EVALUATION OF BIM APPLICATION FOR WATER EFFICIENCY ASSESSMENT

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ABSTRACT

Application of Building Information Modelling (BIM) in architecture, engineering, and construction industry is known for its productivity and efficiency. Green BIM is one of the recent applications that aids users in achieving sustainability and/or improved building performance objectives through design and analysis of digital semantic models. The focus is on the application of green BIM for water efficiency (WE) analysis in accordance with the Malaysian Green Building Index (GBI) as a sustainability assessment tool. Revit Green Project Template (RGPT) and Autodesk Green Building Studio (GBS) as two available BIM tools were selected to evaluate and compare the applicability of each method for GBI WE assessment. To resolve the limitations identified from each evaluated method, automated GBI assessment tool (AGBIA) was developed as an alternative. The AGBIA as a supporting tool was established with the use of Dynamo, a visual programming tool to compensate for the limitations faced in the investigated methods. The practicality of each method was explored using a hypothetical model in Revit to automate information correspondent to 10 water efficiency assessment points and generate reports and documents necessary for the GBI design stage certification. The final phase involves verification of results obtained from each method using the conventional GBI WE calculator. AGBIA is suitable for the green BIM users in Malaysia based on the flexibility and automation over defining and assigning green parameters that are in line with the local context, the direct link of green information to the model, as well as the detail of presented data.

KEYWORDS

Building Information Modelling, Green BIM, Green Building Index, Water Efficiency, Green Building Assessment

INTRODUCTION

One of the initiatives in Malaysia targeted at the development and construction industry, towards a comprehensive framework for sustainable and efficient use of resources including

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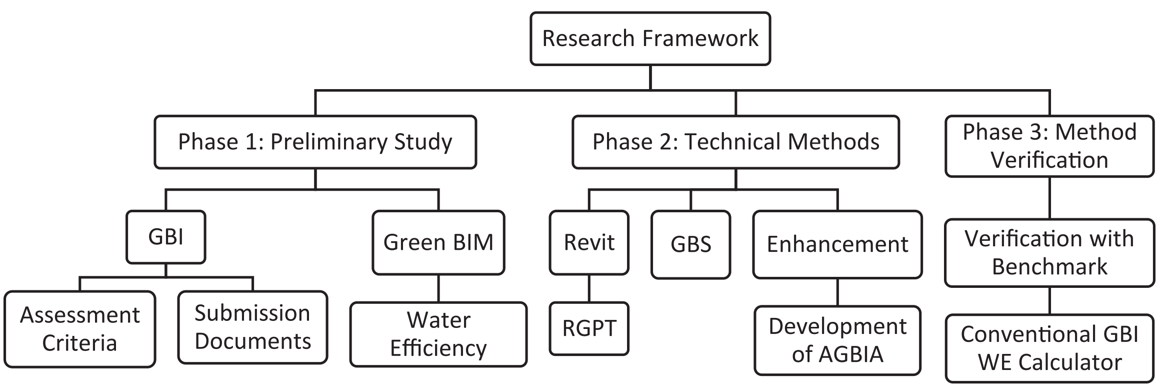
water, is the Green Building Index (GBI). GBI is designed specifically for the Malaysian climate, environmental and developmental circumstances, as well as to meet cultural and social needs (Eastman et al., 2009). GBI is focused on assessing buildings based on six main criteria of Energy Efficiency (EE), Indoor Environment Quality (IEQ), Sustainable Site Planning & Management (SM), Materials & Resources (MR), Water Efficiency (WE), and Innovation (IN). Currently, the process for green building assessment and certification in Malaysia is carried out manually, which requires additional time and effort especially with large and complex projects. Combining several building features from different disciplines demands tools and technology that can ensure integrity (Samari et al., 2013). Many researchers have stated the need for a BIM application to overcome some of the barriers in delivering green buildings since BIM is known as an efficient tool that integrates various building aspects digitally. Ayman et al. (2018) anticipated the direct impact of BIM utilisation on sustainability barriers is reduction in time and cost due to better design coordination and effective decision making during the design phase. Based on the review conducted by Lu et al. (2017), the application of popular BIM tools for green building assessment are more focused on specific regions. Therefore, there is a gap to identify appropriate methods for integration and automation of the Malaysian green building guideline through available BIM tools in order to address local references and baselines for calculation, analysis and documentation.

The objective of this paper is to evaluate three different BIM approaches in order to identify the suitability and limitations of each method for the GBI design assessment stage based on process automation, parameter input flexibility, dynamic link to the model, as well as the detail and accuracy of the presented data. A new method is developed to resolve the limitations faced from the existing methods and to automate the process of analysis, documentation and assessment of green buildings in accordance to GBI requirements.

RESEARCH METHODOLOGY

The initial phase is dedicated to investigate the GBI WE assessment criteria and the requirements for submission of supporting design documents in order to identify relationships between GBI and BIM properties. Furthermore, a literature study was conducted focusing on application of green BIM for water efficiency related analysis. The second phase is a technical study on the available green BIM applications. Based on the review conducted by Lu et al. (2017), Autodesk® Revit and Green Building Studio (GBS) were amongst the most popular BIM tools

FIGURE 1. Research Framework.



utilised by green BIM researchers for global green building assessment standards such as LEED, BREEAM, Green Star, and BEAM Plus. Therefore, these two BIM tools were selected to evaluate and compare the applicability of each method for GBI WE assessment. To resolve the limitations identified from each evaluated method, an automated GBI assessment tool (AGBIA) was developed as an improved method. The practicality of each method was explored using a hypothetical BIM model in Revit to automate information correspondent to 10 water efficiency assessment points (Table 1). The final phase involves verification of results obtained from each method using the conventional GBI WE calculator.

Preliminary Study

The initial stage was aimed to study extensively the GBI guideline and assessment requirements followed by reviewing relevant literature focusing on the existing green BIM application for water efficiency aspects.

GBI Assessment Criteria

The GBI assessment basis regarding each subcategory and their respective requirements for submission was studied in detail. GBI Non-Residential New Construction (NRNC) version

TABLE 1. GBI WE Assessment Criteria (Greenbuildingindex, 2011).

Item	Area of Assessment	Point
Water Harvesting & Recycling		
WE1	Rainwater Harvesting	
	Rainwater harvesting that leads to ≥15% reduction in potable water consumption	1
	Rainwater harvesting that leads to ≥30% reduction in potable water consumption	2
WE2	Water Recycling	
	Recycle ≥10% wastewater leading to reduction in potable water consumption	1
	Recycle ≥30% wastewater leading to reduction in potable water consumption	2
Increased Efficiency		
WE3	Water Efficient—Irrigation/Landscaping	
	Reduce potable water consumption for landscape irrigation by ≥50%	1
	Do not use potable water at all for landscape irrigation	2
WE4	Water Efficient Fittings	
	Reduce annual potable water consumption by ≥30%, OR	1
	Reduce annual potable water consumption by ≥50%	2
WE5	Metering & Leak Detection System	
	Use of sub-meters to monitor and manage major water usage	1
	Link all water sub-meters to EMS to facilitate early detection of water leakage	1

TABLE 2. Identified GBI-WE Submission Requirement (Greenbuildingindex, 2011).

Item	GBI Submission Requirement
WE1	Rainwater Harvesting
	Preliminary calculation of rainwater harvested, storage tank capacity and building usage distribution system.
WE2	Water Recycling
	Preliminary calculation of the percentage of wastewater to be treated and distributed
WE3	Water Efficient—Irrigation/Landscaping
	Calculation of the reduction of potable water for landscape irrigation
WE4	Water Efficient Fittings
	List of the proposed water efficient fittings and calculations of percentage water saved
WE5	Metering & Leak Detection System
	Tabulated inventory of proposed sub-meters of all major water consuming system/equipment and interface with EMS

1.05 was selected as the latest available guideline for preparation of documentations required at the design stage assessment (Table 1). The GBI water efficiency is focused on controlling water usage by implementing water efficient systems/features and adoption of alternative sources for potable water (Zainol et al., 2016). The main objective behind the GBI WE assessment category is to demonstrate how the proposed design is helping to save, conserve and recycle water compared to a baseline design. The baseline refers to a scenario whereby every water fixture associated with the building is assumed to use potable water at a baseline flowrate. The total water consumption depends on other factors such as building type, consumer behaviour, and occupancy schedule. Based on the GBI WE guideline, the documents required for the design assessment stage must represent the information regarding each water supply system designed and provide preliminary calculation for the estimated consumption demand of the building and estimated capacity of each water supply system proposed (Table 2).

