ISSUES OF INTEGRATING BUILDING CODES IN CAD

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Abstract. In this age of information revolution, design professionals are looking forward to exploring new methods and tools that could help them in delivering better designs and particularly understanding and incorporating of code-compliant design provisions in their projects. Automation of building code analysis is a vital factor in leveraging building codes from what is as a textual legal document to more graphical interactive source of building criteria. The argument of the paper will be based on the International Building Code (IBC) which is issued by the International Code Council (ICC) and considered as the most comprehensive and coordinated national model code in the US and is currently commonly used and enforced in 44 states. The paper will also examine and report on the purpose, types, interpretation, understanding and use of building codes applied in the United States; evaluation of recent research activities on automation of building code analysis; evaluation of current building code analysis tools; and a conceptual framework of a Computer-Aided Analysis of Design (CAAnD) program for building codes that could assist design professionals during project design development.

1. Introduction

Not so many years ago, all of the documentation in architectural design practice was produced manually. However things started to change and computer technology becomes more and more fully incorporated into the practice of building design. Although there is a widespread availability and variety of CAD software for each project design phase, complete computer integration are still far from perfect. For instance, in comparison with other architectural design factors, the “Analysis and Evaluation” issue is considered the currently least served and integrated design aspect in CAD systems (Khemlani, 2001). Designers are obligated to check the compatibility of their architectural design with locally adopted building codes and other requirements preferred by the owner (e.g. energy, cost, circulation, egress and lighting).

It is a tedious process to manually search for building code provisions. Designers read a relevant code section, interpret the intent of the code and then try to visualize any code problem in their design. There are no illustrations in building codes to help designers visualize what is described in the text. The building permit-issuing body checks the drawings and may have a different interpretation. The consequences of this process are costly and time-consuming rework, costly last minute design changes and delays during construction.

It is the time for design professionals to demand more than simple 3D model CAD software that provides geometrical representation with textual support. The concept of the Building Information Model (BIM) as a 3D digital database of the building should extent beyond properties, prices and manufacturers of building elements to support the creation and extraction of graphical and non-graphical characteristics of building components that support the analysis of design data and the next generation of smart building models that will transform the CAD industry from the era of computer-aided design to computer-aided analysis of design.

In order to understand the issues of integrating building codes in BIM and before evaluating the current efforts in the subject of automation of building code analysis, it is crucial to explore the nature of building codes and how they are applied during various design phases. The structure of the paper will start with exploring what are building codes and their application during the design process; evaluation of current research activities and software used in building code analysis; and will conclude with the conceptual framework for automating building code analysis process during various design phases.

2. Building Codes

2.1. WHAT ARE BUILDING CODES?

The Webster's Third New International Dictionary defines a building code as: "A collection of regulations adopted by a city to govern the construction of buildings" (Gove, 2002).

2.2. PURPOSE OF BUILDING CODES

The purpose of having building codes "is to establish the minimum requirements to safeguard the public health, safety and general welfare through structural strength, means of egress facilities, stability, sanitation, adequate light and ventilation, energy conservation, and safety to life and property from fire and other hazards attributed to the built environment and to provide safety to fire fighters and emergency responders during emergency operations" (IBC, 2003).

However, designers are expected to challenge those minimum requirements and to implement higher standard. In addition to what was locally adopted, designers might be obligated to apply other codes in their designs such as the American with Disability Act (ADA), Federal Fair Housing Act or NFPA 5000 which is developed by National Fire Protection Association and mostly used in the design of federal and hospital buildings.

2.3. TYPES OF BUILDING CODES (PRESCRIPTIVE VS. PERFORMANCE)

A prescriptive code describes the criteria, technical guidelines and possible detailed solutions. It mostly focuses on creating specific and prescribed responses to recognized problems. All the codes prior to the IBC are considered prescriptive in nature (IBC, 2003; Ching and Winkel, 2003).

On the other hand, a performance code sets specific goals, and reference approved methods and requirements that can be used to achieve compliance. The emphasis of performance code is on how a building and its components must perform in preference to how the building must be designed and constructed.

