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The Automation of BIM for Compliance Checking: A Visual Programming Approach

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Abstract — A study by FIATECH confirmed that human interpretation causes inconsistencies in applying building compliance & regulations (Solihin & Eastman, 2015). Producing, updating and quality assuring such processes is inconsistent and unreliable (Preidel & Borrmann, 2016). A barrier to interpretation of building regulations is that software is designed by developers that are separate to local authorities (Solihin & Eastman, 2015).

The current literature suggests Singapore, Norway, USA & Australia have all implemented BIM automation systems for building regulations. This study reviews current automation systems and based on this proposes a system of creating a checking system is efficient in the control of professionals skilled with local authority and building regulation knowledge. Dynamo visual programming software is selected as the software to assist the automation due to the open source availability and widespread adoption in the BIM field.

A methodology of Design Science is applied to diagnose the problem of manual checking through review of the current literature (Kehily & Underwood, 2015). An automation solution is proposed and evaluated in a design office. Architectural professionals provide feedback of the implemented solution and this feedback is applied iteratively to a second automation solution, where feedback is also obtained from users to further improve the solution. Results show a change in workflow and an improvement of traditional compliance checking. The study concludes by proposing a similar BIM automation approach could be applied in local government, within the Irish Planning and Building Control (BCAR) system.

Keywords — BIM, Automation, Compliance, Dynamo

I Introduction

Compliance checking is a complex task to ensure the functionality of the built environment. In scenarios such as Assigned Certifier role under the Building Control and Regulation and Planning Compliance is a key aspect that should be conducted effectively and efficiently. However, there are key challenges in the current practice such as manual checking, some of which involves interpretation of complex technical documents. The challenges in Building Compliance are revealed more when the information is non-compliant during design and construction of buildings (Solihin & Eastman, 2015).

There is a need for optimising compliance checking for planning and building compliance. A study by FIATECH confirmed that human interpretation causes inconsistencies in applying Building Regulations (Solihin & Eastman, 2015). Producing, updating and quality assuring such processes is inconsistent and unreliable (Preidel & Borrmann, 2016). The certification process is carried out manually by assigned certifiers with a dependence on contractors workmanship. Due to inconsistencies and uncertainties in the process; double-working and revising of design changes causes unnecessary time consumption and is prone to error (Malsane et al., 2015). The compliance requirements of BCAR and Planning compliance of a building such as Accessibility and Floor Area Standards require a reliable approach due to implications of construction reworking. It is also important to identify non-compliance at design stage to avoid revising designs while buildings being constructed. Floor area compliance should not be overlooked at design stage as this impacts the planning decision if non-compliant.

Best practice projects of automated compliance such as Singapore's E-Plan Check System and BIM E-Submission, the ByggSøk System in Norway, DesignCheck in Australia, SmartCodes and the General Services Administration in USA projects provided some evidence of gains and benefits from automating compliance checking. Some key benefits are:

- Streamline business approaches in the construction industry
- Improve application turnaround time.
- Increase quality and productivity.
- Reduce the burden of compliance with regulations.
- Provide feedback to assist Architects and clients in designing buildings.

However, there is still a lack of clear evidence on whether and how BIM could benefit decision making in compliance checking at design stage. That is to say, despite acting as a virtual building, more benefits from BIM for compliance are still to be clarified and explained in an itemised way. The issue should be explored and assessed with current practice workflows. This research paper applies *Dynamo* visual programming software to assist in automating compliance checking.

II GLOBAL CONTEXT – AUTOMATED COMPLIANCE

A literature review, conducted around automated systems provided information on current systems.

Singapore BCA BIM E-Submission (2016)

Currently developments of a Gross Floor Area larger than 5,000sqm is accepted by Singapore BCA in a native BIM format, Revit Archicad or Bentley. These were submitted in a dwf or pdf format until recently. Since October 19th 2016 BIM models can be submitted in a Native BIM format. BIM submission is voluntary, this is intended to support industry in familiarizing themselves with BIM submissions. Mandatory BIM submission will be required in the second half of 2017 (Tan Jwu Yihn, 2016). It aims to improve business approaches in the construction industry to improve application turnaround time, quality and productivity. In turn this will streamline the construction sector.

E-Plan Check Singapore (2005)

The E-Plan Check project was an effort to check building codes automatically through IFC & CAD. It was implemented in the Singapore Building Authority in the year 2000 by CORENET. This system failed initially due to the proprietary nature of the application and its inability to handle bad data. It was aimed at Architecture and Building Services checking. The solution aim of the project was to reduce the burden of compliance to regulations. This effort brought together expert knowledge of regulations, artificial intelligence and BIM Technologies (Khemlani, 2015).