Green BIM

Although analysis regarding water usage and estimation is not directly achievable through BIM authoring tools, users can develop strategies to extract relevant information from the digital model. An ideal model holds various layers of information regarding components and fixtures that handle water, which can help designers to plan for water efficiency, rainwater harvesting, and wastewater recycling (Hammond et al., 2014). Furthermore, automated design code checking and optimisation and renovation of water distribution systems can be performed through BIM (Lu et al., 2017). In terms of BIM-based WE framework, Liu et al. (2019) structured a reference guideline for water efficiency in building design and construction via conducting a survey study from 50 practitioners from the Architectural, Engineering and Construction (AEC) industry. As part of the green BIM technical application, many researchers have investigated the integration of BIM with sustainability assessment rating tools. Azhar et al. (2010)

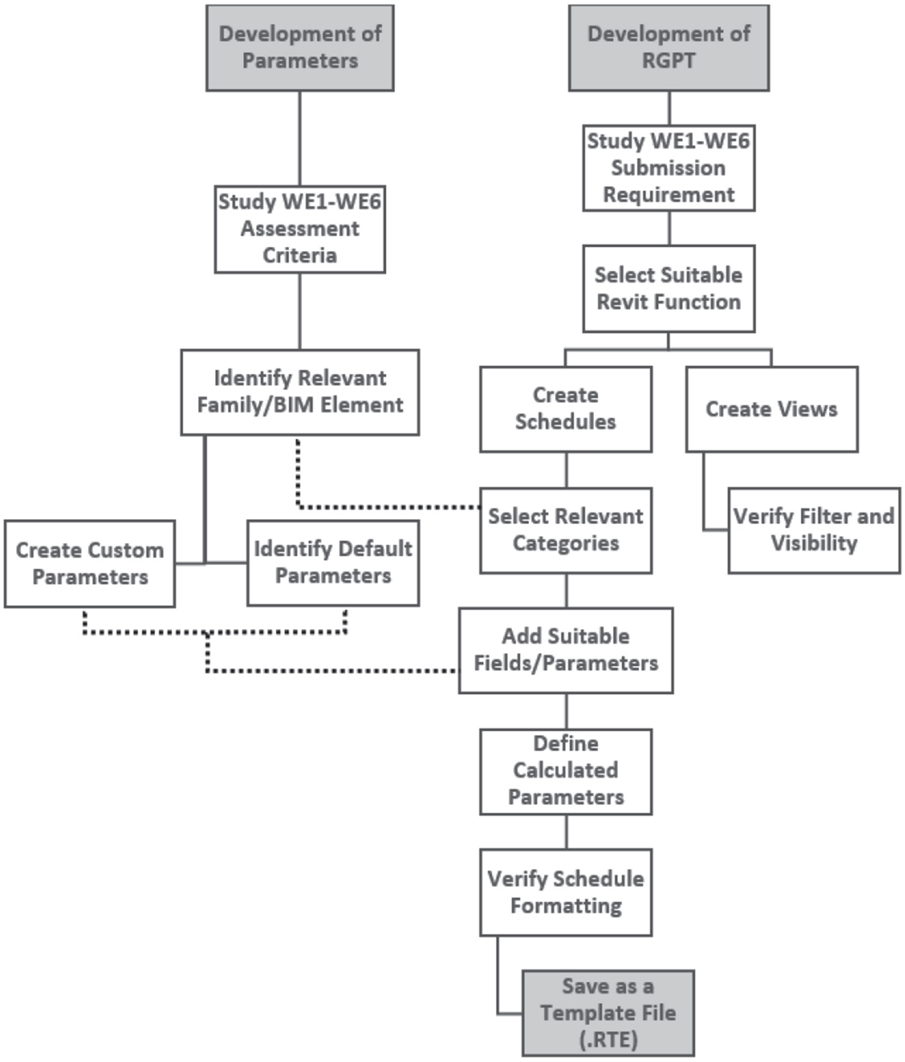
investigated how BIM can aid designers in performing complex building performance analysis and how the analysis result can be used as supporting documentation for LEED certification. They verified via a case study that green BIM application is advantageous in terms of saving time and resources. Azhar et al. (2011), further verified that 5 credit points for LEED certification assessment in WE category can be achieved through adopting BIM tools such as Autodesk Revit™ and IES Virtual Environment™. Water efficient landscaping category was established using Revit™ software whereby innovative wastewater technologies and water use reduction categories were evaluated via IES Virtual Environment™. Kensek and Zhao (2011) demonstrated the application of GBS as an available third-party software to calculate LEED credits for the WE category. Similarly, a green BIM application in context with water efficiency has been evaluated by Gandhi and Jupp (2014) for sustainability analysis aligned with the Australian Green Star rating tool. It was reported that 11 out of 12 points for the WE category could be applied through BIM tools such as Microstation and Revit. Wong and Kuan (2014) developed a methodology to utilize BIM for Hong Kong BEAM Plus sustainability assessment process. It was reported that 26 out of 80 credit points could potentially be automated with documentation produced by BIM tools such as Autodesk Revit. Three points from the WE category (minimum water saving performance, annual water use and effluent discharge to foul sewers) were identified as the potential subcategories of WE to be integrated with the BIM tool. Wong and Kuan's (2014) methodology consists of allocating appropriate parameters to be included in Revit schedules for further calculation. Khoshdelnezamiha et al. (2019) did similarly for the GBI design stage assessment by externally processing the documents extracted from a Revit green project template that contained a set of custom parameters and formulas embedded in the Revit schedule that must be defined in advance to serve as a green project template for the users to save time during the design and analysis stage. Krishnamurti et al. (2012) expanded the BIM application from micro-simulation of a building to urban scale planning and analysis by combining parametric BIM elements with measures of their environmental impacts. The methodology for assessment of the water usage as well as the generated wastewater is based on conventional calculations combined with BIM parametric fixtures, systems and materials. Based on the literature review conducted, the potential and feasibility of BIM application for sustainability analysis and automation in documentation intended for the certification process was evident. The following work evaluates suitable methods for the GBI WE category in order to improve the existing process and develop an automated tool to ease the GBI assessment and documentation process for green BIM users in Malaysia by utilisation of the existing tools.

TECHNICAL STUDY

Method 1: Development of Revit Green Project Template (RGPT)

This method is adopted from Wong and Kuan's (2014) methodology and is adjusted to fit the GBI WE assessment requirement. Utilisation of Revit® for GBI assessment requires combination of two main features: a set of custom parameters compatible with GBI WE requirements and a custom project template referred to as Revit Green Project Template (RGPT). Figure 2 illustrates the process required to create RGPT and input methods. Table 3 contains additional custom parameters identified that are required to be associated with relevant BIM family components in order to indicate water related factors. Furthermore, RGPT, in the format of a project template, is necessary to organise Revit schedules that are mainly used for listing, tabulation and additional calculation intended for estimation of water consumption and comparison between

FIGURE 2. Process Flow to Create RGPT.



the design case scenario and the baseline values (Figure 3). One of the well-known advantages of using BIM authoring tools such as Revit is the dynamic link between the digital model and schedule views. Any changes to the design features are reflected spontaneously and vice versa. The exported RGPT schedules can be used as supporting documents for each GBI WE subcategory. Based on the investigation conducted on the calculation method from the GBI calculator guideline, calculation of totals based on quantities of water fixtures is not applicable because total water consumption for the plumbing fixture category is driven by fixture types and consumer behaviour (Table 3).

Method 2: GBS

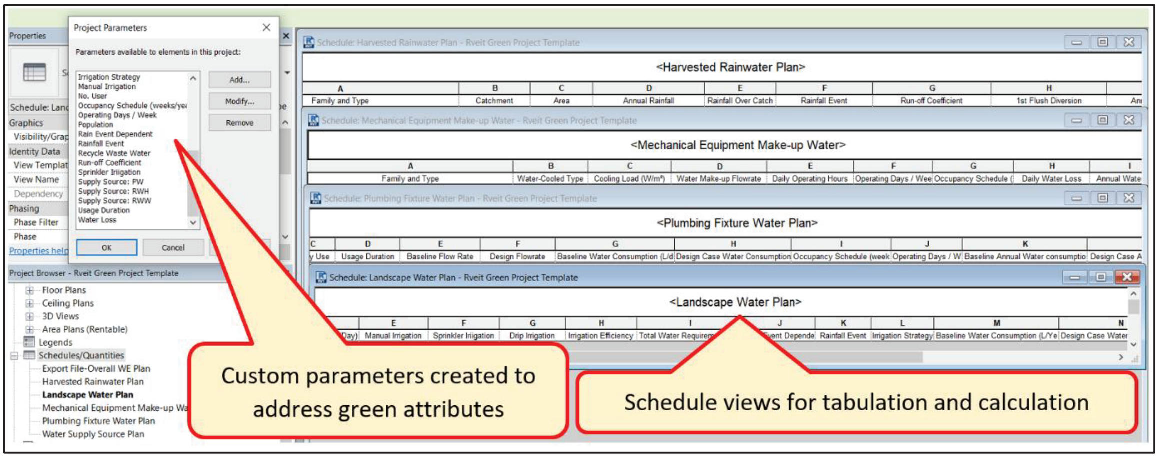
Although GBS is mainly used as a web-based energy analysis tool, there are additional functionalities available to users including water usage estimation (Autodesk© Green Building Studio, 2013). The GBS default settings, methods and assumptions for water calculation were investigated to explore its suitability for other assessment guidelines, in this instance GBI. The water

TABLE 3. Identified parameters and processes required for development of RGPT.