As an example to clarify the difference between the two code systems, a prescriptive code section might state that "travel distance to the nearest exit shall not exceed 200 feet (64 meters)", while a performance requirement might mandate that "means shall be provided to evacuate, relocate or defend in place occupants of buildings for sufficient time so that they aren't exposed to instantaneous or cumulative untenable conditions from smoke, heat or flames" (IBC, 2003).

The advantage of the performance-based design (PBD) option as it offers more freedom and less restricted solutions to designers. However, it involves greater sophistication in comparison with prescriptive design. By adopting a performance code, the designer is obligated to prove scientifically that a building's design meets the code's goals and objectives. This process might incorporate the use of scientific methods, computer and physics models and testing various expected fire-hazard scenarios. In addition, both designers and building officials should demonstrate advanced knowledge, skill and expertise using performance code (NFPA, 2002).

2.4. UNDERSTANDING OF BUILDING CODES

The key word to understand codes and standards and how they were developed is "intent". The intent of the code-writer is to solve a specific design problem with prescriptive words. Based on certain experience, upon construction or a life safety issue, the problem was identified. Accordingly, the code writer defines the performance criteria and then various acceptable solutions are articulated in a "code section". Therefore the "Why" is more important than "What" when it comes to interpretation of codes (Ching and Winkel, 2003).

IBC - Section 104: Duties and power of building officials, states that "The building official is hereby authorized and directed to enforce the provisions of this code. The building official shall have the authority to render interpretations of this code and to adopt policies and procedures in order to clarify the application of its provisions. Such interpretations, policies and procedures shall be in compliance with the INTENT and PURPOSE of this code. Such policies and procedures shall not have the effect of waiving requirements specifically provided for in this code."

The building code provides the designer with the flexibility to visualize the spatial requirements, develop applications and search for alternate means and methods to those given in the associated code provisions. The above code section also recognizes the ongoing innovation in building materials and construction technologies. It describes how building officials should proceed in the approval of alternative design solution. The proposal should comply with the intent and be at least equivalent with what is prescribed in the code in terms of quality, strength, effectiveness, fire resistance, durability and safety.[2]

2.5. INTERPRETATION OF BUILDING CODES

Building officials and designers are having different views concerning code interpretation based on their functional responsibilities. The role of building official is defined in IBC as “to clarify the application of code provisions” while the designer aims primarily to satisfy the building owner’s needs; functionally, economically and aesthetically. Verifying compliance is the prime task of building officials while demonstrating compliance is what designers must do. The difference of opinions may occur as both sides’ work on applying general code statements to a specific project. Similar projects may have a different interpretation in different jurisdictions. In order to resolve these differences, designers must work with building officials to bridge any gap between the intent of the design and the interpretation of the intent of the code. If no agreement is reached between both parties, the designer can appeal the ruling of the Authorities Having Jurisdiction (AHJ) to a prescribed civic body in the jurisdiction.

The construction documents prepared by the designer should incorporate minimum code analysis items such as occupancy classification, type of construction, building height and area.

In addition, as stated in IBC - section 106.1.1: “Construction documents shall be of sufficient clarity to indicate the location, nature and extent of the work proposed and show in detail that it will conform to the provisions of this code and relevant laws, ordinances, rules and regulations, as determined by the building official.”

2.6. USING BUILDING CODES

The following procedure outlines the steps for code analysis. These steps are used in multiple codes such as the Uniform Building Code 1997 (developed by ICBO) and California Building Code 2000. It applies to a majority of situations that involve an analysis of code requirements for a specific use and anticipated construction type (CBC, 2001).

1. Classify the building:

   A. Occupancy: Determine the occupancy group according to the intended uses of the whole building or the portion it most nearly resembles. Calculate the gross floor area and the allowable occupant load of the building.

   B. Type of Construction: Determine the type of construction of the building by the building materials used and the fire resistance of various parts of the building.

C. Location on Property: Determine the location of the building on the site and clearances to property lines and other surrounding buildings. Determine the fire resistance of exterior walls and wall opening requirements based on proximity to property lines.

D. Allowable Floor Area: Determine the allowable gross floor area of the building. Verify the basic allowable floor area based on occupancy group and type of construction. Compute the allowable increases in floor area based on location on property and the installation of approved automatic fire-sprinkler system. Determine allowable floor area of multistory buildings.

