N. Gu, S. Watanabe, H. Erhan, M. Hank Haeusler, W. Huang, R. Sosa (eds.), *Rethinking Comprehensive Design: Speculative Counterculture, Proceedings of the 19th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2014,* 305–314.

BIM ADD-ON TOOL FOR AUTOMATED CUI CALCULATION

DANIELS CHANDRA[1] and NING ZHOU[2]
[1,2] *ONG&ONG Pte Ltd, Singapore*
chandra.daniels@group.ong-ong.com, bim@group.ong-ong.com

Abstract. The Building and Construction Authority (BCA) of Singapore established Sustainable Construction Master Plan with the goal of achieving a Sustainable Singapore Blueprint. The Concrete Usage Index (CUI) is a part of Sustainable Construction scoring under Singapore's 'Green Mark' system. Since computation of CUI score was formerly calculated manually without the use of BIM software, it was an inaccurate and tedious process. Although calculation of CUI is currently much faster through the use of BIM software, it still faces challenges. The objective of this project is to address those challenges by creating a BIM add-on tool which is capable of automating the process of CUI calculation with minimum user input. Our intention is to help the industry to calculate CUI systematically and efficiently while promoting the adoption of BIM.

Keywords. CUI; Concrete Usage Index; BIM; Green Mark; sustainable design.

1. Introduction

The Building and Construction Authority (BCA) of Singapore has defined the Concrete Usage Index (CUI) for the optimal use of concrete in building construction (BCA, 2012). When a building is designed efficiently, it will usually achieve a lower CUI value without compromising construction safety and productivity. Prior to the advent of BIM software, the CUI score was calculated manually. This method required design/engineering consultants to spend a week or more on the calculations. Although the time required for this process has been reduced due to the use of BIM software, some manual processes are still necessary, including data extraction and post data processing of total concrete volume and constructed floor area from structural and architectural BIM models.

Certain conditions of the BIM model need to be met in order to achieve accurate results. The calculation is only accurate if the concrete elements are modelled correctly with the correct material input. This process involves challenges for minimising error due to software limitations and the degree of the user's modelling skill.

Moreover, modelling only serves as a partial automated CUI calculation, as the extracted data from structural and architectural BIM models will be consolidated for manual CUI calculation to get the actual CUI score. Although this consolidation does not take as long as the modelling process, it still contributes to the total time required to complete it.

Since the BIM model already has all the data needed for CUI calculation, it should be possible to streamline the process. In this case, BIM authoring software should be able to generate the CUI score automatically without manual calculation. The CUI score should also include the concrete usage for both architectural and structural so users do not need to repeat the process twice. However there are still limitations on the BIM software, and although add-on software is useful for filling these gaps, it may not address all the issues.

Currently, most well-established types of BIM software have opened their programming interfaces. We can have access to their system for creating an add-on tool which serves as a plug-in for the software. The objective of this paper is to explain the current challenges of calculating CUI by using specific BIM software. We will also conduct some experiments by developing an add-on tool to address those challenges which affect the accuracy of the final CUI score. We will compare the output of CUI calculation using the current 'out-of-the-box' tool versus our CUI add-on tool. Due to time constraints, the experiment will only focus on the use of the add-on tool to help increase the accuracy of the calculation.

2. Scope of work

Although there are many versions of BIM authoring software on the market, this project will focus on one type of BIM authoring software, namely Autodesk® Revit®. We have chosen Revit® since it is widely used in the Architecture, Engineering and Construction (AEC) industry. The process will involve data collection from the model, data processing/filtering, post processing and finally generating the report. All these processes are being generated within the Revit® platform by utilising the Revit® Application Programming Interface (API).

The add-on will be developed based on the BCA guidelines for calculating CUI. The BCA (BCA, 2012) definition of CUI is the amount of concrete required to construct a superstructure, including structural and non-structural elements. CUI is defined as the "volume of concrete in cubic metres to cast a square metre of constructed floor area."

Calculation of CUI does not include concrete used for external works, or sub-structural works such as basements and foundations.

According to BCA (BCA, 2012) the CUI is expressed as:

$$\text{Concrete Usage Index} = \frac{\text{Concrete Volume in m}^3}{\text{Constructed Floor Area in m}^2}$$

In addition to the total CUI, the report should provide the breakdown of volume and area of each level with a detailed element explanation.