GBI-WE Criteria	Custom Parameter	Parameter Type	BIM Category	Calculated Parameter	Formatting: Calculate Total
WE1	Annual Rainfall	Number	Project Information	Annual RWH Potential	Yes
	Rainfall Frequency	Number			
	Run-off Coefficient	Number	Roof/Face		
	Supply Source: RWH	Yes/No	PF, ME& PL	Annual RWH Supply	Yes (Except for PF)
WE2	Wastewater Type: Grey	Yes/No	PF	Annual RWW Collected	No
	Wastewater Type: Black	Yes/No			
	Recycle Wastewater	Yes/No			
	Supply Source: RWW	Yes/No	PF, ME& PL	Annual RWW Supply	Yes (Except for PF)
WE3	Landscape Area	Number	PL	Annual Irrigation Volume (Baseline& Design Case)	Yes
	Landscape Type: Tree, Shrub or Turf	Yes/No			
	Daily Water Demand	Number			
	Irrigation Type: Manual, Drip or Sprinkler	Yes/No			
	Irrigation Efficiency	Number			
	Rain Dependent	Yes/No			
	Irrigation Strategy	Number			
WE4	Operation day/week	Number	Project Information	Annual Water Consumption (Baseline& Design Case)	Yes (Except for PF)
	Operation week/year	Number			
	Usage duration	Number	PF		
	No. User	Number			
	Baseline Flowrate	Flowrate			
	Design Flowrate	Flowrate			
	Daily Usage	Number			
	Water Loss Rate	Number	ME		
WE5	Filter keywords in the multicategory schedule		PF& ME	Use of Water Meter and Leak Detector	—

Legend: PF: Plumbing Fixture, ME: Mechanical Equipment, PL: Planting, RWW: Recycled Waste Water, RWH: Rain Water Harvested

FIGURE 3. Revit Green Project Template containing custom parameters and schedule views.

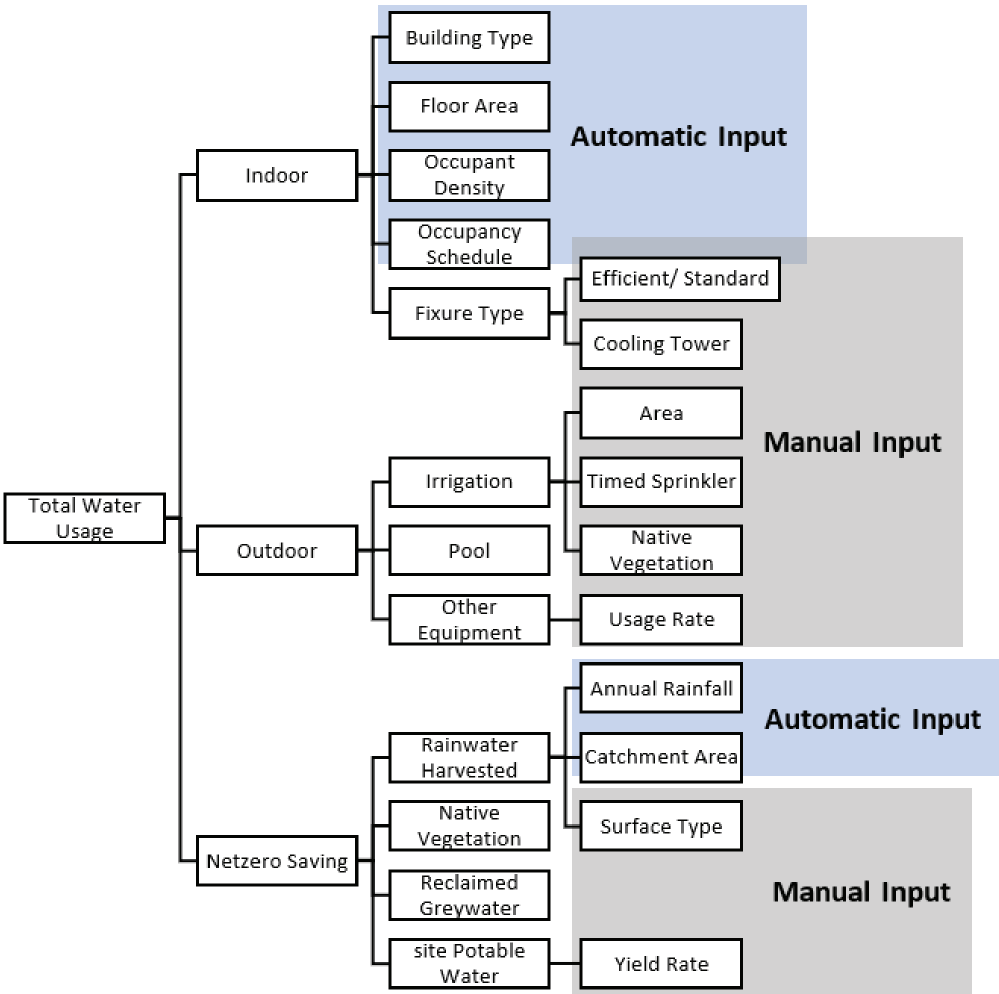


usage calculation is categorised into indoor, outdoor and net-zero saving. The calculation basis for the GBS system and the input source for each estimation is summarised in Figure 4. The benchmark values are according to the American Water Works Association (AWWA) Research Foundation 2000 End Uses of Water based on historic database of water billing records and surveys for residential, commercial and institutional buildings (Green Building Studio, 2013). The automatic inputs are extracted from the digital model that holds some contextual project information such as building type and floor area. The design case calculation is independent from the model, and the user is required to verify all the remaining inputs manually.

Method 3: AGBIA

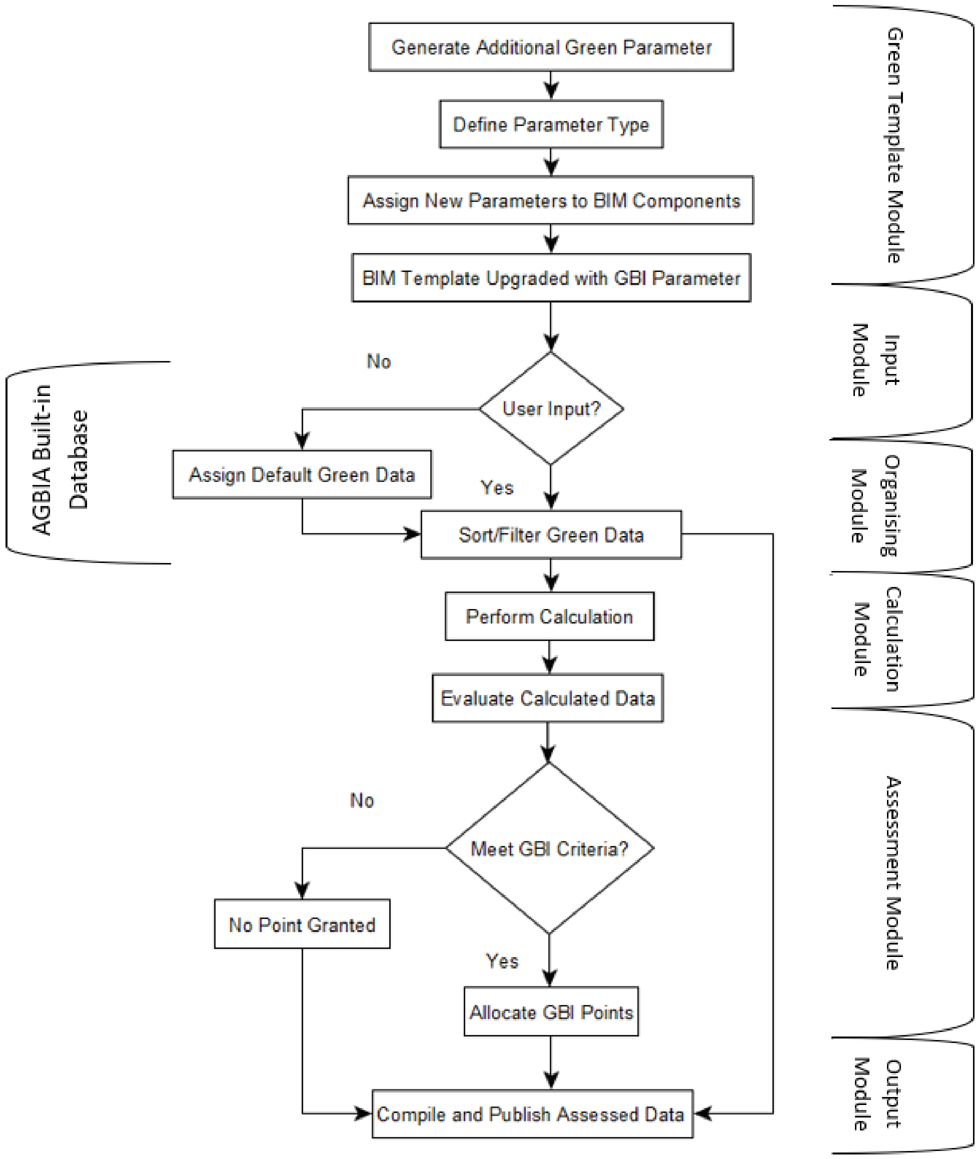
Based on the flexibility over defining custom parameters, and the direct link to the digital model, application of RGPT was found to be more suitable for GBI documentation. However, the default interface of the software caused calculation limitations mainly in terms of Revit schedule functionality that needed to be resolved via a programming tool. Furthermore, in order to improve and automate the process of creating a green template, assessment and reporting of green data, a supporting tool was developed referred to as Automated GBI Assessment (AGBIA). AGBIA provides a full automation procedure that minimises manual inputs by the user. The AGBIA system consists of 6 modules that automatically define green parameters as a green template, organise green building data, process building data in accordance to GBI requirements, assess the green building information, produce documentation and report the final output (Figure 5). The objective of proposing the AGBIA as an improved process is to demonstrate an automated solution to compensate for the shortcomings faced from Revit as well as limitations faced from GBS. As identified in Table 3, a set of custom parameters are defined and assigned to relevant categories of the BIM model. The AGBIA database developed was intended to compile a built-in reference source for automatically matching information and assigning default values to various parameters such as baseline flowrates based on fixture type, consumer behaviour according to the building type, type of wastewater generated (black/grey) based on the fixture category, regional rainfall data based on project location, runoff coefficient based on the catchment material as well as design flowrates by fixture unit conversion. Building such a database for the automated analysis of water systems is beneficial to minimise

