTION INDUSTRY

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ABSTRACT

Computer-aided design (CAD) applications have been widely used in the architecture, engineering and construction (AEC) industry to aid architectural design, to visualize the physical appearance of a building, and to specify design details for building construction and operations. As web technology continues to grow rapidly and the Internet becomes ubiquitously accessible, the ability to interact with online information and to integrate web applications and services within CAD applications has significant values. A web-enabled CAD application could facilitate architectural design, enhance the communication between architects and other stakeholders, and create new business opportunities. As building information modeling emerges, the technology has the potential to provide new ways of designing and managing constructed facilities. In a building information model, each component has its properties, information, and semantics. The building information such as product data and supplier information can be used for decision-making, design analysis, and project management. This paper discusses the principles and implementation details of a web-enabled model-based CAD framework, utilizing Autodesk Architectural Desktop (ADT) and Google Sketchup which are widely used in architectural and engineering design as demonstrative CAD platforms. Four example scenarios are presented to demonstrate the web-enabled model-based CAD for AEC applications. The first scenario shows the extraction of the object component information from CAD models to facilitate material procurement process. The second scenario demonstrates the usage of CAD applications to perform configuration design by directly interacting with online information through a CAD software plug-in, namely SpecifiCAD. The third scenario illustrates application of the web-enabled CAD environment to dynamically evaluate design alternatives according to energy and carbon emission simulation and analysis results, using the Integrated Environmental Solutions (IES) software. The fourth scenario demonstrates the filtering by component information and the connection to web services in a CAD environment for a "pull-based" material delivery process.

KEYWORDS

Building information modeling (BIM), computer-aided design (CAD), web-enabled, construction management, procurement.

INTRODUCTION

Computer-aided design (CAD) technology are now used for a wide variety of applications in the architecture, engineering and construction (AEC) industry, such as drafting of plans and drawings, visualization of architectural design, and preparation and documentation of technical specifications. Traditionally, in a computer aided design (drafting) system, a design is drawn using a combination of geometric entities such as vertices, lines, faces, and volumes. Geometry-based CAD has since evolved to current CAD applications that support 3D and parametric modeling. In a 3D CAD model, changes of the models in one view are updated and reflected in all views. 3D modeling can therefore ensure consistency of drawings viewed from different orientations and perspectives. In an object-based parametric modeling CAD application, an object component is defined by the parameters and rules of a particular template describing the component. To define a window, for example, users simply need to select a pre-defined window template and specify the dimensions. Drawing every detail of a window component is not needed. Object-based CAD applications also allow object components to interact with each other intelligently. For instance, a window has a relationship to the wall that contains it. If the wall is moved or deleted, the window reacts accordingly. Object-based CAD can be enriched by further extending to a model-based approach, in which each design object component (e.g. door, wall, and

slab) has its properties, information, and semantics (Eastman et al. 2008). The object information such as product data, cost information, and schedule information can be manipulated by other software applications and can further be utilized throughout the project life cycle. This model-based approach can facilitate decision making, production of construction documents, prediction of building performance, cost estimating, and construction planning.

Currently CAD applications are often used as standalone tools for design and specification. There is significant potential to leverage the web to extend the scope and to enrich the functionalities of CAD applications. Several studies have demonstrated using the Internet to connect distributed CAD software clients to a centralized product data server for collaborative design (Fuh and Li 2005; Han et al. 1999; Zhuang and Chen 2000). These web-enabled collaborative CAD frameworks support concurrent design and ensure data consistency. The Internet can also be leveraged to explore and retrieve information available on the web, and to integrate distributed applications as web-based services within CAD applications. This paper describes a framework that supports interactive integration between web-based information and CAD applications and provides example scenarios to illustrate the potential benefits of a web-enabled interactive CAD environment.

In this paper, we present the principles of web-enabled model-based CAD framework and demonstrate the potential uses of the framework for architecture, engineering and construction (AEC) applications. For demonstration purposes, the prototype implementation is built upon Autodesk Architectural DeskTop (ADT) and Google Sketchup, which are widely used in architectural and engineering design. Both ADT and Sketchup support 3D and parametric modeling. Autodesk Architectural DeskTop (ADT) consists of built-in tools and functions specialized for architectural design. Google Sketchup is a 3D modeling software application designed to be user-friendly and compatible with Google Earth. This paper first discusses a model-based CAD environment. An example is provided to illustrate the extraction and usage of object component information in CAD models for material procurement process. The paper then describes a web-enabled CAD environment. An example which leverages a CAD software plug-in, namely SpecifiCAD, is given to demonstrate the interaction between CAD models and online information. The paper finally presents a general web-enabled model-based CAD framework. Two examples are used to demonstrate the potential applications of the framework for building design and project management. The first example illustrates dynamic evaluations of design alternatives in a CAD environment according to energy and carbon emission simulation and analysis results, whereas the second example demonstrates a web-enabled CAD-based implementation of a "pull-based" material delivery system.

MODEL-BASED CAD SYSTEM

A model-based CAD system is defined as an intelligent, object-oriented, and parametric platform that stores not only the geometry information of CAD object components but also the information which supports the activities involving the objects and their relationships with the other objects. A model-based CAD system enables different representations and behaviours for object components with different properties in a CAD drawing. Building information models (BIM) have been actively studied and utilized as a tool for information integration and interoperability in the construction industry. National Building Information Modeling Standard (2010) defines a BIM as a computable representation of all the physical and functional characteristics of a building and its related project/lifecycle information, which is intended to be a repository of information for the building owner/operator to use and maintain throughout the lifecycle of a building. Although model-based CAD is applicable to many engineering industries, illustrative examples in the building industry are used in this paper.