E. Height and Number of Stories: Determine the height of the building and the number of stories. Verify the maximum allowable height and number of stories based on occupancy group and type of construction. Determine the allowable height and story increase based on the installation of an approved fire-sprinkler system.

2. Review the building for conformity with occupancy requirements.
3. Review the building for conformity with the type of construction requirements.
4. Review the building for conformity with exiting requirements.
5. Review the building for other detailed code regulations.
6. Review the building for conformity with structural engineering regulations and requirements for materials of construction.

Although the steps mentioned above seem sequential, in practice it is more interactive and requires back and forth process of review to achieve an optimized compliant design solution (CBC, 2001).

3. Building Code Analysis during and after Project Design Phases

All design projects proceed through certain phases that are common in most designs. Each design phase characterized by its defined activities and requirements although there is slight overlap between the sequential ones. The sequence of these phases is not strict and may slightly vary depending on the size and nature of the project, which can range from a simple extension to an existing building to a completely new building. Each design phase will be defined and discussed in relation to building codes requirements (CSI, 1996).

3.1. PLANNING/PRE-DESIGN PHASE

Every project begins with an idea or a need. The owner will then perform or demand the services of a registered design professional to perform or assist in the preparation of planning/ pre-design phase activities such as feasibility studies, facilities planning, site analysis, budgeting, or environmental impact analysis. If the project includes remodeling, the existing condition of the facility should be explored in the study. The objective of this phase is to determine whether or not the idea is economically sound and whether the return on investment will satisfactory cover the projected construction cost, operating expenses and generate the projected level of revenue. The designer will investigate basic building code and Zoning Ordinances related items through this analysis, such as zoning restriction, pedestrian or vehicular accessibility and the existence of local amendments to building codes. (Ching and Winkel, 2003) This investigation will lead to preliminary design decisions at the project level.

3.2. DESIGN PHASE

The design phase consists of four sub-phases.

1. Conceptual design phase
2. Schematic design phase
3. Design development phase
4. Construction Documents and specifications phase

3.2.1. Conceptual Design Phase

After reviewing and evaluating the owner's building program and budget requirements, the designer provides the owner with alternative approaches to the design and construction of the project. The designer prepares various design schemes and a detailed design program listing all the spaces, functions, estimated areas, preferred adjacencies and inter-relationships. The results will be in a form of small-scale preliminary sketches of overall form of the building, the massing, relationship diagrams and an outline of the building in relation to the site and possibly a simple sketch of the key sections and elevations. The designer presents these conceptual drawings to the owner in order to obtain his/her approval of a design scheme for development during the next phase (Khemlani, 2001).

During the preparation of design schemes, the designer should examine and revise the decisions taken during the previous phase and extend the analysis to the building code related issues at building and major space level.

3.2.2. Schematic Design Phase

The design scheme selected by the owner is detailed during this phase. The designer will start identifying the criteria for the building materials and products, for exterior elevation finishes and for structural, mechanical and electrical systems based on the approved design criteria. Based on the design program and overall shape and form, the designer begins to locate and dimension major spaces at an abstract level. The designer presents the development of design to the owner in a format of plans, elevations, sections, renderings, perspectives, 3D models and basic detailing of particular areas. The owner also receives written documents, which provide preliminary project description, outline specifications and cost projections (Khemlani, 2001; CSI, 1996).

During the schematic design phase, the building code analysis process continues in revising former building design data and checks all design decisions at floor and space level.

3.2.3. Design Development Phase

The design development phase follows the approval of the schematic design and any necessary modification to the budget or the design program. During this phase, the design is further refined and detailed plans, sections, elevations and construction details are developed. The designer determines the type and size of equipments and focuses on technical issues, such as, constructability and integration of building systems and components. The space layout is now finalized to include its physical characteristics (length, height and depth) and material properties of walls, doors, windows, floor and ceiling. The outline specifications are revised after update of all of these design elements.

Before preparing the construction documents, the design has to be intensively checked against locally adopted building code and other design criteria related to circulation, energy, lighting and others preferred by the owner. (Khemlani, 2001; CSI, 1996)

The intensive building code checking process covers every building code related items and details. The design data at this phase are considered “Exact” and “99% Final”. These data includes but not limited to:

1. Occupancy and construction type of all spaces.
2. Construction details that reflect the relation and connection between building materials and components.
3. Layout and height of the building.