The complexity of rules in Singapore, led to as much as 30% of the total time to implement an automated rule within an automated system. The complexity of Building Regulations and variations of interpretation are typical features of automating regulations. A study by FIATECH confirmed Building Inspectors from varying local authorities gave different interpretation of building regulations The CORENET system went through several iterations as a result of human interpretation (Solihin & Eastman, 2015). An independent platform; FORNAX, was developed to extract basic BIM information from IFC data and links to regulation information (Khemlani, 2015).

Australia DesignCheck (2006)

Designcheck is an automated regulation checking system for the Building Code of Australia (Ding, Drogemuller, Rosenman, Marchant, & Gero, 2006). The system employs a shared object oriented database with and Express Data Manager Platform (Drogemuller, Jupp, Rosenman, & Gero, 2004). The EDM contains model schmeas, rule sets and querying schemas (Lee, Lee, Park, & Kim, 2016). The rule sets define the regulations to validate data models using the Express language. The initial feasibility project “Design for access and mobility” building regulation was encoded. Object based interpretation was tested for specification and used descriptions, requirements of performance, objects, properties and relationships to domain specific knowledge. The object based interpretation was encoded into the EDM rule sets (Lee et al., 2016).

ByggSøk Norway (2009)

ByggSøk in Norway is a public system of zoning and building information. The electronic system handled building applications and zoning proposal information. This system was part of a collaboration with Singapore to share experiences. The Norwegian system is based on the Singapore CORENet E-Plan Check System platform and performed accessibility and spatial checking against regulations (Lee et al., 2016). The system uses dRofus software with Solibiri Model checker. The model is in IFC format and stored on an IFC model server (Greenwood, Lockley, Malsane, & Matthews, 2010). The project suggested six stages for a standardization process (Lee et al., 2016):

1. Define scope and source for regulation data.
2. Computability assessment,
3. Committee assessment,
4. Logic rule notation,
5. Selection of rule format and
6. Implementing of the rule in checking software.

USA International Code Council SmartCodes

The SMARTcodes project of the International Code Council implemented code checking with Model Checking Software (See & Conover, 2008). The system was developed to automate regulation compliance checks for federal and state codes (Wix, Nisbet, & Liebich, 2008). Architects and designers could submit their BIM model online as part of a planning application . The hierarchy of this system linked table information in a cell format, similar to Excel (Choi & Kim, 2015). The system was a bespoke programming based on XML to only address Smartcodes commands and operations (Wix et al., 2008). The models are viewed using Solibiri Model Viewer through an IFC format.

Dynamo BIM

Dynamo BIM is a visual programming platform developed as an open source download. It aims to extend BIM with the data and logic environment of a conceptual graph method. The platform works on C## and Python programming language (Rahmani Asl, Zarrinmehr, Bergin, & Yan, 2015). It reduces the requirement to understand computer programming by providing a node based environment. The author was aware of Dynamo and this was chosen based on its prominence in architectural offices, knowledge was gained from attending the Dynamo Users Group Ireland. Other visual programming tools include Grasshopper and Flux, this study has not used these platforms. Dynamo was selected due to its integration in Revit, it is a plugin that resides in the Revit toolbar and automatically links to the open Revit file. A limitation of the research is that not all visual programming tools were tested for automation. Although, based on the research of Eastman et al (2015) of conceptual graph mapping that was applied in the Singapore BCA checking system, Dynamo functions as a form of conceptual graph mapping.

II ANALYSIS OF IMPLMENTED SOLUTION

The proposed solution was developed and tested as Solution No.1. An Architectural Technologist who is familiar with Revit was used to test the solution in practice. A user feedback survey was provided after the use of the solution. The feedback from Solution No. 1 was applied to Solution No. 2 in order to further develop the solution in a cyclical process.

Solution No. 1

This was an initial automation carried out through Dynamo and Revit to Excel. The Dynamo element was entirely not part of the users assessment as the subject only needed to operate Revit and then to view the spreadsheet of areas. However, users were given a demonstration of the function of the Dynamo

Solution No. 2

The second solution was based on user feedback from Solution No. 1. Additional features were added as a result of the feedback from Solution No 1. A lookup table of standards was compiled in a spreadsheet in Excel. This was linked to the floor area output data from Dynamo. Formulas were added for floor area data to be retrieved and checked against the standards lookup table. Excel allowed the data to be filtered by house type and house number. This was enabled by adding a parameter in the Revit model to each room tag.