Autodesk ADT and Google Sketchup are widely used CAD systems in the architecture and construction industry. They are employed here as the CAD platforms to demonstrate the behaviours and implementation of a model-based CAD system. Since model-based CAD systems are object-based parametric modeling programs, every object component can be conveniently created from pre-defined component templates. Many parametric CAD systems can intelligently handle and manage their CAD component templates. For example, when Google Sketchup users replace existing components in their designs with Scalable Dynamic Components, the new components are scaled automatically and parametrically to the dimension of the old components.

Model-based CAD users can create their own component templates, and/or utilize the built-in templates provided by the vendors. For instance, Autodesk ADT provides built-in component templates for common structural elements such as windows, doors, walls, structural columns, roof slabs, and stairs. Each of these built-in templates has a different set of pre-defined parameters. As shown in Figure 1, a structural column is defined by parameters such as length, offsets, and roll in Autodesk ADT. Different sets of parameters may be used to define a structural column in other CAD applications.
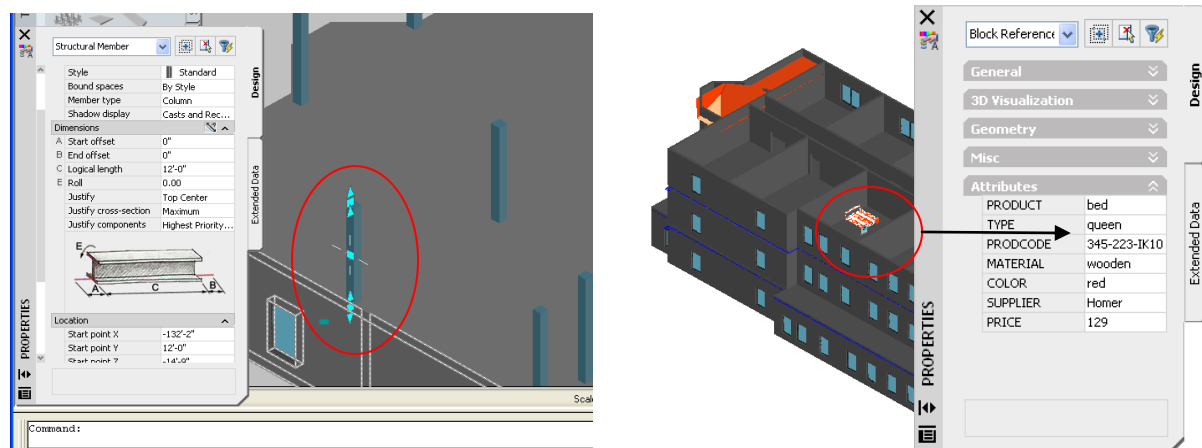
Figure 1 Examples of information in a model-based CAD environment - (Left) The property window of a structural column component in Autodesk ADT showing the parameter values of the column; (Right) Extended attributes of an object component in Autodesk ADT

In a model-based CAD system, specific component parameters such as location and geometry of the components are defined for drawing purpose, and support building and facility lifecycle management. Many parametric modeling CAD tools including Autodesk ADT and Google Sketchup allow users to add attributes to pre-defined component templates and to component instances. For example, supplier, color, material, and price information can be added to a CAD object to facilitate logistics management and cost estimating (see Figure 1). Adding attributes to object components inside CAD applications is a straight forward way to extend the component information. However, the internally stored information is often difficult to be extracted and manipulated by other applications without complex programming through the application programming interface (API) of the CAD applications. In addition, the amount of information that can be stored internally for each object component is limited.

Alternatively, component information can be stored externally in a database or a local file, such as Microsoft Excel. Storing component information externally provides a convenient and easily accessible way to modify, retrieve, and integrate the component information of a CAD model. For databases, communication channels and programming functions are often provided to enable users to access the data stored in the databases and to manipulate the data internally. For local files, those in plain text format can easily be retrieved by text editors and parsed by simple programs, whereas those in binary commercial format may need application-specific APIs or software programs for data extraction and processing. Therefore, connectivity to databases and/or local files should be supported in a model-based CAD system. For instance, Autodesk ADT has a built-in function called "dbConnect", which supports connection to a Microsoft SQL Server database, while Google Sketchup has a Ruby API which can implement programming codes to access databases such as SQLite and MySQL.

Scenario Example 1: From Design to Procurement

Procurement officers often need to refer to architectural CAD drawings when creating item lists for material procurement. It saves time and reduces human errors if the procurement item lists can be automatically generated and linked to CAD drawings. This example shows the association and extraction of the information model of a Sketchup CAD drawing to facilitate material procurement process. In this example, customized attributes are added to major components such as windows, doors, and furniture, as shown in Figure 2. The attributes include color, material, price, product code, and supplier. During the material procurement, the component attribute values are exported using a Ruby-based plug-in that reads the attribute values of all components and exports them into a CSV (comma-separated values) file. The CSV file "items.csv" is saved to the local machine. The data in the CSV file are then processed and imported into an Excel spreadsheet using a VBA program that we developed. By simply clicking the "Read CAD" button in the Excel spreadsheet, procurement officers can conveniently obtain a list of products and their information that are specified in a CAD model.