4. Number, height and area of floors.
5. Circulation routes including location, type and size of elevators, stairs and ramps.
6. Intensive occupant load analysis.
7. Number, type and size of exit doors.
8. Travel distances to exit doors and areas of refugee.
9. Locations, sizes and types of openings in exterior and interior walls.
10. Level of fire hazards between adjacent spaces
11. Topological information (i.e. spatial relations between building components, such as separation, adjacency, connectivity & intersection)
12. Zoning Ordinances and ADA related items.

3.2.4. Construction Documents and Specifications Phase

The construction documents and specifications phase is considered the final design phase and it is based on the approved design development documents. The objective of this phase is to provide graphic and written information necessary for bidding, construction and future building management. All the documents produced during this phase in the form of drawings and specifications are considered as legal documents and should clearly illustrate the work, rights, duties and responsibilities of all parties involved in the construction process. (Khemlani, 2001; CSI, 1996)

The designer is obligated to explicitly prove the project compliance with various adopted building codes by graphically presenting and textually affirming the description of every building component or detail related to issues addressed by the building code.

4. Automation of Building Code Analysis Process

4.1. INTRODUCTION

An observer of the CAD market could simply notice the widespread availability and variety of CAD software for each design phase. Everyone may agree that computer technology has become more and more fully incorporated into the architectural practice. However, complete computer integration and automation are still far from perfect.

"Why does software for building design and construction continue to imitate manual procedures?" This question rose during the International Symposium on "Building Systems- Automation and Integration." (Building Systems, 1993)

Unfortunately, little has been done to tackle this crucial subject. No substantial development will occur without the transformation of AE computer-based technology from the era of Computer-Aided Drafting and Design (CADD) to the stage of Computer-Aided Integration and Analysis of the Design process (CAIAD). The building design team is under pressure to use as much design tools for design analysis and building performance prediction as possible.

4.2. RELATED WORK

Very little research was made and few papers were published about automation of building code analysis. Among those papers which directly addressed this issue was "A client/server framework for on-line building code checking" (Han et al) which aimed to develop an on-line automated building code checking system to service both designers and permit-issuing bodies.

4.2.1. A Client/Server Framework for On-line Building Code Checking

The paper focused on developing a framework for handling architectural building code issues by initially investigating handicapped accessibility requirements in building designs. Several issues were explored as major elements in the study:

1. The criteria of the building model.
2. The representation of code provisions.
3. The relevance of the provisions with respect to design components.
4. The encoding of component-based provisions.

In order to facilitate design data exchange, the study recommends that the client should use a standard product model such as the Industry Foundation Classes (IFC) and the Standard for the Exchange of Product Data (STEP). The plan was developed using an "IFC compliant CAD package" to create an IFC EXPRESS file from an architectural design. The file would then be sent to a code-checking program (CCP) located on a remote server. The program examined the IFC data file and posted the results to a web page. The web page presents the building model graphically with the "redline" information and hyperlinks to the review comments and the building code related provisions. The study has only applied to those issues related to door accessibility as an example that could extend to accommodate others associated with a building code or ADAAG.

A simple AutoCAD-to-IFC translation module was developed to generate the building class attributes and relationships required by the code-checking program in order to perform the building code analysis. Since AutoCAD natively does not support IFC building model format, an additional layer was created of building component objects with semantics compliant with the IFC hierarchy. An AutoLISP routine extracts and converts the IFC information from the enhanced AutoCAD database into an IFC EXPRESS file.

The paper studied the following ways applied in examining the relevancy of a building design to certain building code provisions:

1. Determine the provisions applicable to a specified building component or system of building components.
2. Determine building component or system of building components applicable to a certain provision or set of provisions.
3. Resolving exceptions within a provision.