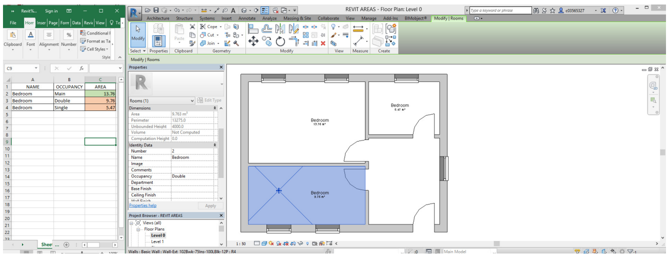

Figure 13 - Solution No. 1 linked Revit to Excel using Dynamo.

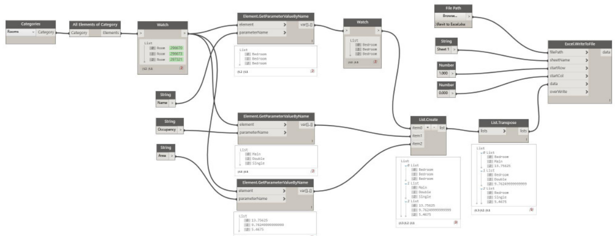

Figure 14 - Dynamo nodes creating Revit Link to Excel.

Solution No. 2 focused on enhancing the spreadsheet function. A lookup table of Figure 16 was created in a spreadsheet and condition functions were added in Excel. This function was not ran in Dynamo due to the complexity of the data required.

DWELLING TYPE	TARGET GROSS FLOOR AREA	MINIMUM - MAIN LIVING ROOM	AGGREGATE LIVING AREA	AGGREGATE BEDROOM AREA	STORAGE
	(m^2)	(m^2)	(m^2)	(m^2)	(m^2)
Family Dwellings - 3 or more persons					
4BED/7P House (3 storey)	120	15	40	43	6
4BED/7P House (2 storey)	110	15	40	43	6
4BED/7P House (1 storey)	100	15	40	43	6
4BED/7P Apartment	105	15	40	43	11
3BED/6P House (3 storey)	110	15	37	36	6
3BED/6P House (2 storey)	100	15	37	36	6
3BED/6P House (1 storey)	90	15	37	36	6
3BED/6P Apartment	94	15	37	36	10
3BED/5P House (3 storey)	102	13	34	32	5
3BED/5P House (2 storey)	92	13	34	32	5
3BED/5P House (1 storey)	82	13	34	32	5
3BED/5P Apartment	86	13	34	32	9
3BED/4P House (2 storey)	83	13	30	28	4
3BED/4P House (1 storey)	73	13	30	28	4
3BED/4P Apartment	76	13	30	28	7
2BED/4P House (2 storey)	80	13	30	25	4
2BED/4P House (1 storey)	70	13	30	25	4
2BED/4P Apartment	73	13	30	25	7
2BED/3P House (2 storey)	70	13	28	20	3
2BED/3P House (1 storey)	60	13	28	20	3
2BED/3P Apartment	63	13	28	20	5
1BED/2P House (1 storey)	44	11	23	11	2
1BED/2P Apartment	45	11	23	11	3

Figure 15 - Quality Housing for Sustainable Communities, Department of Environment (DOE, 2007)

The linking of this information to Dynamo and Revit workflow outlined below.

1. Local Authority and relevant design standards are established before a project is modelled.
2. The design standards are cross-referenced to BIM space and room parameters.
3. Compliant and Noncompliant elements highlight in Green or Red within a Revit Schedule and in a linked Excel spreadsheet.
4. The next step is to correct non-compliant spaces or note them accordingly should a dispensation be sought from the local council.
5. The architect / technician or technologist preparing the application, submits the BIM model to the council via an online submission. This means skilled staff are not wasting time printing drawings.
6. The local authority planning department perform a similar checking task facilitated through their own Dynamo link to the model. This could be their check to confirm no information has been misrepresented in the submitted model.
7. At this point the compliant areas have been checked.
8. The information of floor areas is now stored in the model and can be retrieved along a building supply chain at any point in time, including land registry.

Each automation workflow aims to save time and maintain consistency of information. The significant changes in the manual checking tasks of architects practices and local authorities achieved through BIM Based processes is reported in the results of user feedback. However, there was a steep learning curve for all involved and this caused more problems for some employees than others.

The automation process has a profound impact on the current work practices of individuals and on offices as a collective. Without implementation of BIM-based Automation processes, architects, technicians and technologists were involved in manual tasks in relation to the checking of floor areas and again when revisions were made and then to update an isolated spreadsheet document. Skilled workers can now solely focus on design because they have automation tools that are managed by a BIM specialist, as opposed to each individual having their own method of checking. As long as the visual scripting is well-managed and reliable it takes the onus away from individuals.