WEB-ENABLED CAD ENVIRONMENT

Currently CAD systems are often used in a standalone manner. As online information continues to grow rapidly and web technologies become mature, there are significant potential and business opportunities to leverage and
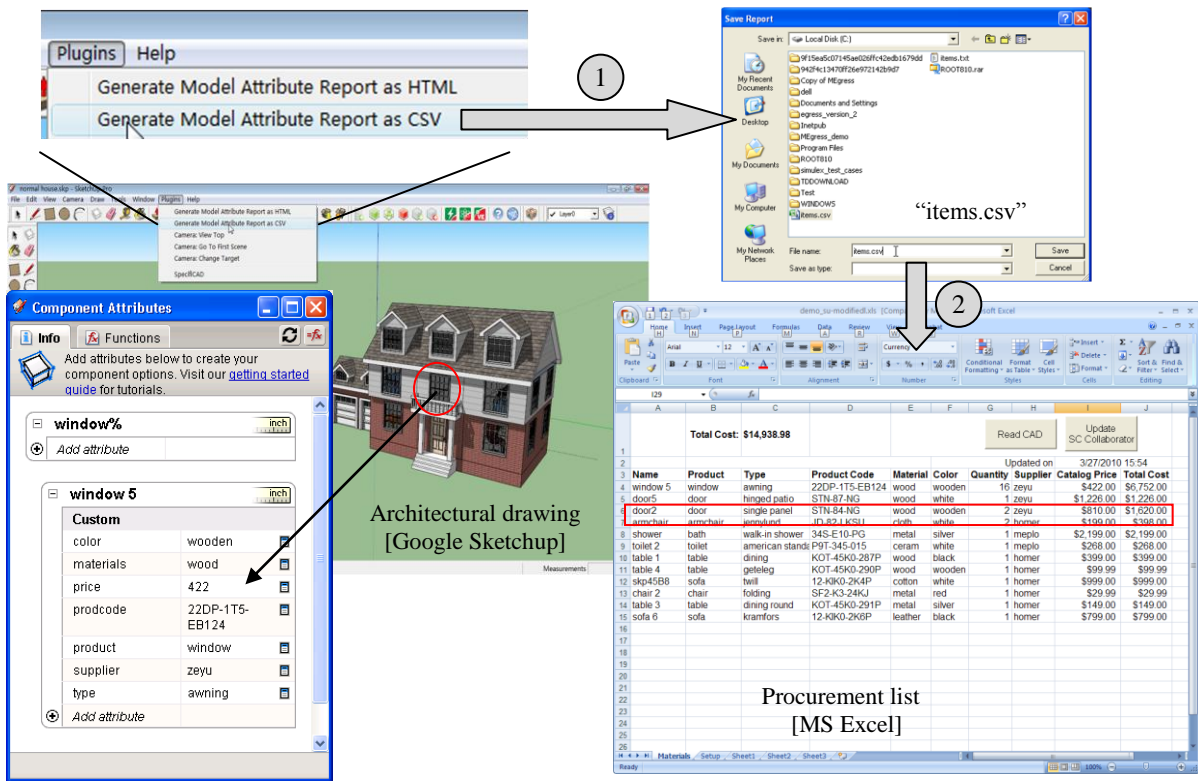
Figure 2 Generation of procurement list from a CAD model embedded with component information

integrate with the web directly within a CAD system. A web-enabled CAD environment is a setting of CAD systems that enables users to incorporate, interact, and integrate with online information and/or services within the CAD systems, therefore extending the scopes and functionalities of the system. The following discuss two ways to support a web-enabled CAD environment. The first way is the capability of CAD interfaces to import objects and information from the web through simple drag-and-drop activities. The second way is the capability of CAD interfaces to access, retrieve, and display online information dynamically when users interact with object components within a CAD environment.

A CAD environment can become web-enabled by allowing its users to drag an object over the web and directly drop them into a CAD design. There have been growing interests in drag-and-drop capability among CAD vendors such as Autodesk and Google Sketchup. For instance, Autodesk has developed the i-drop technology which allows users to drag-and-drop contents from the web directly to several Autodesk design products including ADT. It is an XML-based technology that consists of four major components – an i-drop enabled web page, an i-drop XML package file, an i-drop indicator, and an i-drop-aware client application. To create an i-drop enabled web page, an <object> tag is added to the HTML file to specify the width and height of the i-drop enabled area on the web page and the associated i-drop package file "data/bed1.xml", as illustrated in Figure 3. An i-drop package file is a small XML (Extensible Markup Language) file that specifies the file type, location, and proxy image of the web contents being dragged-and-dropped. For instance, the XML package file shown in Figure 3 indicates that the proxy image "data/bed1.jpg" will be displayed in the i-drop enabled area on the web page. The package file also indicates that the files "IK-CA-0789.max" and/or "IK-CA-0789.dwg" will be dragged-and-dropped using the i-drop technology. When the pointer passes the i-drop enabled area on a web page, the pointer changes its appearance as an i-drop indicator. The users can drag an object from the website to any i-drop-aware client applications, including AutoCAD, Autodesk ADT, Autodesk VIZ, and Autodesk 3ds Max. Behind the scenes, these client applications are loading the client-supported object from the websites.