FIGURE 4. Input details for GBS water estimation.



user inputs. Martins and Monteiro (2013) automated design code for the checking of water distribution systems to develop a database containing tables and hydraulic calculations. Once the model holds sufficient parametric details in terms of green data, the organizing module performs filtering and sorting. Organised green data is further processed through the calculation module. The calculation module performs various formulas in accordance to GBI requirements. Using programming tools during this stage is beneficial as the general functionalities available through the general interface in Revit is limited (refer to Discussion section for details of the limitations). The evaluation module performs assessment on the processed green data through conditional statements. Upon meeting each conditional statement, GBI points are allocated accordingly. The final stage involves producing reports based on the aggregated GBI points and final building rating. Green Building information generated from the calculation module is exported to be used as supporting design documents for the GBI certification procedure. The AGBIA application procedure for users is designed as a 2-stage assessment to allow flexibility for user-defined values apart from the default inputs within the AGBIA database (Figure 6). Users have access to AGBIA via Dynamo Player in Revit (Figure 7).

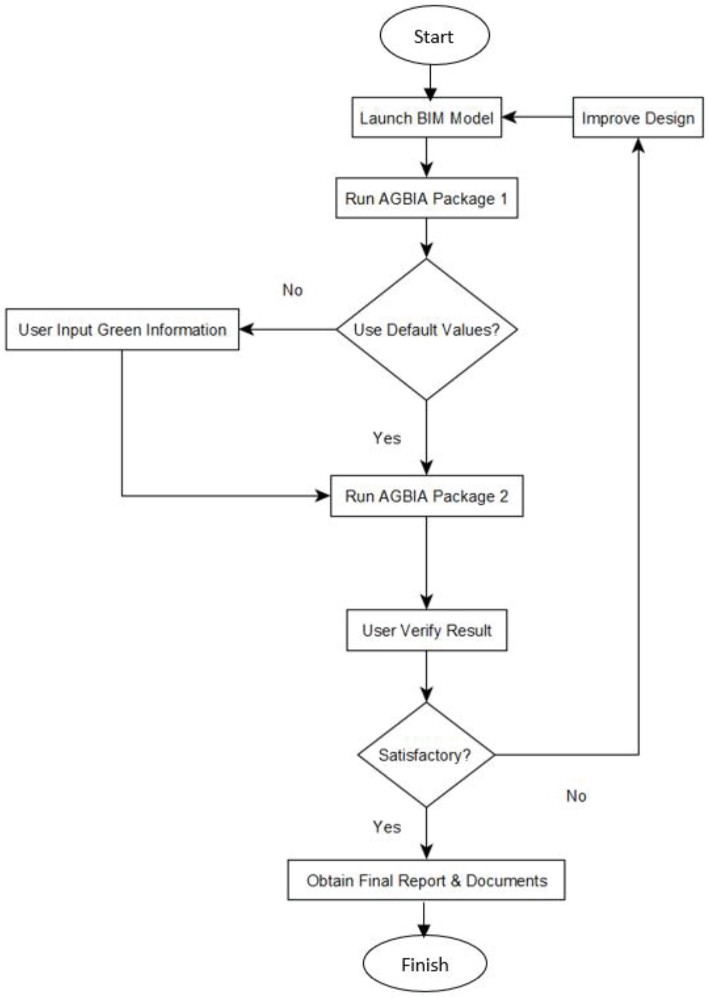
FIGURE 5. AGBIA System Workflow.



AGBIA System

AGBIA was developed to resolve the RGPT limitations and enhance the details of the design calculation from GBS with the use of a visual programming platform (Dynamo). As demonstrated in Figures 8–10, AGBIA is developed using the visual programming tool (Dynamo) that works with sequenced wired dialogue boxes called nodes which is an alternative to text-based programming languages (Kensek, 2018). In the context of automating procedures, systems can be categorised into plug-ins tied to design tools, standalone application or web-based platforms (Eastman et al., 2009). AGBIA is considered as a plugin that is tied to the design software (BIM authoring tool) to maximise effective data exchange between the developed tool and the digital model. Developing a supporting tool through the Dynamo interface was beneficial in order to

FIGURE 6. AGBIA User Application Procedure.



gain better access to the BIM model information, flexibility over performing calculations and reporting, linking built-in database for regional references and more importantly to automate several Revit functionalities. As shown in Figure 8, the AGBIA Green Template Module is automated via a simple dynamo script to define additional green parameters with similar concept to the RGPT method. AGBIA ultimately reduced the amount of manual inputs required by the user. For instance, the AGBIA input module is programmed to distinguish the rain dependency for each landscape item from the BIM model by detecting any obstruction (roof/shade cover) above (Figure 9). Likewise, water fixtures connected to piping systems are checked based on the system name/classification in order to detect the supply source of water. AGBIA also allows users to manually influence the green parameters related to the design case for each component individually in terms of water source type, reclaiming wastewater, and irrigation method to be able to estimate water efficiency through different scenarios. This feature provides flexibility to assess both the conceptual and detailed design model. The design calculation report is aligned with the recommended format provided by the GBI conventional calculator that can be used as supporting documents for the design certification stage. The AGBIA organizing module

FIGURE 7. AGBIA User Access in Revit

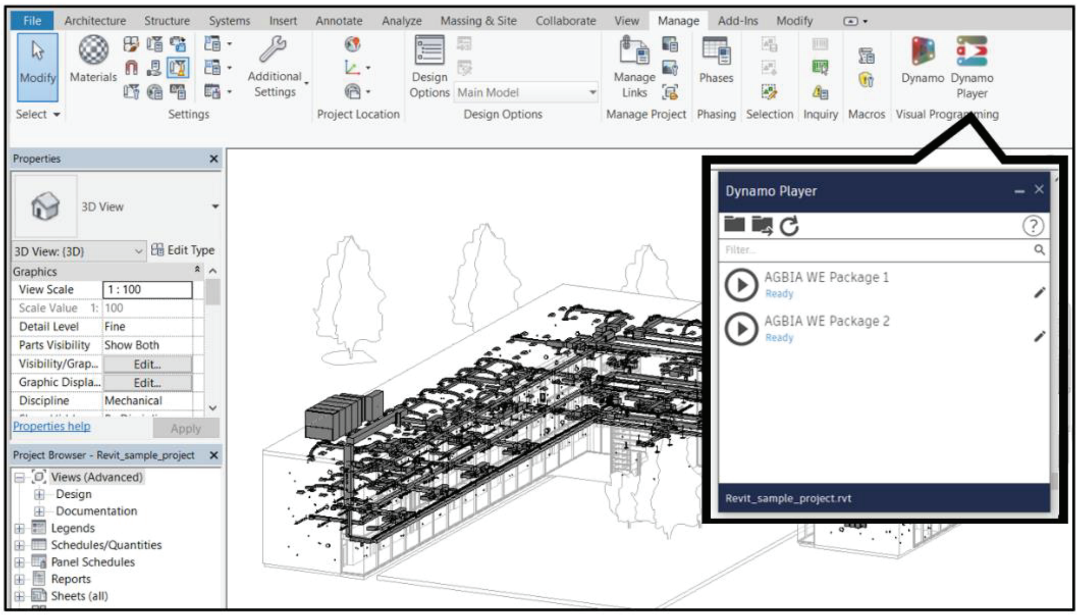
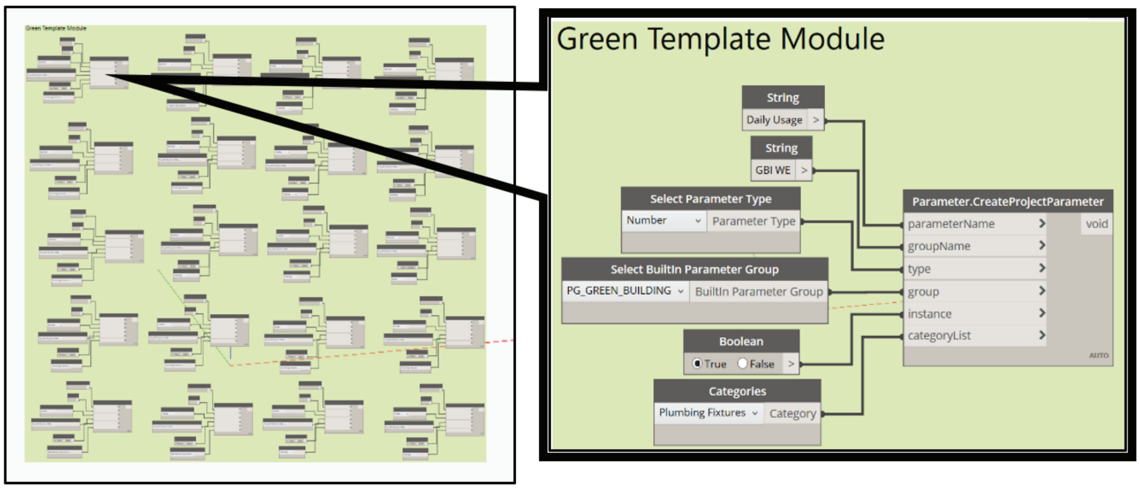


