Modeling Water Use for Sustainable Urban Design

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Abstract. Achieving sustainability on an urban scale is an overwhelming problem. We can address this by dividing the problem into manageable proportions. Environmental impacts of urban design fall into measurable categories, for example, air quality, biodiversity, solid wastes, water and wastewater, hazardous materials, and impacts of nonrenewable energy use. Such measures are incorporated into building rating systems as a way of codifying sustainability. In this chapter, to illustrate such codification, we examine water use as well as generated wastewater according to the requirements of a specific sustainable building rating system. Conventional calculations are coupled with building information modeling to illustrate the overall effects of parametrically selecting fixtures, systems and materials to control the use of potable water. We further demonstrate how this approach of combining parametric building information modeling with measures of their environmental impacts can be employed on an urban scale, thereby, guiding the design of sustainable urban spaces.

Keywords: Sustainability, Sustainable Building Rating System, Building Information Modeling, and Parametric Design.

1 Introduction

In 2008 the number of urban dwellers surpassed those living in rural areas [1]. Cities and their residents occupy 2% of the terrestrial surface and consume a vast amount (75%) of the earth's natural resources. While these resources are becoming scarcer, the nature of the use and waste of resources contribute to environmental degradation. Among the resources to run our cities—energy, water, building materials—are some that can be reasonably quantified. Water consumption reduction, water recycling, and wastewater minimization are supported by almost all sustainability principles that are codified by sustainable building rating systems.

Urbanization is growing at a staggering scale, according to census 2000 population statistics, almost 80% of the total world's population live in urban areas today [2], and approximately 44.2 bgal/day of water withdrawals are used for public supply [3]. Rise in urban population shows an increase in the use of potable water from public supply from 62% in 1950 to 86% in 2005. Increase of population further complicates, with the geographical shift of population requiring rapid increase in water supply demand and maintenance of aging systems in areas of diminishing populations. In the last

S. Müller Arisona et al. (Eds.): DUMS, CCIS 242, pp. 138–155, 2012.

twenty years, communities have spent $1 trillion in 2001 dollars on drinking water treatment and supply, and on wastewater treatment; although this is a staggering amount; moreover, it may be insufficient for future needs [4].

Water conservation is more widely followed in the arid areas of the United States. However, using water efficiently is increasingly becoming an essential part of creating sustainable buildings and environment [5]. Ezel [6] cites a recent study by McGraw Hill's Construction [7], which indicates that after energy efficiency, water is treated with the next highest priority.

In order to study the effects of water use in the urban setting, we begin, firstly, by looking at water use in a residential building and then look at typical water use in commercial office buildings. According to Vickers [8], water use reduction in residences can be improved by efficiencies in water use, that is, by a combination of using less water with water efficient fixtures, and reusing wastewater generated by water use activities such as showers, baths, and laundry. Wastewater generated from bathtubs, wash basins, dishwashers and laundry is defined as *graywater* by the Uniform Plumbing Code (UPI) in its Appendix G [9]. Graywater reuse strategies and possibilities for rainwater collection and reuse have an effect on reducing overall water requirements. Reusing graywater and/or harvested rainwater pose technical problems. For example, adequate filtration, treatment facilities and water tank volumes would need to be determined during design. This requires additional modeling [5], for example, for water tank sizing. The same applies to rainwater reuse. However, although accounting for graywater and rainwater reuse is important, our focus in this chapter is to illustrate water savings. This is easily demonstrated by using data tables for efficient water fixtures. Likewise, if data tables for gray- and rainwater can be constructed, the same technique would still apply.

According to Mayer et. al. [10], toilets use 29% of total indoor water consumption. Water used for showering/bathing, dishwashing and laundry respectively account for approximately 36%, 14% and 21% of total indoor water consumption. In the urban scenario where we consider commercial office buildings, according to Dziegielewski [11], indoor water use falls into three main categories. These are: indoor use for toilets and wash basins; cooling systems; and outdoor use for irrigation based on the landscape and types of plants.

Outdoor water use depends on the site area around the building and type of landscaping. If the plants chosen for landscaping require only a small amount of water that can be provided by harvested rainwater, then the amount of outdoor water use is insignificant in comparison to indoor water use. Even when fixtures used indoors are efficient and even waterless, water is still required for flushing toilets and faucets. Under these water use conditions, without further research, it would be difficult to determine a typical outdoor versus indoor water use ratio. We are not aware of any literature on the subject.

In this research we focus on water use from the first category—these deal with water use for toilets and washbasins. For this, we consider an urban mass model centered on the office building. Previously we had developed a prototype to validate requirements for a green building rating system [12], linked to a commercial building information modeling software [13]. We implemented an application to visualize effects of using efficient water fixtures. Accordingly, we tested the model for a typical office building and then extended it to the urban area. It is important to point out that our original prototype application was primarily created for individual sustainable building projects—our aim is to expand its capabilities to meet needs at an urban scale. In this respect, there is other work, for example, by Müller et al on rule-based procedural modeling of cities [14]. However, it is not clear to us whether their shape rules can incorporate calculators and/or aggregations, for example, for sustainability related evaluations.