A web-enabled CAD environment can also be implemented by building programs that interact with CAD objects and at the same time link to online information and/or services. As many CAD applications provide APIs to support computer programming, there have been attempts to leverage the APIs and build programs or plug-ins to bridge the CAD drawing environment and the web environment. SpecifiCAD developed by CADalytic Media, Inc. is an example. SpecifiCAD is a plug-in that dynamically matches user-defined building product content with online product data from the McGraw-Hill Construction Sweets Network and the Google
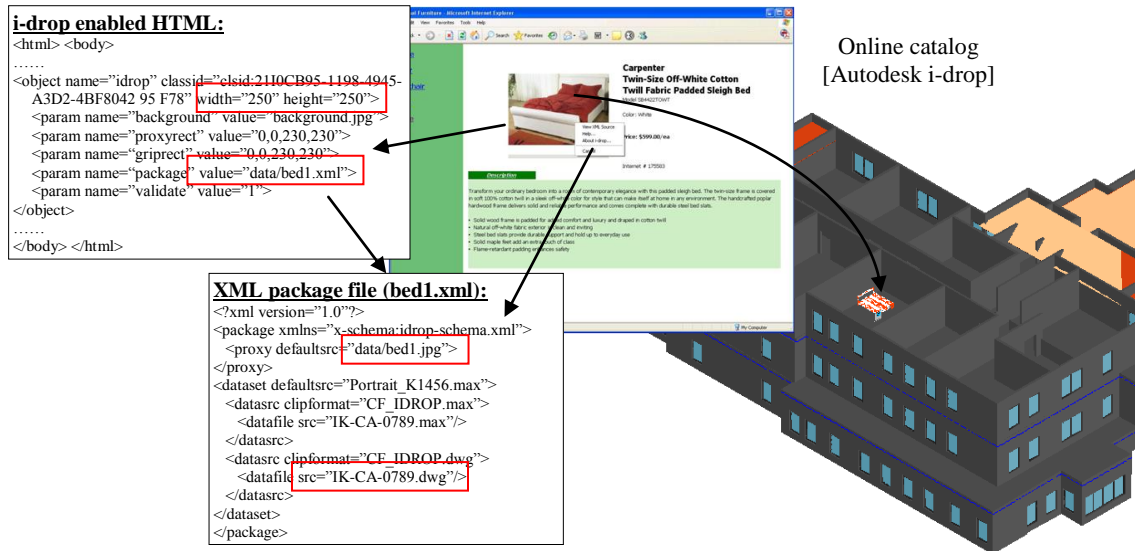
i-drop enabled HTML:
```
<html> <body>
……
<object name="idrop" classid="clsid:2H0CB95-1198-4945-
    A3D2-4BF8042 95 F78" width="250" height="250">
    <param name="background" value="background.jpg">
    <param name="proxyrect" value="0,0,230,230">
    <param name="griprect" value="0,0,230,230">
    <param name="package" value="data/bed1.xml">
    <param name="validate" value="1">
</object>
……
</body> </html>
```

XML package file (bed1.xml):
```
<?xml version="1.0"?>
<package xmlns="x-schema:idrop-schema.xml">
    <proxy defaultsrc="data/bed1.jpg">
</proxy>
<dataset defaultsrc="Portrait_K1456.max">
    <datasrc clipformat="CF_IDROP.max">
        <datafile src="IK-CA-0789.max"/>
    </datasrc>
    <datasrc clipformat="CF_IDROP.dwg">
        <datafile src="IK-CA-0789.dwg"/>
    </datasrc>
</dataset>
</package>
```

Online catalog
[Autodesk i-drop]

Figure 3 Drag-and-drop web contents to Autodesk ADT using Autodesk i-drop technology

Architectural drawing
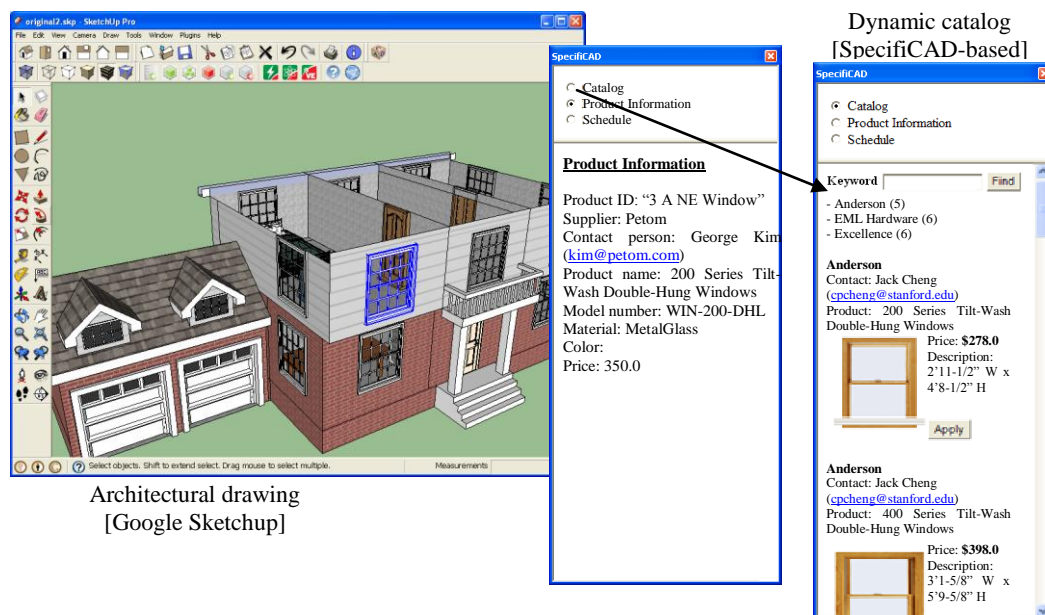[Google Sketchup]

Dynamic catalog
[SpecifiCAD-based]

Figure 4 Web-enabled interactive tool in Google Sketchup leveraging the technology of SpecifiCAD

3D Warehouse in CAD environment. SpecifiCAD is available on various CAD applications including Google Sketchup, Autodesk ADT, Autodesk Revit Architecture, and Bentley Architecture. This work leverages the interface and the technology of SpecifiCAD to develop a web-enabled interactive tool for Google Sketchup and Autodesk ADT. As shown in Figure 4, the interactive tool has three modules – catalogue module, product information module, and schedule information module. The catalogue module links to the product web services of multiple partnering suppliers. The product information module displays the model contents of the selected CAD product component. The schedule information module connects to the back-end database and retrieves the schedule data of the selected component.