4.2.2. Conclusion

This paper is considered as an indispensable contribution in mapping the directions in the field of CAIAD. I think there are fundamental issues that the paper either failed or avoided to address relative to building code checking. These issues include:

1. Although the study was titled to handle building code issues, it applied only one example of the disabled persons' architectural design requirements, which do not represent the core, and body of building codes. (Refer to the Purpose of Building Codes).
2. The study assumed without providing factual indications the similarity between the application of handicapped accessibility issues and other building code essential subjects. The generalized solution proposed by the study applied one case only (i.e. door clearance) and therefore it lacks behind in demonstrating enough evidences for generalizing the on-line framework.
3. The study did not address some basic subjects related the automation of building code analysis. For instance, it did not establish the relation

between the study and the building code analysis process during various project development phases.

4. IFCs are still under continuous development by the IAI and still lack the consideration of the requirements of the building code model and the building data model. The paper in this case may help in the continuous development of the IFCs and object model.
5. The target groups, as defined by the study, were design professionals and permit- issuing bodies. Although they may collaborate with each other in particular after the construction document phase, the two entities have different role and responsibilities. Therefore the proposed framework may best fit designers after the construction document phase. What about the preliminary building code analysis process during the design phases those are ahead of the construction document phase?
6. The study focused on the framework without defining and explaining key elements in the success of the proposed system such as:
   A. Which “IFC compliant CAD package” was used to create an IFC EXPRESS file from an architectural design?
   B. What is AutoCAD-to-IFC translation module and how it works within AutoCAD design environment?
   C. How and what program was used to develop the link between the building components, code comments and code sections?
   D. How building codes or ADAAG were organized to achieve their research goals?
7. The paper described the functions of the framework without much detail on how those functions work.
8. The study did not discuss other possible valid scenarios about on-line building code checking.

4.3. AUTOMATED BUILDING CODE CHECKING SOFTWARE

4.3.1. Plan Analyst-IBC 2000 (PA-2000)

Plan Analyst-IBC 2000 is stand-alone software developed to be an easy and affordable tool to streamline the plan checking process during the early stages of the design process. Three types of projects can be checked against the IBC using the software; commercial, single family dwelling and open parking garage. The software provides a customized check list and a code compliance report that shows code deficiencies based on user textual inputs. Other building code-checking software such as “Build2Code” with features and procedures has similar limitation to Plan Analyst which was developed to offer designers various benefits, as indicated by the software developer such as:

1. Improve in efficiency and quality of code checking process.
2. Convenience in the plan checking process.
3. Elimination of simple math errors and inconsistencies.
4. Reduction in plans checking time and elimination of hours of code study research.
5. Customization of code requirements.

4.3.2. How Plan Analyst Works

To use the Plan Analyst software, the designer extracts the required building code related information from the drawings and enters this information as textual into the software interface following particular steps:

Step 1: Enter basic description of the building

Step 2: Enter the basic description for each floor

Step 3: Select the use of each area and enter its floor area.

Step 4: Enter site description

Step 5: Indicate the type of construction and fire sprinkler info

Step 6: Select additional building features.

Step 7: Select customized Checklist.

Before viewing the analysis report, the user may select the question groups to use in completing the code checking process. The user will select whether each item/question was addressed or not on the plans. If the answer is not, the user will be asked to enter the location of the problem on the drawing to be added to the final correction report with reference to the applicable code section.

Step 8: Analysis Report

When the project description finished, automatically the analysis report is generated to include:

1. The relation between the project description and code requirements by referencing the description to the applicable building code section.
2. Explanation of where and where not the design does comply with the IBC with reference to building code section.
3. Indication of missing information

4.3.3. Conclusion

The Plan Analyst Software can be considered as a vital but immature step towards complete automation and integration of building code checking practice into the architectural design process. This statement could be seen more evident if we regarded the following conclusions:

1. It is also regarded as a rudimentary tool and could only be used in early design phases. (Khemlani, 2004)

2. The steps of plan checking as described above is a strictly linear process and it does not conform with the conventional design process which sometimes requires search of minor building code issues.

3. The nature and procedures of plan checking as adopted by the Plan Analyst software requires the user to have a comfortable knowledge in order to benefit from it. That's mean designers with no code checking experience could hardly use the tool.

4. The application of Plan Analyst software is based on tedium procedure of textual rather than graphical input besides calculating manually the area of different building components. (Khemlani, 2004)

5. Plan Analyst could not be integrated into any other CAD tools. That means it is still far away from becoming desirable by the mainstream of designers.