3. Findings

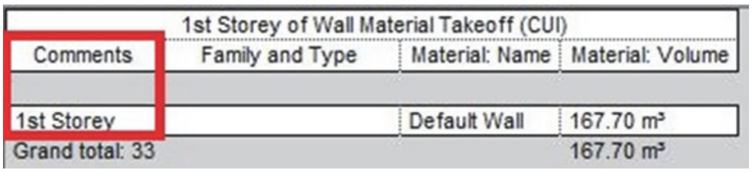
The accuracy of the CUI calculation using BIM software relies mostly on accurate modelling at the beginning. Sometimes users model the building without considering that the same model will be used for the purpose of CUI calculation. In addition, some workarounds may be necessary due to software limitations.

3.1. LIMITATIONS WITHOUT ADD-ON

If we just want to use 'out-of-the-box' tools from Revit® without any add-on we can use the 'Material Take-off' schedule as a starting point. The Material Take-off schedule lists the sub-components or material of any Revit® product (Autodesk, 2013). This, which is useful in cost estimates and CUI calculation. The Material Take-off schedule will track the amount of concrete in the model so that it can be used to create the CUI calculation report, provided the user did input the material and model the building correctly, with consideration of its limitations.

Based on our observation, the Revit® Material Take-off tool has some limitations including:

1. Material Take-off does not have 'Level' parameter. The take-off volumes are combined regardless of which level the element belongs to. Level is one of the important parameters to use so that the report can be generated in detail, level by level. The current workaround approach is to create a manual input by utilizing the 'comments' parameter, provided 'comments' parameter is not being used (figure 1).



1st Storey of Wall Material Takeoff (CUI)			
Comments	Family and Type	Material: Name	Material: Volume
1st Storey		Default Wall	167.70 m³
Grand total: 33			167.70 m³

Figure 1.

2. Vertical element that spans across multiple levels will not be reported correctly. As per figure 2, a wall spanning from 1st storey up to 3rd storey. This will create a potential error whereby the report will show wall on level 1 only but not on level 2 and level 3.

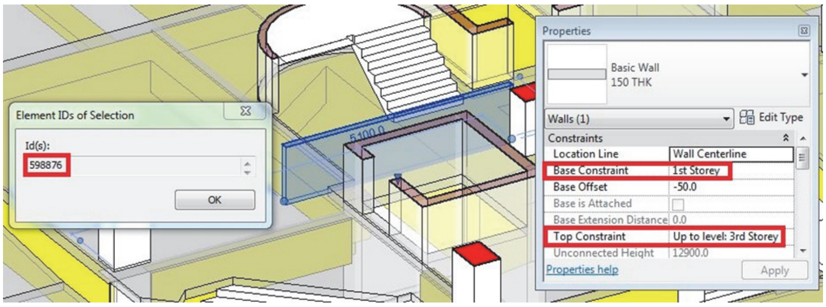
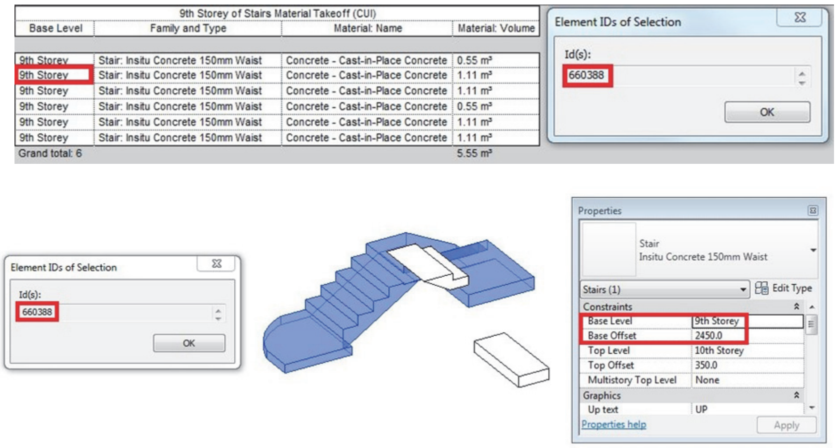


Figure 2.