Scenario Example 2: Configuration Design

In configuration design, parts are selected and connected to meet customer specifications and engineering and physical constraints (Darr et al. 1998). The drag-and-drop capability and the web-enabled interactive interface in CAD applications can facilitate configuration design of building components. These technologies not only allow designers to create and change a design conveniently and quickly, but also enhance the communication among the designers, the manufacturers, and the suppliers.

Google Sketchup is used in this illustrative example. As illustrated in Figure 4, when a designer clicks on a window component in the Sketchup environment, the web-enabled interactive tool displays the product ID, supplier name, supplier contact person, product name, model number, material, color, and price of the window component which are defined internally as the component attributes of the window product. When the designer switches to the catalogue module, the tool searches the catalogue databases of partnering suppliers using the supplier name, product name, model number, and material as the search keyword. In this demonstrative example, the catalogue module finds five search results from supplier Anderson, six from EML Hardware, and six from Excellence (see Figure 4). The search results are sorted by relevancy. In this example, the selected window component has a product name "200 Series Tilt-Wash Double-Hung Windows" with a price of $350. The first search result displayed in the interactive tool is in fact the same product but offered by another supplier Anderson at a price of $278. Since the search result is cheaper than the original one, the designer can then click the "Apply" button to update the information of product "3 A NE Window" at the back-end database. Drag-and-drop capability is enabled on the search result page. Therefore, the designer can conveniently drag the product contents from the interactive tool to the Sketchup drawing session to replace the selected window component.

GENERAL WEB-ENABLED MODEL-BASED CAD FRAMEWORK

A web-enabled model-based CAD framework is an inter-connected network consisting of a CAD application that is supported by back-end information models and that enables the input, output, interaction, and integration of web contents in the CAD environment, upon which the associated information of the web contents is transferred to the CAD environment and updated in the back-end information models. Figure 5 summarizes the major components of a general web-enabled model-based CAD framework. In the general framework, CAD models are made up of parametric object components, each of which has its geometry information and other supporting information. The information can be embedded inside the object components as attributes or stored externally in a database or local files. The methods of incorporating component information and the connectivity to external storage of building information model may vary with the CAD applications used. Information in databases is easily accessible while component information in proprietary CAD applications is often accessible only through application programming interfaces (APIs). To facilitate the interactions with the web, the CAD applications may provide a web-enabled drawing interface and/or plug-ins that leverage the supported APIs.

Scenario Example 3: Analysis of Design Alternatives

This example illustrates the evaluation of design alternatives according to energy and carbon emission simulation and analysis results, leveraging the information in a CAD model. In this example, Integrated Environmental Solutions (IES) Virtual Environment is leveraged to simulate the energy consumption and carbon emissions of a building modelled in Google Sketchup. After processing the Sketchup drawing model, as shown in Figure 6, IES Virtual Environment extracts the information from the model and identifies individual rooms. Users then specify the room types for each room that is identified, using the interface provided by the IES plug-in. The size and properties of the rooms and of the object components such as windows and doors are then transferred to the IES Virtual Environment. The program simulates each day of a year and finally estimates the annual energy use and carbon emissions of the building.

Web-facilitated configuration design presented in Scenario Example 2 can be used to aid the generation of various architectural designs. Designers can conveniently modify a design and evaluate its building performance before procurement. For illustration, Figure 7 shows four architectural design alternatives generated through web-facilitated configuration design. Compared to the original design, the second design consumes less energy for heating, cooling, and equipment because the window components have been replaced
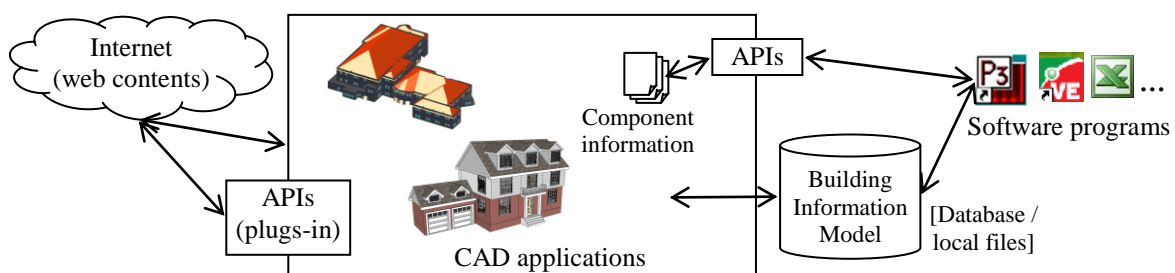

Figure 5 Schematic representation of a web-enabled model-based CAD framework
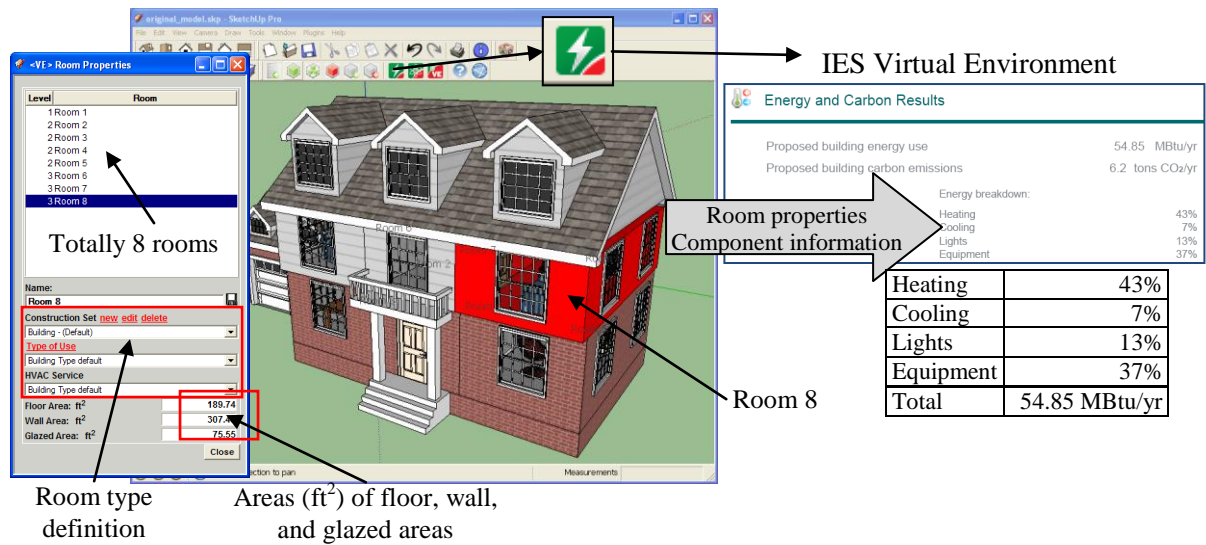
Figure 6 Energy and carbon emission analysis of a building