6. It doesn't provide users with very important information/service such as:
   A. Updates on building code sections
   B. Inquiry tool to search various code issues.
   C. Graphical support that interprets code sections.
   D. Limited scope of projects could be checked using Plan Analyst.

7. Although the checklist covers a lot of issues, it doesn't clearly explain how to comply with the requirement addressed in the question. This means that the user will still need to go back to the building code book to search for answers.

5. Conceptual Framework of a Computer-Aided Analysis of Design (CAAnD) program

Considering the nature of building codes and their application during different project design phases, the conceptual framework of automating the building code analysis process should consists of three digital development areas which based on the transformation of graphical representations and textual information into data that could checked using computer-analysis program. (See Figure 1)

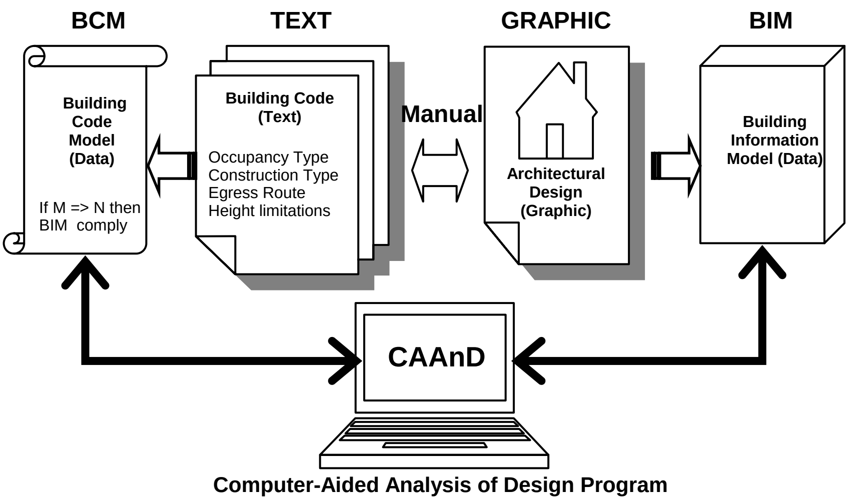

Figure 1. Conceptual Framework for automated building code analysis of design

These transformations include:

A. Building Codes ► Building Code Model (BCM).

B. Architectural Design ► Building Information Model (BIM).

C. CAD systems ► Computer-Aided Analysis of Design program (CAAnD)

5.1. OBJECTIVES

This framework aims to:

A. Correspond to the functions, attributes and structure of a BIM that conforms to the requirements of building codes.

B. Reorganization of building codes in relation to an automated code check process and design practice. The reorganization will assist in leveraging the code from what is now a textual legal document to more graphical interactive source of building criteria.

C. Provide designers with a program that will assist them in the analysis of project design and to inform and advise them on how to understand and search various building code aspects related to project design.

5.2. MODEL CRITERIA

The subsequent criteria define the capabilities of the automated building code analysis program.

5.2.1. Building Code Model (BCM)

The BCM should correspond to the following:

1. The nature, development and application of building codes.
2. The building code compliance checking process at each design phase.
3. The type and subjects of building code.
4. The need to use building codes as Design criteria and an opportunity rather than a constraint.

5.2.2. Architectural Design and Building Information Model (BIM)

The hierarchy and relationships of various objects in the BIM should maintain and facilitate the tasks to:

1. Identify and classify building information objects or entities requested for building code compliance during various project design phases.
2. Extract and categorize the classified information.
3. Structure building information in a data model that's compatible with the nature of the building code and based on each design phase and each design level.

5.2.3. Computer-Aided Analysis of Design Program (CAAnD)

The CAAnD program should be to accomplish the following tasks:

1. Search the building code database by subject.
2. Sort various building codes encoded provisions and highlight those applicable to a particular project type based on input data.

3. Sort various building information and identify those required by the building code.
4. Evaluate the values extracted from building information against the conditions set by building codes. The structure of program should be based on steps followed in building code analysis. (Refer to the section titled "Using Building codes")
5. Associate the outcome of step "4" with the equivalent encoded building code section.
6. Link the encoded building code sections to the original text-based ones and vise versa.
7. Produce a final analysis report on the compliance of building design.