The BIM environment is very different to traditional CAD.With BIM modelling software a tag must simply be added to an area immediately the associated spreadsheet is populated with floor areas. Their trust is now placed in the reliability of the software and in the individuals responsible for maintaining the Dynamo programming link. Upskilling is required for designers to use BIM modelling software but programming skill is only required by but programming by BIM management or their sub-contractors.

The ability to tracing of the information which could be considered invasive by professionals, could also be a major positive once fully implemented due to reduced in the full lifecycle of a project. Evidence of this benefit was shown in a case study of lean processes in the off-site manufacture of mechanical components (Keane, McCarthy, Ahern, & Behan, 2014).

During the early stages of implementing automation, a risk is involved if users do not name their rooms and spaces to stringent modelling and naming standards. This could be overcome once users are familiar to the new workflow and a model guideline document is implemented similar to Singapore (Samaniego, 2016).

The visual programming through Dynamo that was central to this particular study of automating a manual process, provides a linking of software to workflows that wasn't previously possible. When first used the software did not have all the functions currently available but the researcher in conjunction with individuals feedback, customised and developed to optimise the solution and to ensure that it supported rather than hindered the workflow.

Among other items, the automation connects information that can be reused at a later stage similar to the Korean system of linking planning to legal information (Yoo et al., 2015). If a problem arises with boundary information or site areas in the future. It can be traced back through the supply chain from design office to planning to sale of a building. This could act as an incentive to improve the quality of information along the supply chain. It also ensures that BIM information maintains a consistent standard. The data recorded may also indicate the timeline and productivity of an overall office or local authority workflow (Yoo et al., 2015). This may inform operational costs and lead to cost savings (Yoo et al., 2015).

Although there may still be occurrences of the system proving to be too rigid, a flexibility could be built into the automation process to not entirely remove the human factor of traditional practices. In solution No. 1, standard areas that are known to be fixed in a planning system were trialled as according to Survey no. 2 these can take cad users additional time to ensure areas are correct.

Some additional skills and workflow changes are required to adopt visual programming as the automation facility. For example this research was based on mainly cad users, the automation however is based on BIM software with a requirement to learn visual programming. Despite the additional requirement, user feedback on the use of the automation demonstrated a more efficient process.

III CONCLUSION

The research presented here demonstrates the results of applying BIM Automation at a small scale in an architects practice. It has shown that it can work and be efficient, particularly through good management of the automation programming.
It was predicted by the researcher that automation would appeal to architectural professionals surveyed, surprisingly the returned data proved that design rigidity i.e. being bound to rules was a concern as certain regulations have unforeseen outcomes. This is addressed in the research by suggesting that flexibility of design is always considered at design stage by allowing compliance exemption suggestions. The automation is a design assist rather and at local authority level a stringent rule enforcer. However, as suggested by Ding et Al (2006) the certification process is improved by the automation process, thus in an Irish context, this offers rigour to the Assigned Certifier role under the Building Control and Regulation Amendments 2014.

Industry Foundation Classes (IFC) has been identified as adding value to semantically rich models. IFC is used in the countries covered in this paper to adopt a compliance system. This is due to IFC adding value to semantically rich models. This research does not use IFC parameters but could be applied due to it having such comprehensive schema coverage (Malsane et al., 2015).

Evaluation of BIM automation through Design Science methodology by. This methodology set out by Diagnosing the Problem, Developing a solution and Evaluating the solution with user feedback has been completed (Von Alan et al., 2004).

The Dynamo visual programming that has been adopted and implemented in support of automation fills the gap, identified by reviews of most national automation systems of the required computer programming-development skills.. As suggested by Choi and Kim (2015) in Korea an open source and easy to use software does not hinder but rather enhances creativity. The easy to use Dynamo software gives control of BIM information to BIM Managers, Architectural Technologists, Technicians and Architects.

As a result of this research, the researcher and users involved have developed skills by observing visual programming. The mundane manual tasks have been removed daily users of the automation. This allows designers to focus on more complex compliance and design challenges. It is envisaged that these factors will support consistency of information throughout the supply chain of a building's delivery; i.e. Design, Planning, Tender, Construction and Handover.

The use of visual programming similar to Dynamo offers a flexibility of compliance checking. In systems implemented globally all these rules are hardcoded with knowledge of computer programming required. This hard coding does address the risk of non compliance but it does take out the human element. Human interpretation is still required in some elements of design and can vary on a case by case basis. This human element can be further applied through conceptual graphs of visual programming.

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