(a) Original model

(b) Double glazed windows replaced with triple glazed ones

(c) Replaced with larger windows

(d) Windows on the sides and at the back are removed

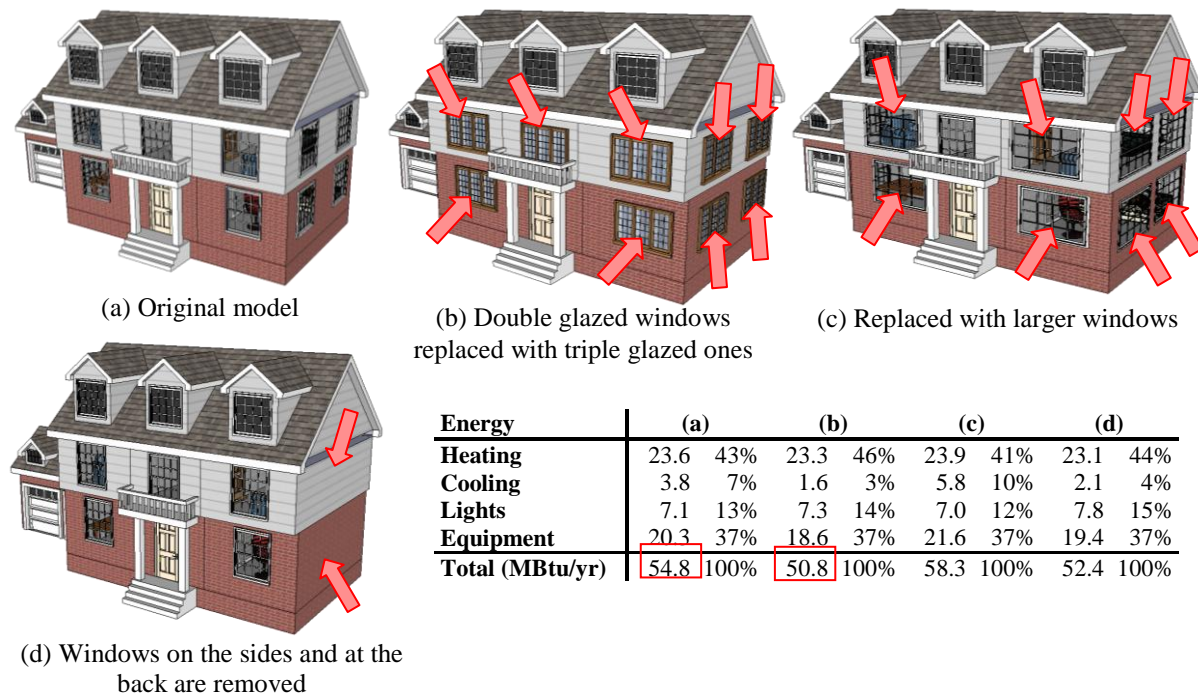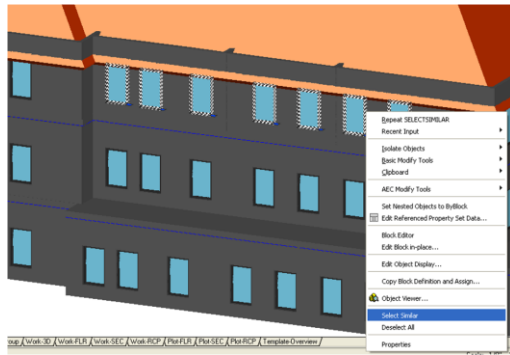| Energy	(a)		(b)		(c)		(d)	
Heating	23.6	43%	23.3	46%	23.9	41%	23.1	44%
Cooling	3.8	7%	1.6	3%	5.8	10%	2.1	4%
Lights	7.1	13%	7.3	14%	7.0	12%	7.8	15%
Equipment	20.3	37%	18.6	37%	21.6	37%	19.4	37%
Total (MBtu/yr)	54.8	100%	50.8	100%	58.3	100%	52.4	100%

Figure 7 Evaluation and comparison of different architectural design alternatives in terms of energy use

with triple glazed windows, which increases the insulation of the house. For the third design, the energy consumptions for heating, cooling, and equipment are increased because the bigger windows raise the chance of energy loss. However, energy consumption for lighting is slightly reduced since more sunlight is allowed. For the fourth design, removing the windows on the sides and at the back has similar effect as replacing windows with triple glazed ones in the second design. This example illustrates that the combination of the web-facilitated configuration design and the building performance analysis in the model-based CAD environment could provide significant values for architectural design process.