3. User may manipulate the level setting by using 'base offset' feature in order to adjust the position of the object. This is will create inaccuracy in the report hence some objects may be reported on different levels (figure 3).



9th Storey of Stairs Material Takeoff (CUI)			
Base Level	Family and Type	Material: Name	Material: Volume
9th Storey	Stair: Insitu Concrete 150mm Waist	Concrete - Cast-in-Place Concrete	0.55 m³
9th Storey	Stair: Insitu Concrete 150mm Waist	Concrete - Cast-in-Place Concrete	1.11 m³
9th Storey	Stair: Insitu Concrete 150mm Waist	Concrete - Cast-in-Place Concrete	1.11 m³
9th Storey	Stair: Insitu Concrete 150mm Waist	Concrete - Cast-in-Place Concrete	0.55 m³
9th Storey	Stair: Insitu Concrete 150mm Waist	Concrete - Cast-in-Place Concrete	1.11 m³
9th Storey	Stair: Insitu Concrete 150mm Waist	Concrete - Cast-in-Place Concrete	1.11 m³
Grand total: 6			5.55 m³

Figure 3.

In principle these limitations relate primarily to the level in the BIM environment. Level placement is one of the key factors for CUI because structure works in such a way that basement level may be excluded, based on BCA guidelines. If elements are placed or calculated on different levels, this will exert a significant impact on the overall CUI score.

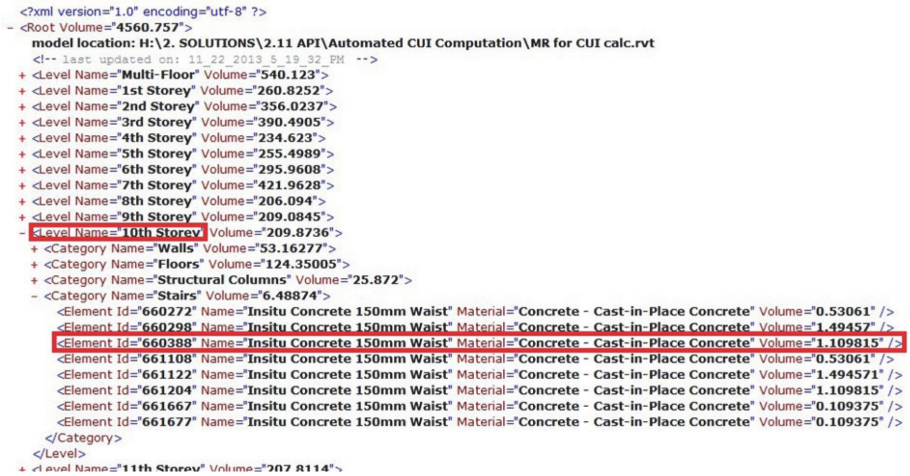
3.2. ADD-ON POTENTIALS

Issues discussed earlier can be corrected by developing an add-on. Currently we developed our Revit® API using C# and have generated an XML report to address the limitations. Figure 4 shows an XML report where element spans across multiple levels can be calculated accurately level by level, using a mathematical average. The XML report shows that the element is located on 'Multi-Floor' instead of having a base constrain on 1st storey as shown in Figure 2.


```
<?xml version="1.0" encoding="utf-8" ?>
- <Root Volume="4560.757">
  model location: H:\2. SOLUTIONS\2.11 API\Automated CUI Computation\MR for CUI calc.rvt
  <!-- last updated on: 11_22_2013_5_19_32_PM -->
- <Level Name="Multi-Floor" Volume="540.123">
  - <Category Name="Walls" Volume="145.46477">
      <Element Id="207822" Name="Retaining - 300mm Concrete" Material="Default Wall" Volume="21.158539" />
      <Element Id="207832" Name="Retaining - 300mm Concrete" Material="Default Wall" Volume="9.375557" />
      <Element Id="207952" Name="Retaining - 300mm Concrete" Material="Default Wall" Volume="7.093634" />
      <Element Id="219415" Name="250 THK" Material="Default Wall" Volume="13.096" />
      <Element Id="219416" Name="250 THK" Material="Default Wall" Volume="9.330007" />
      <Element Id="219417" Name="250 THK" Material="Default Wall" Volume="12.072875" />
      <Element Id="219418" Name="250 THK" Material="Default Wall" Volume="9.41275" />
      <Element Id="223743" Name="250 THK" Material="Default Wall" Volume="11.3575" />
      <Element Id="223744" Name="250 THK" Material="Default Wall" Volume="11.3575" />
      <Element Id="223745" Name="250 THK" Material="Default Wall" Volume="10.264037" />
      <Element Id="223746" Name="250 THK" Material="Default Wall" Volume="9.2925" />
      <Element Id="449096" Name="Retaining - 300mm Concrete" Material="Default Wall" Volume="11.785385" />
      <Element Id="598876" Name="150 THK" Material="Default Wall" Volume="9.868489" />
    </Category>
  + <Category Name="Structural Framing" Volume="394.65821999999997">
  </Level>
- <Level Name="1st Storey" Volume="260.8252">
  + <Category Name="Walls" Volume="84.5696">
  + <Category Name="Floors" Volume="72.9905">
  + <Category Name="Structural Columns" Volume="43.96151">
  + <Category Name="Structural Framing" Volume="41.57363">
  + <Category Name="Stairs" Volume="17.72995">
  </Level>
+ <Level Name="2nd Storey" Volume="356.0237">
```