5.3. POTENTIAL IMPACT

The above listed objectives and model criteria will have significant impact on the following:

1. Hierarchy structure of the building information model (BIM) that represents the building design information related to building code requirements.
2. Hierarchy structure of the building code model that symbolizes the building code analysis process.
3. Reorganization of building codes.
4. The future development of BIM and IFCs in relation with the area of computer-aided analysis of design.

5.4. CONCLUSION

The further development in architectural practice is embodied in the progress of computer-aided analysis of design programs and building code checking is an essential element of this progress.

This paper highlighted some of the issues of integrating building code checking in CAD that has become more critical in shaping the criteria of the next generation of architectural software. The paper outlined the conceptual framework that will advance the automated building plan approval initiatives and inspire the continued interest in architectural design analysis.

References

Access Board, ADAAG Manual: A guide to the American with Disability Act Accessibility Guidelines, U. S. Department of Architectural and Transportation Barriers Compliance Board.

AECbytes, www.AECbytes.com

Autodesk Building Industry Solutions, Autodesk. Inc.: 2002, White paper on: Building Information Modeling, www.autodesk.com/buildinginformation.

Bentley, Keith and Workman, Brad: 2003, Does the Building Industry Really Need to Start Over? A response from Bentley to Autodesk's BIM/Revit proposal for the future, Bentley Systems Inc.

Building Systems: Automation and Integration: 1993, Proceedings of the 1991 and 1992 International Symposium – University of Wisconsin at Madison.

Build2Code, www.build2code.com

CBC: 2001, State of California, ICBO, Whittier, CA.

CHBC: 2001, Chicago Building Code, Chicago, IL.

CSI: 1996, Manual of Practice, Construction Specification Institute.

Cyon Research Corporation: 2003, The Building Information Model: A look at Graphisoft's Virtual Building Concept.

Ching, Francis D.K. and Winkel, Steven R.: 2003, Building codes illustrated: A guide to understanding the International Building Code, Hoboken, John Wiley & Sons, Inc., New Jersey, NJ.

Gove, Philip Babcock: 2002, The Webster's Third New International Dictionary - Unabridged, Merrian-Webster Inc., Springfield, MA.

Han, Charles S. – Kunz, John C.- Law, Kincho H., A Client/Server Framework for On-line Building Code Checking, The Center for Integrated Facility Engineering (CIFE), Stanford University.

HUB: Department of Housing and Urban Development, (Docket No. N-94; FR-2665-N-08), Supplement to Notice of Fair housing Accessibility Guidelines: Questions and Answers about the Guidelines, www.hud.gov

IBC: 2003, International Building Code, International Code Council.

Ibrahim, Magdy Krawczyk, Robert and Schipporeit, George: 2002, CAD Smart Objects: Potentials and Limitations, eCAADe 21.

Ibrahim, Magdy and Krawczyk, Robert: 2003, The Level of Knowledge of CAD Objects within the Building Information Mode, ACADIA 2003 Conference, Muncie, IN.

International Code Council www.iccsafe.net

Khemlani, Lachmi: 2001, Architectural CAD: A Look across the Spectrum, CADENCE AEC Tech News #52, www.cadenceweb.com.

National Fire Protection Association (NFPA): 2002, Performance-based design option-NFPA 5000: Building Code will include a performance-based design option for greater flexibility, NFPA Journal, March/April 2002, link www.nfpa.org.

National Fire Protection Association website - http://www.nfpa.org

New Zealand Building Industry Authority www.bia.govt.nz

Oloufa, Amr and Nguyen, Tang-Hung, Automation in Building Design with Spatial Information. http://fire.nist.gov/bfrlpubs/build02/PDF/b02124.pdf .

Plan Analyst, www.plananalyst.com

Singapore Construction and Real Estate Network Project www.corenet.gov.sg

Teichoz, Paul: 1993, The Center for Integrated Facility Engineering (CIFE) at Stanford University: Experience in establishing and running an Industry - University cooperative program for AEC research, Building Systems: Automation – Integration, Proceedings of the 1991and 1992 International Symposium, University of Wisconsin at Madison.

Williams, Arnie: 2004, BIM Sets a New Direction for Architecture, Cadalyst.