FIGURE 8. AGBIA Dynamo Script for Green Template Module.



has better access to retrieve and sort the restricted parameters and properties identified from RGPT limitations. Furthermore, the AGBIA calculation module fixed issues such as obtaining grand total values from multiple categories. Likewise, an outstanding issue faced from obtaining total water consumption for the plumbing fixture category through the RGPT method (Figure 10) was resolved by using a programming command (node) that filters unique items in a given list. Similarly, the evaluation module was important in order to assess calculated water saving ratio/percentages that are required for the estimation of GBI score points. The AGBIA internal database developed was intended to compile a built-in reference source for automatically matching information and assigning default values to various parameters such as baseline

FIGURE 9. AGBIA Dynamo Script for the Input Module.

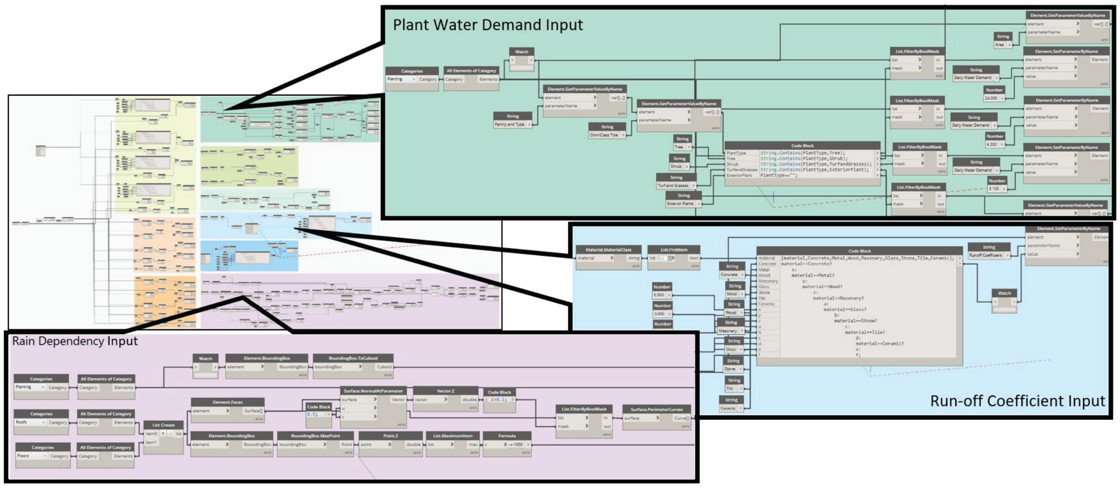
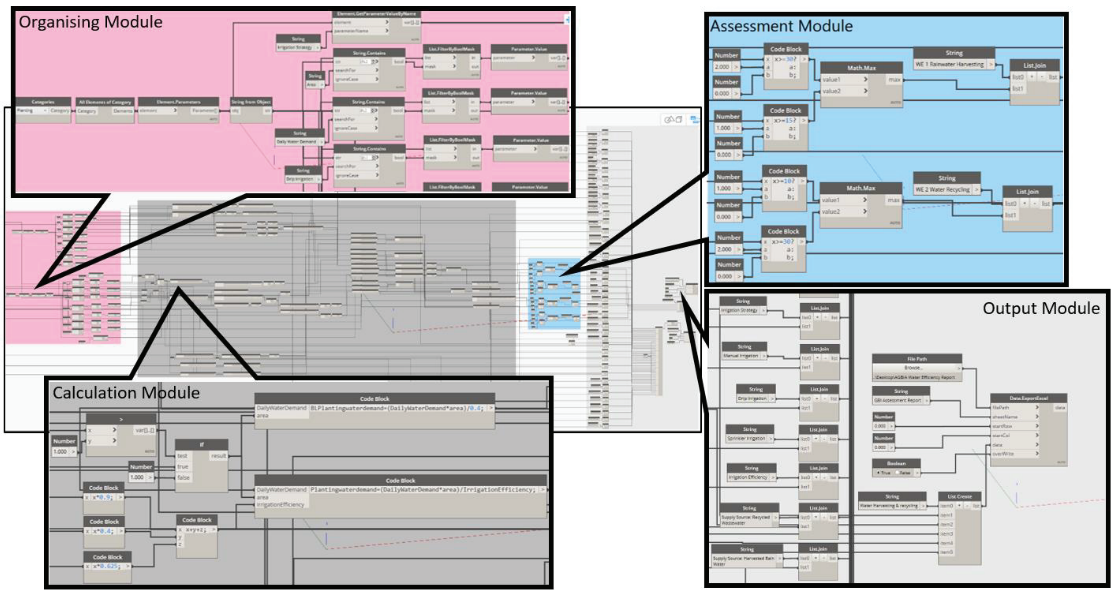


FIGURE 10. AGBIA Dynamo Script Organising, Calculation, Assessment and Output Module.



flowrates based on fixture type, consumer behaviour according to the building type, type of wastewater generated (black/grey) based on the fixture category, regional rainfall data based on project location, runoff coefficient based on the catchment material as well as design flowrates by fixture unit conversion.

METHOD VERIFICATION

Benchmark

The GBI WE conventional calculator was selected to benchmark the results obtained from each method and to verify the formulas used for calculation in RGPT and AGBIA. The GBI

WE calculator is an Excel spreadsheet that operates exclusively based on the user manual inputs and assumptions, making it entirely independent from the digital model. The conventional method involved extracting data manually from the model and subsequently used in the GBI WE Calculator to obtain results. The baseline values are provided inside the Excel spreadsheet, and the user is expected to verify contextual project information (building type and number of occupants and operation schedule) and information related the design case for each system.

Comparison

The practicality of each methodology was explored using a hypothetical model in Revit to automatically evaluate information correspondent to 10 out of 100 GBI assessment points (Figure 11). A similar model was linked to GBS by creating an energy model in Revit, while maintaining consistency for design inputs and water estimation factors. The project information (building type, location, occupancy schedule) was verified in order to avoid default assumption by the tool. AGBIA was used to automatically assess the model and obtain reports. The GBI WE Calculator as a conventional method was used for benchmarking purposes and to verify the accuracy and reliability of each method. Figure 12 shows the process flow used for application of each method/tool. Table 4 shows all the inputs and assumptions used for all methods.

RESULTS

Figure 13 contains the results obtained from the GBI conventional calculator. As mentioned in the preliminary study section, GBI WE design assessment requires demonstration on how the proposed design is helping to save, conserve and recycle water compared to a baseline design. Table 5 summarises the calculated items used for verification and benchmarking of each method. The result from each method was evaluated and compared with the GBI calculator estimations.

Figure 14 contains the RGPT schedule layout containing water consumption estimation for plumbing fixtures, mechanical equipment, and landscape. Table 6 summarises the water

FIGURE 11. The sample model in Revit used to evaluate each method.