Figure 4.

Figure 5 will also explain that element can be calculated based on the physical level location instead of relying on the level parameter, which may not be accurate if the user did not input it correctly. The XML report shows that the element is physically located on level 10 instead of on level 9 as shown in Figure 3 earlier.



```
<?xml version="1.0" encoding="utf-8" ?>
- <Root Volume="4560.757">
  model location: H:\2. SOLUTIONS\2.11 API\Automated CUI Computation\MR for CUI calc.rvt
  <!-- last updated on: 11_22_2013_5_19_32_PM -->
+ <Level Name="Multi-Floor" Volume="540.123">
+ <Level Name="1st Storey" Volume="260.8252">
+ <Level Name="2nd Storey" Volume="356.0237">
+ <Level Name="3rd Storey" Volume="390.4905">
+ <Level Name="4th Storey" Volume="234.623">
+ <Level Name="5th Storey" Volume="255.4989">
+ <Level Name="6th Storey" Volume="295.9608">
+ <Level Name="7th Storey" Volume="421.9628">
+ <Level Name="8th Storey" Volume="206.094">
+ <Level Name="9th Storey" Volume="209.0845">
- <Level Name="10th Storey" Volume="209.8736">
  + <Category Name="Walls" Volume="53.16277">
  + <Category Name="Floors" Volume="124.35005">
  + <Category Name="Structural Columns" Volume="25.872">
  - <Category Name="Stairs" Volume="6.48874">
      <Element Id="660272" Name="Insitu Concrete 150mm Waist" Material="Concrete - Cast-in-Place Concrete" Volume="0.53061" />
      <Element Id="660298" Name="Insitu Concrete 150mm Waist" Material="Concrete - Cast-in-Place Concrete" Volume="1.49457" />
      <Element Id="660388" Name="Insitu Concrete 150mm Waist" Material="Concrete - Cast-in-Place Concrete" Volume="1.109815" />
      <Element Id="661108" Name="Insitu Concrete 150mm Waist" Material="Concrete - Cast-in-Place Concrete" Volume="0.53061" />
      <Element Id="661122" Name="Insitu Concrete 150mm Waist" Material="Concrete - Cast-in-Place Concrete" Volume="1.494571" />
      <Element Id="661204" Name="Insitu Concrete 150mm Waist" Material="Concrete - Cast-in-Place Concrete" Volume="1.109815" />
      <Element Id="661667" Name="Insitu Concrete 150mm Waist" Material="Concrete - Cast-in-Place Concrete" Volume="0.109375" />
      <Element Id="661677" Name="Insitu Concrete 150mm Waist" Material="Concrete - Cast-in-Place Concrete" Volume="0.109375" />
    </Category>
  </Level>
+ <Level Name="11th Storey" Volume="207.8114">
```


Figure 5.

The above observation clearly demonstrates that developing an add-on is the solution to the current limitation.

4. Experiments

We understand that the BIM model will be generated differently depending on the use of different modelling methods. However some basic modelling needs to be done correctly before the add-on can be used. For example, positioning the element at the correct level, assigning correct material, naming convention, avoiding any duplicate elements, etc. It is best to check the model and review it for any structural conflicts as well.