Scenario Example 4: Pull-based Material Delivery System for Supply Chain Management

In a construction project, material products are often delivered to the site according to schedule plans. Despite accurate planning and forecasting, the schedule plans may vary from the actual demands, leading to inventory in case of early delivery or task delay in case of late delivery. Pull-based material delivery is a supply chain management technique to minimize on-site inventory level. It suggests that products are requested and pulled

Window components with the same ID   Product information of the selected window components

ID*	3 A NE Window
product	Window
productName	200 Series Tilt-Wash Double-Hung Window
modelNumber	WIN-200-DHL
material	MetalGlass
color	
quantity	7
supplier	Petom
contact	Jack Cheng
activityId	3039
startTime	2010-04-07
endTime	2010-04-13
contractor	Kenso

Data in Table 'description' in 'cad' on 'CE-556L-PC6'

ID	product	productName	modelNumber	material	color	quantity	supplier	conta
3 A NW Window	Window	200 Series Tilt-Was	WIN-200-DHL	MetalGlass		5	Petom	Jack
2 A NE Window	Window	200 Series Tilt-Was	WIN-200-DHL	MetalGlass		7	Anderson	Jack
3 A NE Window	Window	200 Series Tilt-Was	WIN-200-DHL	MetalGlass		7	Petom	Jack
3 A SW Window	Window	200 Series Tilt-Was	WIN-200-UOW	MetalGlass		4	SuppliTwo	Wilso
2 A SW Window	Window	200 Series Tilt-Was	WIN-200-UOW	MetalGlass		4	SuppliTwo	Wilso
1 A NE Window	Window	200 Series Tilt-Was	WIN-200-DHL	MetalGlass		9	Anderson	Jack
1 A NW Window	Window	200 Series Tilt-Was	WIN-200-DHL	MetalGlass		8	Anderson	Jack
1 A SW Window	Window	200 Series Tilt-Was	WIN-200-UOW	MetalGlass		4	SuppliTwo	Wilso
3 B NE Window	Window	200 Series Tilt-Was	WIN-200-DHL	MetalGlass		2	Anderson	Jack
2 B NE Window	Window	200 Series Tilt-Was	WIN-200-DHL	MetalGlass		2	Anderson	Jack
1 B NE Window	Window	200 Series Tilt-Was	WIN-200-DHL	MetalGlass		2	Anderson	Jack
1 A NW Door	Door	200 Series 2-Panel	DOR-200-MB	MetalGlass	White	1	Anderson	Jack
1 Main NW Door	Door	200 Series 2-Panel	DOR-200-MB	MetalGlass	White	3	Anderson	Jack
2 Main NW Window	Window	200 Series Tilt-Was	WIN-200-DHL	MetalGlass		6	Anderson	Jack
4 A Roof	Roof	Roof	ROF-MH02	Roof	Orange	1	Scott	Mark
4 B Roof	Roof	Roof	ROF-MH02	Roof	Orange	1	Scott	Mark
3 Main Roof	Roof	Roof	ROF-MH02	Roof	Orange	1	Scott	Mark
2 A 1 Bed	Bed	Twin-Size Cotton T	SB4422TOWT	Wooden	White	5	SuppliOne	Dan E
2 A 2 Bed	Bed	Twin-Size Cotton T	SB4422TOWT	Wooden	White	5	SuppliOne	Dan E
2 A 2 Chair	Chair	Tullsta Armchair	EPEL0995	Leather	Black	3	SuppliOne	Dan E
2 A 12 Table	Table	Patricia Finish Table	12193-69	Wooden	Dark Brown	1	SuppliOne	Dan E
2 B 1 Bed	Bed	Twin-Size Cotton T	SB4422TOWT	Wooden	White	6	SuppliOne	Dan E
2 A 2 Sofa	Sofa	Karlanda Sofa	1300SOWT	Leather	Black	1	SuppliOne	Dan E
2 B 2 Sofa	Sofa	Karlanda Sofa	1300SOWT	Leather	Black	2	SuppliOne	Dan E

Building component information model stored in Microsoft SQL Server

Figure 8 Back-end product data stored in Microsoft SQL Server

by the clients rather than pushed to the site by the suppliers. Therefore, it can help ensure that material products arrive on site just in time. This example illustrates the facilitation of material pull system in a web-enabled model-based framework.

Autodesk ADT is used in this example. Information models are stored and managed in a Microsoft SQL Server as the back-end database. The product specification information, supplier information, and activity information are recorded for each product item. The ADT built-in function "dbConnect" is used to link CAD object components to database row items. It is a many-to-one mapping. In other words, a single database item can be linked to multiple CAD components whereas each CAD component can only be linked to a single database item. As shown in Figure 8, when a project manager selects a window component on the third floor of a building and chooses the built-in function "Select Similar", seven window components are selected because they are all assigned with the same ID internally. These seven window components are linked to the same database item, which has an ID of "3 A NE Window". ID is the primary key in the database table. The attribute values of the row item are listed in Figure 8.