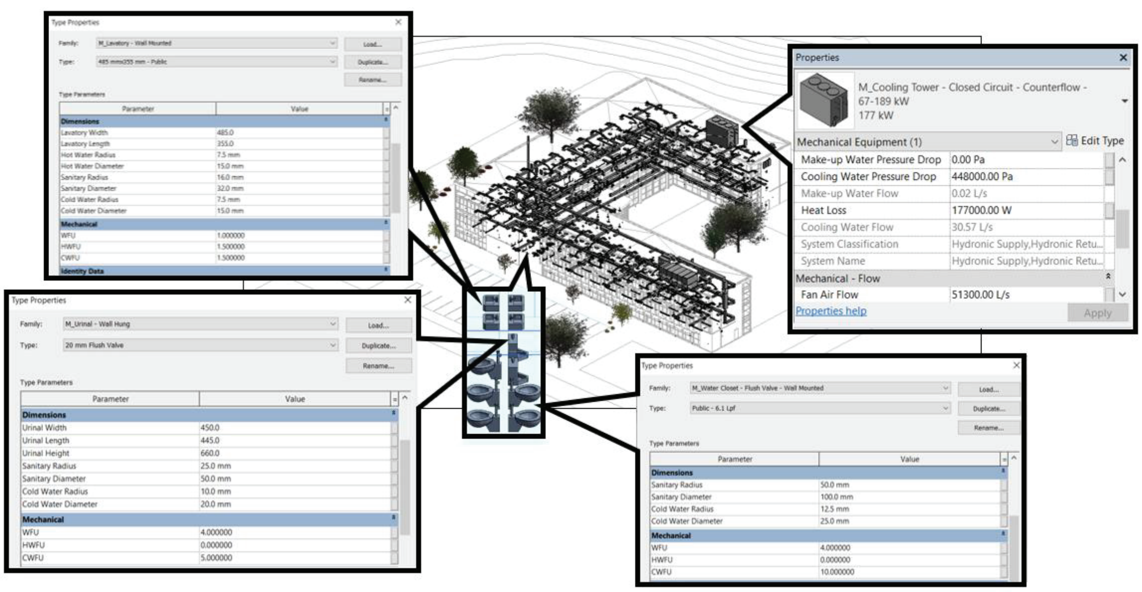


FIGURE 12. Process Flow Used for Each WE Method.

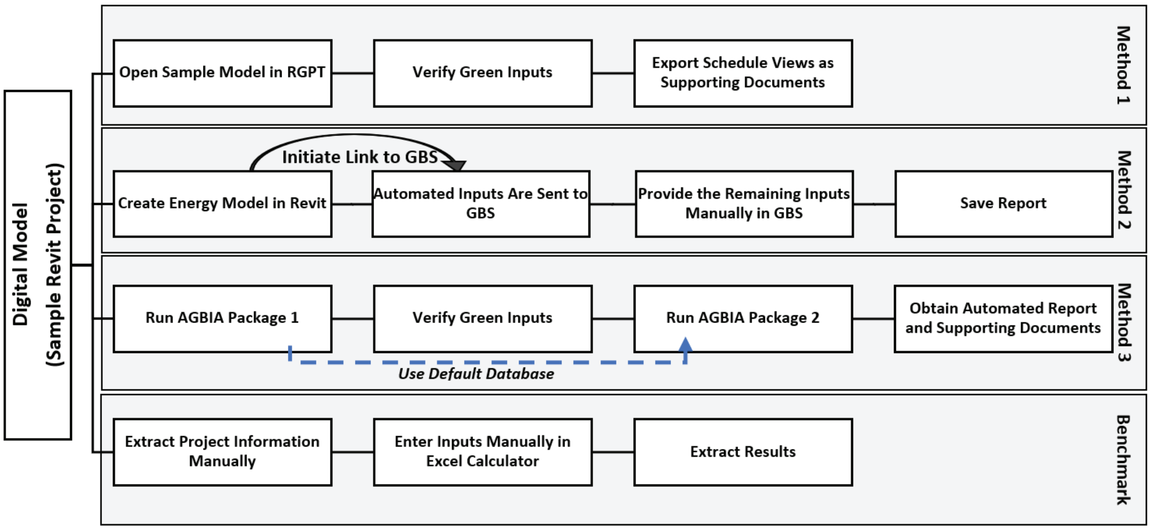


TABLE 4. Sample Revit Design Inputs.

<table>
<tr><th colspan="7">Contextual Information</th></tr>
<tr><th colspan="3">Building Type</th><th>Occupant Density</th><th colspan="3">Operating Schedule</th></tr>
<tr><td colspan="3">Office</td><td>28.5 m^2/person</td><td colspan="3">12/5</td></tr>
<tr><th colspan="7">Design Information</th></tr>
<tr><th colspan="3">Floor Area</th><th colspan="4">Roof Area</th></tr>
<tr><td colspan="3">3557 m^2</td><td colspan="4">1650 m^2</td></tr>
<tr><th colspan="7">Water Related Components</th></tr>
<tr><th colspan="3">Plumbing Fixtures</th><th>Mechanical Equipment</th><th colspan="3">Planting Details</th></tr>
<tr><td rowspan="2">Ordinary Water Closet</td><td rowspan="2">Low-flow Urinal</td><td rowspan="2">Low-flow Sink</td><td rowspan="2">177kw Cooling Tower</td><td>Tree</td><td>Shrub</td><td>Turfgrass</td></tr>
<tr><td>12 units</td><td>17 units</td><td>1150 m^2</td></tr>
<tr><td rowspan="2">Supply Source: RWW</td><td rowspan="2">Supply Source: RWW</td><td rowspan="2">Reclaim WW</td><td rowspan="2">—</td><td rowspan="2">Supply Source: HRW</td><td rowspan="2">Supply Source: HRW</td><td>Sprinkler Irrigation</td></tr>
<tr><td>Supply Source: HRW</td></tr>
</table>

FIGURE 13. Water Efficiency Report Obtained from GBI Conventional Calculator.

Annual Water Consumption		Baseline: Potable Water Consump-tion	Baseline: Percentage Distribution	Design Case: Consump-tion	Design Case: Percentage Distribution	Design Case: Greywater Recycling	Design Case: AC Condensate Recovery	Design Case: Resultant potable water usage	Design Case: Rainwater Harvesting
Fixtures Usage	Flushing	746	21.6%	558	23.0%	205	-	353	-
	Shower	-		-				-	
	Wash hand basin	325	9.4%	206	8.5%			206	
	Ablution	-		-				-	
	Bib tap	-		-				-	
	Pantry/Dish washin	-		-				-	
	Sub-total	**1,071**		**764**		**205**	**-**	**559**	**-**
Others	Cleaning	-		-		-	-	-	-
	Air Cond make-up	188	5.5%	188	7.7%	-	-	188	-
	Water Feature	-		-		-	-	-	-
	Swimming Pool	-		-				-	-
	Irrigation	2,188	63.5%	1,479	60.8%	-	-	1,479	1,440
	F&B	-		-				-	
	Laundry	-		-				-	
	Not used	-		-				-	
	Sub-total	**2,376**		**1,667**		**-**	**-**	**1,667**	**1,440**
Total		**3,447**		**2,431**		**205**	**-**	**2,226**	**1,440**

TABLE 5. Calculated items used for verification and benchmarking.

	Benchmark Results Obtained from the GBI Calculator					
Design Case	Indoor Water Consumption	Outdoor Water Consumption	RWW	Resultant Potable Water	RWH Potential	RWH Supply
	952 m^3/yr	1479m^3/yr	205 m^3/yr	2226 m^3/yr	6331 m^3/yr	1440 m^3/yr
GBI WE Categories	Reduction in PW through RWH	Reduction in PW through RWW	Irrigation PW Reduction	Indoor PW Reduction	Water Meter and Leak Detection	
	64.70%	26.80%	100%	28.60%	—	
Baseline	Indoor Water Consumption	Outdoor Water Consumption				
	1259 m^3/yr	2188 m^3/yr				

efficiency calculation obtained from the RGPT method. The RGPT method failed to report some final values and water saving percentages due to some limitations from Revit schedules that required additional manual calculation and extraction to be able to compare the results as highlighted in Table 6. The limitations faced from this method is covered in the discussion section. The calculation method and formulas used in the RGPT method were verified to be within acceptable range compared to the benchmark values (the differential error was less than 1%).

FIGURE 14. Water Efficiency Calculation Obtained from Revit Green Project Template (RGPT) Method.

Plumbing Fixture Water Plan

Family and Type	Count	BL Flowrate	Design Flowrate	Daily Usage	Usage Duration	Usage Frequency	Operating Days/Week	Annual Design Case Water Demand	Annual Baseline Water Demand	Recycle Wastewater	Annual Recalimed WW	Supply Source: RWW	RWW Demand	Supply Source: HRW	HRW Demand
M_Lavatory - Wall Mounted: 485 mmx355 mm - Public	4	0.15	0.096	4	15	125	5.5	205920	321750	Yes	205920	No	0	No	0
M_Urinal - Wall Hung: 20 mm Flush Valve	2	3.8	0.32	3	1	62.5	5.5	17160	203775	No	0	Yes	17160	No	0
M_Water Closet - Flush Valve - Wall Mounted: Public - 6.1 Lpf	5	6	6.1	2.5	1	125	5.5	545188	536250	No	0	Yes	545188	No	0
Grand total: 11															

Mechanical Equipment Water Plan

Family and Type	OmniClass Title	Water Make-up Flowrate	Operating Hours/Week	Operating Days/Week	Annual Water Loss	Supply Source: RWH	Supply Source: RWW	RWW Demand	RWH Demand
M_Cooling Tower - Closed Circuit - Counterflow - 67-189 kW: 177 kW	Cooling Towers	0.015285	12	5.5	188849	No	No	0	0