We will explain the process of the add-on tool that we are currently developing in more detail through the steps below.

4.1. DATA COLLECTION AND PROCESSING

This Process will involve element selection, filtering, setting the constrain and fine tuning.

4.1.1. Material and Category

Considering the current Revit® limitation and user behaviour, we developed a selection set and filters so the user can customise it according to their Revit® model condition. The user can select all elements based on specific material and filter them further by category as shown in Figure 6.

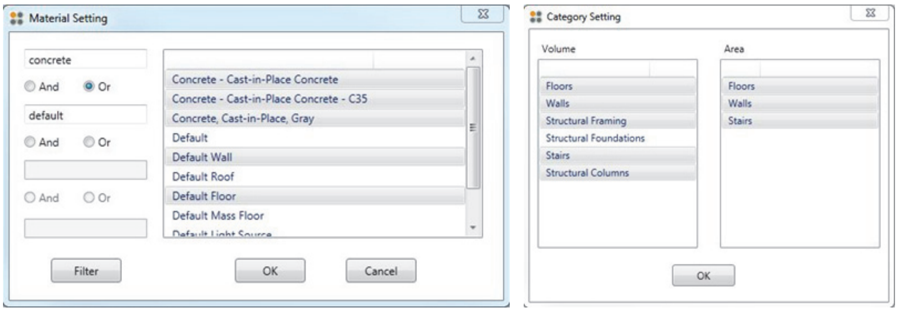


Figure 6.

4.1.2. Boundary Setting

Since level is critical, we developed a tool so that the user can group all selected elements by level, by setting up the boundary tolerance in the setting or by picking a boundary box on the screen. With this feature, beams, columns, walls or any other concrete elements can be included at the correct level.

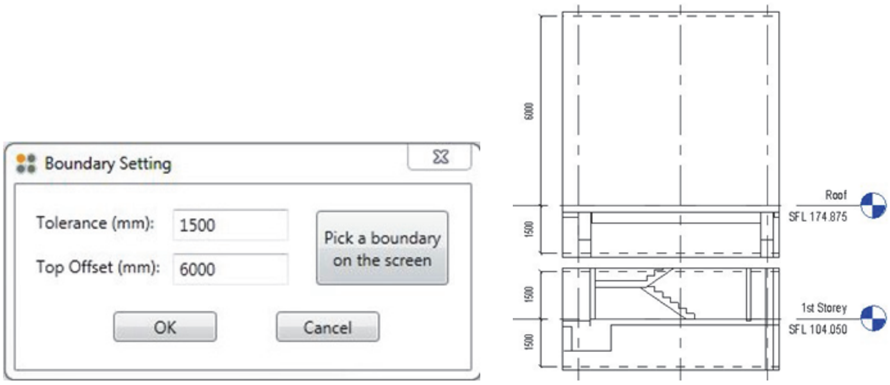


Figure 7.

4.1.3. FINE TUNING SELECTION

The final step of data collection would be fine tuning. The user can fine tune and make necessary adjustments to the selected elements, level by level, in 3D view as shown in Figure 8. This is to make sure that elements are located correctly.

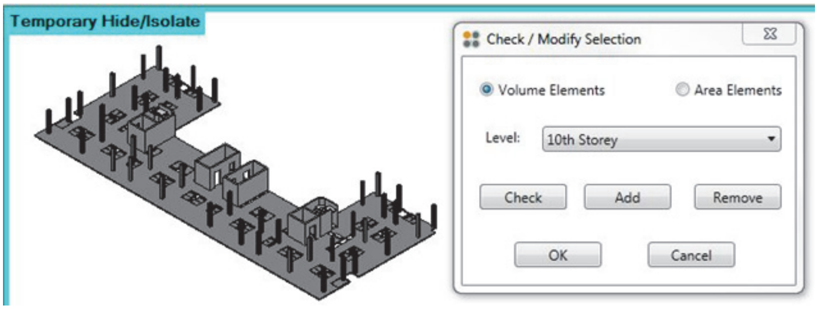


Figure 8.

4.2. POST PROCESSING

Once data collection or selection is completed and processed, the user can view the XML data via the menu shown in Figure 9.