Figure 9 shows a pull-based delivery process using the web-enabled environment. Using the built-in dbConnect Manager in Autodesk ADT, the project manager can submit a query for the building components involved in the activities within the following two weeks, from April 5, 2010 to April 16, 2010 (see circle (1) in Figure 9). The building components can be highlighted by hiding the components that are not included in the query result. As shown in Figure 9 (circle (2)), several window components, door components, and walls on Floor 3 are scheduled for installation in the specified period. The SpecifiCAD-based web-enabled interactive tool aforementioned is installed in Autodesk ADT. When the project manager selects a window component, its associated activity and schedule information stored in the back-end database is displayed in the schedule

information module of the SpecifiCAD-based interface (see circle (3) in Figure 9). There is also a "Shipping Request" button on the display which connects to the supplier's web service. The project manager can click the "Shipping Request" button and specify the target delivery date.
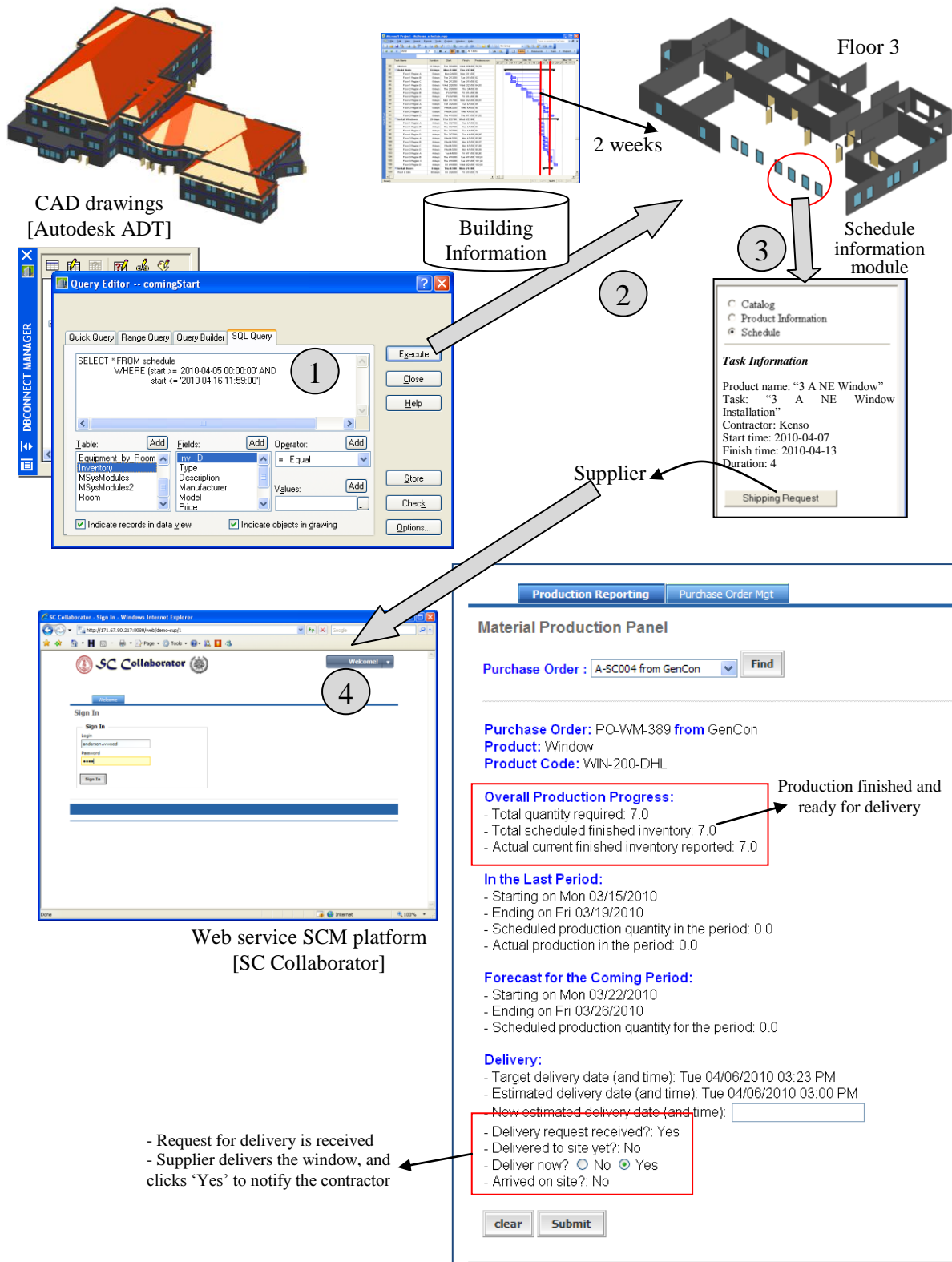

Figure 9 Material pull system scenario using web-enabled model-based CAD framework

In this example, the window product supplier adopts a web service platform namely SC Collaborator (Cheng et al. 2010) for supply chain management. After logging in its SC Collaborator platform, the supplier can see its received delivery requests (see circle (4) in Figure 9). The supplier can further investigate the product and review its production status and availability. The supplier can therefore adjust its logistics schedule to ensure a just-in-time delivery to the site.

CONCLUSIONS AND FUTURE WORK

This paper has discussed the concepts and implementation details of a web-enabled model-based CAD framework using Autodesk ADT and Google Sketchup. This paper has also showcased four example scenarios to illustrate the potential uses of web-enabled model-based CAD for material procurement, configuration design, analysis of design alternatives, and construction supply chain management. CAD applications are traditionally used as a standalone tool for architectural design in the AEC industry. The ability to integrate CAD model with web contents, the building information models, and API supports make CAD applications more extensible, flexible, and accessible. CAD applications can serve as an information hub and interactive tool for knowledge management, communication, and construction planning, operations and maintenance.

In the example scenarios presented in this paper, the data schema of object components are designed on a case-by-case basis without a consistent approach. The Industry Foundation Classes (IFC) standard has become mature and commonly used by CAD vendors as a building information modeling representation in recent years. Further developments will leverage the IFC terminology and data structure to describe and model CAD component information in the web-enabled model-based CAD framework. In addition, CAD information models can be stored externally in a back-end database, which may be accessible to other software applications. Issues of information concurrency and consistency in the model-based CAD framework will need to be addressed in future work.

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