Landscape Water Plan

Family and Type	Count	Area	Daily Water Demand	Irrigation Strategy	Manual Irrigation	Sprinkler Irrigation	Drip Irrigation	Irrigation Efficiency	Rain Dependent	No. of Rain Events	Supply Source: RWW	Supply Source: RWH	Annual Design Case Water Demand	Annual Baseline Water Demand	RWW Demand	RWH Demand
M_RPC Shrub: Acacia - 1.1 Meters	17	1	6.3	1	Yes	No	No	0.4	Yes	144	No	Yes	59173	59173	0	59173
M_RPC Tree - Deciduous: American Beech - 6.0 Meters	6	1	24	1	Yes	No	No	0.4	Yes	144	No	Yes	79560	79560	0	79560
M_RPC Tree - Deciduous: Lombardy Poplar - 12.2 Meters	6	1	24	1	Yes	No	No	0.4	Yes	144	No	Yes	79560	79560	0	79560
Turf Grass: Turf Grass	1	1150	3.1	1	No	Yes	No	0.625	Yes	144	No	Yes	1260584	1969663	0	1260584
Grand total: 30	30												1478877	2187955	0	1478877

Harvested Rainwater Plan

Family and Type	Area	Material: Name	Runoff Coefficient	Annual Rainfall	Rainfall Events	Annual Rainfall Over Catchment	Annual Potential HRW
Basic Roof: Generic - 400mm	1656 m²	Concrete - Cast In Situ	0.5	3823	144	6332361	3046921

TABLE 6. Calculated Items obtained from the RGPT (Method 1).

	Results Obtained from RGPT (Method 1)					
Design Case	Indoor Water Consumption	Outdoor Water Consumption	RWW	Resultant Potable Water	RWH Potential	RWH Supply
	*956 m³/yr**	1479 m³/yr	*206 m³/yr**	2229 m³/yr	6333 m³/yr	*1479 m³/yr**
GBI WE Categories	Reduction in PW through RWH	Reduction in PW through RWW	Irrigation PW Reduction	Indoor PW Reduction	Water Meter and Leak Detection	
	—	—	—	—	No	
Baseline	Indoor Water Consumption	Outdoor Water Consumption				
	1250 m³/yr*	2188 m³/yr				

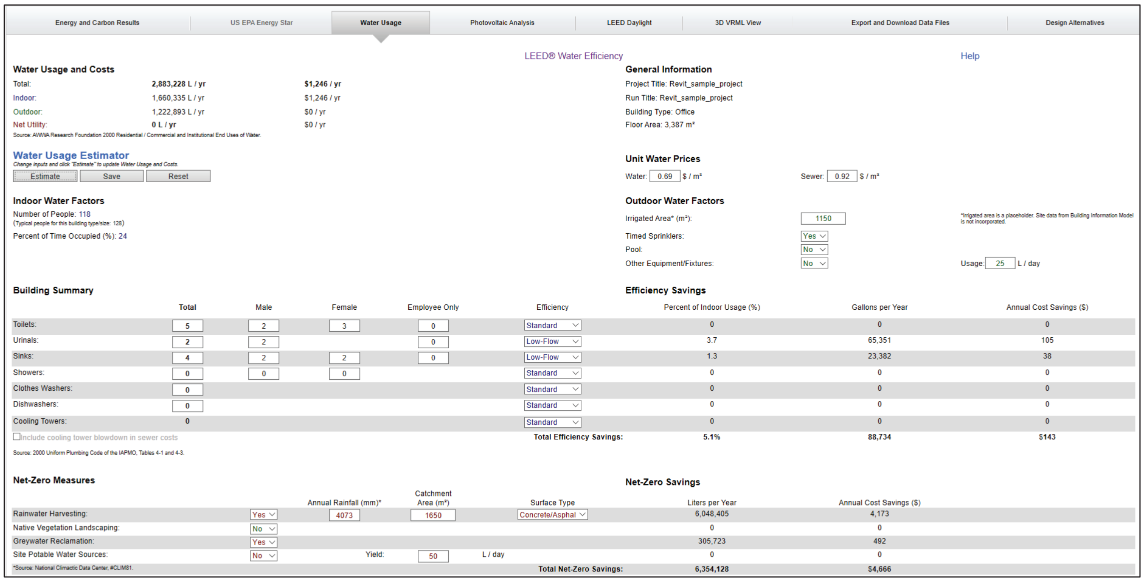
**Values were retrieved indirectly from the result.*

Table 7 summarises the water efficiency calculation obtained from the GBS method. Figure 15 shows the water estimation result provided by GBS. The GBS estimation had lower accuracy due to limitations in the level of details for the design inputs. The lowest accuracy obtained from GBS was the indoor water consumption which was 74% higher than the benchmark followed by 49% higher estimation for the recycled wastewater. The lower accuracy for these two items were due to limited parametric inputs in GBS that influences the water consumption behaviour.

TABLE 7. Calculated Items obtained from the GBS (Method 2).

	Results Obtained from GBS (Method 2)					
Design Case	Indoor Water Consumption	Outdoor Water Consumption	RWW	Resultant Potable Water	RWH Potential	RWH Supply
	1660 m³/yr	1223 m³/yr	306 m³/yr	2577 m³/yr	6048 m³/yr	—
LEED WE Categories	Reduction in PW through RWH	Reduction in PW through RWW	Irrigation PW Reduction	Indoor PW Reduction	Water Meter and Leak Detection	
	100%	100%	25%	5.1%	—	
Baseline	Indoor Water Consumption	Outdoor Water Consumption				
	—	—				

FIGURE 15. Green Building Studio (GBS) Analysis Result for LEED WE.



The estimation for rainwater harvesting potential, resultant potable water and outdoor water consumption were closer to the benchmark values containing 4.5%, 15% and 17% differential error. Moreover, the GBS water usage tab did not present any information for baseline values.

Table 8 summarises the water efficiency calculation obtained from AGBIA Method. The assessment report as well as GBI rating obtained from the AGBIA application are presented in Figures 16 and 17. The calculation method and formulas used in AGBIA were verified to be within acceptable range compared to the benchmark values (the differential error was less than 1%).

TABLE 8. Calculated Items obtained from the AGBIA (Method 3).

	Results Obtained from AGBIA (Method 3)					
Design Case	Indoor Water Consumption	Outdoor Water Consumption	RWW	Resultant Potable Water	RWH Potential	RWH Supply
	*956 m^3/yr**	1479 m^3/yr	*206 m^3/yr**	2229 m^3/yr	6333 m^3/yr	*1479 m^3/yr**
GBI WE Categories	Reduction in PW through RWH	Reduction in PW through RWW	Irrigation PW Reduction	Indoor PW Reduction	Water Meter and Leak Detection	
	66.3%	26.8%	100%	27.6%	No	
Baseline	Indoor Water Consumption	Outdoor Water Consumption				
	1250 m^3/yr*	2188 m^3/yr				

FIGURE 16. WE Design Report produced by AGBIA.

Plumbing Fixtures	Water Closet	Wash Basin	Urinal
Baseline Flowrate (L/S)	6	0.15	3.8
Design Flowrate (L/S)	6.1	0.096	0.32
Daily Usage	2.5	4	3
Usage Duration (S)	1	15	1
Number of Users	125	125	62.5
Recycle Wastewater	No	Yes	No
Supply Source: Recycled Wastewater	Yes	No	Yes
Supply Source: Harvested Rainwater	No	No	No

Plumbing Fixture Baseline Annual Consumption (L/Year)	1,061,775.00
Plumbing Fixture Design Case Annual Consumption Rate (L/Year)	768,267.50
Plumbing Fixture Recycled Wastewater Consumption Rate (L/Year)	205,920.00
Plumbing Fixture Resultant Potable Water Consumption Rate (L/Year)	562,347.50
Plumbing Fixture Harvested Rain Water Consumption Rate (L/Year)	-

Planting	Turfgrass	Tree	Shrub
Unit/Area	1,150.00	12	17
Baseline Flowrate (L/Day)	3.1	24	6.3
Rain Dependent	1	1	1
Irrigation Strategy	1	1	1
Manual Irrigation	0	1	1
Drip Irrigation	0	0	0
Sprinkler Irrigation	1	0	0
Irrigation Efficiency	0.625	0.4	0.4
Supply Source: Recycled Wastewater	0	0	0
Supply Source: Harvested Rain Water	1	1	1

Planting Annual Baseline Consumption Rate (L/Year)	2,188,034.97
Planting Annual Design Case Consumption Rate (L/Year)	1,478,927.77
Planting Recycled Wastewater Consumption Rate (L/Year)	-
Planting Resultant Consumption Rate (L/Year)	1,478,927.77
planting Harvested Rain Water Consumption Rate (L/Year)	1,478,927.77

Mechanical Equipment	Cooling Tower 177KW
Make-up Water Flow	0.015285
Make-up Water Flow	0.015285
Operating Hours per Day	12
Operating Days per Week	5.5
Supply Source: RWW	0
Supply Source: RWH	0

AC Annual Consumption Rate (L/Year)	188,849.23
AC Recycled Wastewater Consumption Rate (L/Year)	-
AC Resultant Potable Water Consumption Rate (L/Year)	188,849.23
AC Harvested Rainwater Consumption Rate (L/Year)	-

Annual Rainfall Over Catchment (L/Year)	6,332,691.98
Annual Potential Harvested Rainfall (L/Year)	3,047,086.25

*AGBIA WE Report

FIGURE 17. Automated GBI Assessment Report Produced by AGBIA.