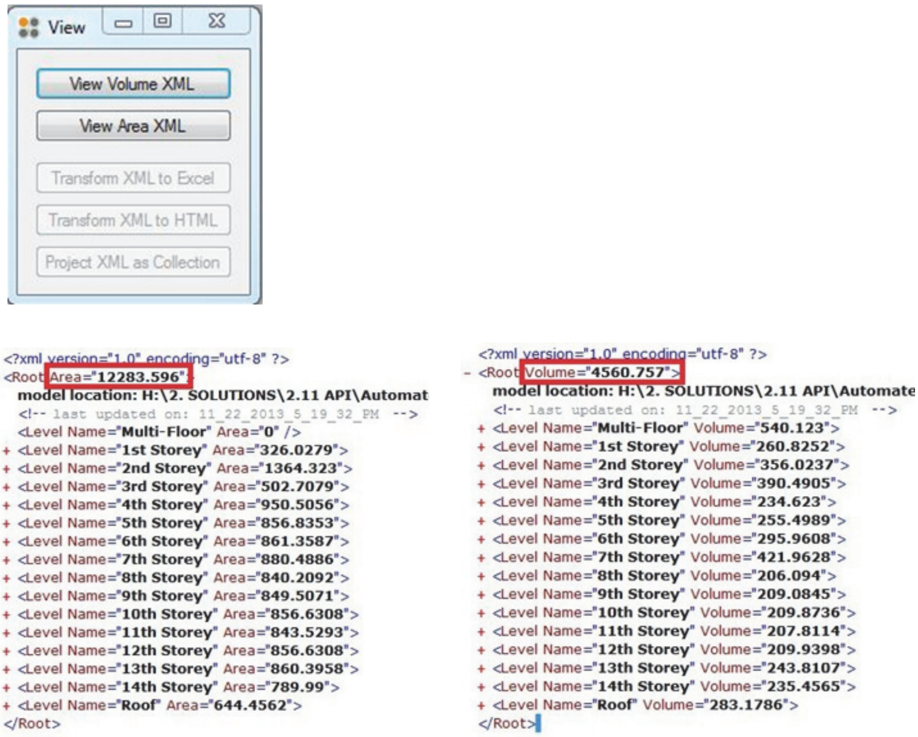


Figure 9.

From this point XML data can be exported or presented in different formats.

4.3. COMPARISON BETWEEN MATERIAL TAKE-OFF AND CUI ADD-ON TOOL

We have done some studies on a real project and can provide a comparison between Material Take-off schedule and our CUI Add-on tool. As shown in Table 1, we can summarise our experiment as follows:

1. There are some columns which were positioned on nearby levels which did not get picked up by Material Take-off schedule. With CUI add-on tool all columns within the range of '1st storey' level will be included.
2. Material Take-off did not include some beams although those should have been included as part of '1st storey' level.
3. Similar to beams, the same issue applied to slabs
4. Some stairs located in between levels were not included in material take-off. CUI add-on tools picked up all stairs within '1st storey' level.
5. Some walls spanned across multiple levels, but Material Take-off schedule will not be able to separate them level by level, hence they were included in '1st storey' level.

Table 1.

1st Storey	Using Material Take-Off Schedule	Using CUI Add-on tool
Columns	16.12	46.92
Beams	555.15	594.57
Slabs	117.01	478.43
Staircases	17.01	22.49
Loadbearing walls	167.7	107.71
Subtotal Volume	873	1250.14
Subtotal Area	566	899.76

5. Conclusion

Currently our add-on development has managed to streamline and improve the accuracy of CUI calculation by improving the data collection process using detailed selections, category and boundary. However since this is still under development we still face some challenges including:

- Our current CUI tool cannot calculate multiple models at the same time. Multiple models (eg. Architecture model and Structure model) need to be combined first before running the CUI add-on tool.
- Further development of the final output of CUI score is required so that the report is more presentable.

References

Autodesk: 2013, Autodesk Revit 2014 Help, Available from: Autodesk website <http://help.autodesk.com/view/RVT/2014/ENU/?guid=GUID-F8270A42-CA71-46C7-B145-85EC2CB8E4A1> (accessed 15 December 2013).

Building and Construction Authority: 2012, Sustainable construction; A guide on Concrete Usage Index, BCA Sustainable Construction Series, 9-14.