WE subcategory	Requirements	Estimation	Credit point
WE1 Rainwater Harvesting	Rainwater harvesting that leads to ≥ 15% reduction in potable water consumption (1 point)	66.30%	2
	Rainwater harvesting that leads to ≥ 30% reduction in potable water consumption (2 point)		
WE2 Water Recycling	Treat and recycle ≥ 10% wastewater leading to reduction in potable water consumption (1 point)	26.80%	1
	Treat and recycle ≥ 30% wastewater leading to reduction in potable water consumption (2 point)		
WE3 Water Efficient - Irrigation/Landscaping	Reduce potable water consumption for landscape irrigation by ≥ 50%	100.00%	2
	Do not use potable water at all for landscape irrigation (2 point)		
WE4 Water Efficient Fittings	Reduce annual potable water consumption by ≥ 30% (1 point)	27.60%	0
	Reduce annual potable water consumption by ≥ 50% (2 point)		
WE5 Metering & Leak Detection System	Use of sub-meters to monitor and manage major water usage for water fixtures (1 point)	No	0
	Link all water sub-meters to EMS to facilitate early detection of water leakage (2 point)	No	0
Total Points	*AGBIA Estimated Points	5	
Max points = 10			

DISCUSSION

The GBS water usage estimation was based on limited factors. For instance, the calculation of efficiency through water fixture types has only descriptive options (Standard/Low Flow) rather than the design flowrates from the Revit model (Figure 15). Furthermore, calculation of water consumption for plants and landscape is not itemised and only presented in terms of area. Similar issues were observed for estimation of reclaimed wastewater and harvested rainwater estimation as the yes/no indicator assumes a total potential volume regardless of the details and capacity of the system designed (Figure15). This issue can be observed from the calculated results obtained from Table 7 as well. Therefore, based on the evaluation and comparison study of the sample model, the GBS water estimation was more suitable for the conceptual and planning stage of the project rather than the detailed design stage. A few factors such as building type, floor area and project location is sufficient for a quick water estimation at the earlier stages of the project, making it advantageous for GBS users, as little preparation is needed for preliminary analysis. A similar advantage was reported by Azhar et al. (2009). However, for a detailed analysis based on the building design features, additional factors and green parameters need to be considered. In terms of automated inputs from the Revit model, GBS extracts information such as building type, operating schedule, floor area and historic rainfall data leaving other factors such as landscape area, rainfall catchment material, catchment area and water fixture types to be verified/provided by the user that limits the data integrity and dynamic link between the GBS and the model (Figure 4). Kensek and Zhao (2011) stated similar observations regarding the problems with interoperability of the third-party software such as GBS and the digital model whereby limited information is transferred from the digital model to the simulation software and several data must be re-entered by the user. Kensek and Zhao (2011) suggested advanced programming to achieve a unified workflow.

Based on the RGPT process flow (Figure 2), additional preparation and efforts were required prior to the design stage. This can be seen as a disadvantage compared to the available green BIM tools such as GBS whereby no preparation is needed prior to the design stage. However, the use of green templates provides flexibility in terms of defining custom parameters to address a wider range of variables influencing water consumption, making it more suitable to the regional context and GBI requirements for documentation. Furthermore, RGPT is beneficial in terms of data integrity. With the RGPT method, the Revit model is continuously connected to its schedules, and the tabulations directly reflect the design features without the need for manual inputs from the user. Likewise, the direct link between the model and schedules prevents unintentional documentation errors since any changes to the design features is reflected spontaneously and vice versa. Another added advantage of RGPT is the method of data presentation, which is closely aligned with the documentation required by GBI for submission (Table 2). On the other hand, some technical limitations were faced while using the RGPT method. Although the BIM model contained adequate information, Revit schedule views had restricted access to the list of parameters that needed be added into the schedule fields for tabulation. For instance, upon verifying the project information such as building type and operating schedule in the settings, such information could not be displayed into the schedule views automatically and had to be manually created in the schedules field that was considered redundant. Likewise, some family parameters in terms of mechanical information such as cooling tower make-up water flow could not be retrieved and had to be provided by the user manually because it could only be accessed from the component/family properties. Moreover, the Revit multi-category schedule was found to be unsuitable for connecting and compiling water related data effectively. To tabulate the total water consumption of the building, a multicategory schedule in Revit was not feasible and each component category had to be listed separately as presented in Figure 8. Similar issues with Revit schedules was observed by Wong and Kuan (2014). Lastly, Revit limits users from linking schedules in terms of calculated parameters, which is ultimately needed for calculation of ratios. Therefore, the user is unable to obtain subsequent water saving percentages meant for GBI score points. Some researchers suggested a workaround solution such as processing the tabulated data externally through Excel (Khoshdelnezamiha et al., 2019). Due to the limitations mentioned, additional items needed to be calculated manually which constrained the automation process. Kensek and Zhao (2011) stated some difficulties with extraction of BIM data and performing calculations when using Revit schedules for LEED assessment.

Table 9 summarises the evaluation of each method applied. GBS was found to be more appropriate for preliminary water estimation with minimal design details; however, the method of calculation and data presentation is not suitable for GBI certification submission. GBS analysis was found to be not entirely connected to the Revit model and required the user to manually verify many design features. The RGPT method is favourable for its flexibility in defining custom parameters to address a wider range of variables that influence water consumption which is closer to the local context and GBI requirements for documentation. The RGPT approach faced some limitations from schedules' functionalities that finally hindered the calculations of water saving percentages required for GBI assessment. Although the RGPT method provided better data integrity to the Revit model compared to the GBS method, it failed to provide a full automated process particularly in producing a GBI rating. Therefore, a new method was developed to overcome the limitations and improve the automation aspect. AGBIA was designed with Dynamo, a visual programming platform to gain better access to digital model data, flexibility over performing calculations and reporting, linking built-in database for regional references and more importantly to automate several Revit functionalities.

The main aspect related to preparation of GBI-WE database is converting the existing technical information and guidelines regarding the plumbing and mechanical properties into a digital format. In Malaysia, the Construction Industry Board of Development (CIDB) has launched the myBIM Centre that also provides an online BIM Inventory as a bridge to fulfil the gap between architecture, engineering, and construction (AEC) and the manufacturing industry (myBIM Malaysia, 2017). A recommended future direction for the Malaysian BIM and green building industry is to provide a standardised digital database that includes green building parameters for commonly used components such as plumbing and mechanical fixtures,

TABLE 9. Summary of Identified Limitations from Method 1 and 2 along with improvements made in Method 3.

Investigated Methods/tools	GBS	RGPT	AGBIA
	Identified limitations		**Improvement made**
Calculation Method	• limited factors influencing water estimation • Some categories only calculated as aggregated amounts	• limitation with linking schedules for grand totals • Restriction for water saving percentage calculation	GBI recommended guideline for calculation Implemented
Level of Details	Suitable for Conceptual stage	Suitable for Detailed Design Stage	Suitable for Detailed Design Stage
Parametric Inputs	• Limited automated inputs • Some design features were defined manually	• parametric values must be assigned in advance by the user • Some parametric inputs inaccessible through schedule	• Minimal manual inputs via internal database to assign default values • Full access to the project data
Connectivity to the Model	Partially connected	fully connected	fully connected
Reporting and Documentation	• LEED points not applicable for GBI • Design calculation not provided • Some parameters were descriptive without values	• Multiple schedules need to be exported • Unable to show water saving percentage • Unable to show provisional GBI points	Able to obtain automated design documentation, water saving percentages and provisional GBI points

native plants and landscape. Such a digital depository can be used as a standardised national baseline for green BIM users in Malaysia.

CONCLUSION

The literature study conducted provided a testament to the potential of utilizing BIM tools for the design, analysis and documentation of green buildings as per intended by sustainability assessment rating tools. Three different BIM methods (Revit Green Project Template (RGPT), Green Building Studio (GBS) and Automated GBI Assessment (AGBIA)) were evaluated in terms of suitability and limitations for automated assessment and documentation of green buildings in accordance for the GBI water efficiency category. The AGBIA method is dedicated to improving the WE assessment process with the use of visual programming. A sample Revit model was analysed by each of the green BIM methods in order to compare various water related estimations. The application of AGBIA was found to be more suitable for GBI assessment based on its flexibility over defining custom parameters, direct link to the model, automatic and realistic inputs as well as the detail of presented data. The development of supporting tools such as

AGBIA is hoped to ease the GBI design assessment and documentation process for the green BIM users in Malaysia through utilisation and automation of the existing tools. Although the methodology presented was intended for one specific region and limited to water efficiency category, the presented technical method for the preparation of a green template and automated process can be adopted for other green building assessment categories with some adjustments to suit the context.

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