2 Background

Environmental Aspects. The total water withdrawn for use in buildings for toilets, faucets and showerheads are from rivers, streams and underwater aquifers. Reducing the amount of water for these uses would benefit potable water conservation. Reduction in potable water means that less water would need to be treated at municipal water treatment works. The accumulated effects of water use reductions go as far as allowing municipalities to defer or keep up with high investments in wastewater treatment infrastructure and supply of clean water.

In the case of rainwater harvesting for systems for reduction of potable water use in flushing, local weather conditions as well as local health ordinances should be taken into account. Quality of water supplied from rainwater collection or recycled graywater have to be accounted for in the selection of fixtures to ensure long-term fixture performance.

Economic Aspects. Reduction of water consumption at the source helps to minimize the overall operating costs of a building. According to USGBC, buildings that have been retrofitted with more efficient plumbing fixtures through incentives programs provide a cost effective way of deferring capital costs of water treatment and supply facilities. The US Environmental Protection Agency (EPA) estimates that public wastewater and supply infrastructure repair costs for the United States in the next 20 years will be about $745 billion to $1 trillion. Infrastructure repair and replacement costs to an already aging system will increase the cost average for water bills from 0.5% of the average household income to 0.9% [15]. Thus, water efficiency on a large scale will decrease the stress on current water management infrastructure such as water distribution networks, sewer lines, and treatment of both sewage and drinking water supplies.

Policy Aspects. Changing existing water fixtures with more efficient ones makes them more affordable; councils and organizations that promote green building rating systems have mobilized the industry to make efficient fixtures and water saving technologies more readily available in the general market. We could also consider harvesting rainwater and or graywater for use in water fixtures. For example, in this context, for flushing toilets in commercial buildings, there are many components that have to be taken into consideration such as roof, pipes, filtration, storage tank, pumps, controls, and available area [16].

2.1 Rating Systems and Water Efficiency

As a way of codifying sustainability, certain measures are incorporated in the form of green building rating systems. Historically, rating systems set requirements for buildings. In 1990 the British Research Establishment (BRE) was the first to develop an environmental impact assessment method, BREEAM, British Research Establishment's Environmental Assessment Method. Subsequently, other countries adopted the BRE approach in developing their own assessment method [17]. In the United States, the US Green Building Council (USGBC) created the Leadership in Energy, and Environmental Design (LEED) system. The latest release is version 3 commonly referred to as LEED v3 [19]. To the present day, there are approximately 1800 LEED certified buildings in the US mostly according to LEED 2.2 [20]. LEED v3 is a substantially different from LEED 2.2. For this paper, we work with LEED 2.2. It is interesting to note that BREEAM has started to expand their benchmarking to the community scale [18].

Table 1. Water efficiency requirements in different rating systems

Water Efficiency	LEED 3.0	Green Star	BREEAM	Green Globes
Water use reduction	WE pre, WE 3.1-3.3 Water use reduction by 20%, 30%, 40%, 50%	Wat-1 Occupant amenity water (reduction of water use)	Wat-1 Water consumption reduction for sanitary purposes	D1. Water consumption reduction
Water efficient landscaping	WE 2.1- 2.2 Reduce water use for irrigation	Wat-3 Landscape irrigation		D 2.3 Minimal use for irrigation D2.4 Efficient irrigation equipment
Waste water treatment	WE 2 Innovative waste water technologies			D3.1 Reduce offsite water treatment
Water use control		Wat-2 Water meters	Wat-2 Water meter for monitoring consumption Wat-3 Major leak detection Wat-4 Sanitary supply shut off	D2.1 Sub-metering for high use areas
Systems water use		Wat-4 Heat rejection water Wat-5 Fire system water use		D2.2 Minimal use for cooling towers

Water use reduction is considered as an essential measure in all building rating systems, generally measured by a percentage of water use reduction. Two cases provide the basis for comparison: water use in the design, and a baseline water use.

Table 1 illustrates water use from the perspective of four different rating systems. The rating systems shown correspond to those designated by Fowler [12] as providing inherently distinct ways of calculating water as an important resource in the building domain. The left-most column captures the broad categories in which water resource use is measured.

Each rating has a distinct way of allocating credits for meeting requirements. For instance, the LEED 2.2 rating system for New Construction has 4 credits dedicated to this criterion. Green Star, the rating system by the Green Building Council of Australia (GBCA) awards from up to a maximum of 5 points for water use reduction. BREEAM allocates 3 credits, while Green Globes, licensed by the Green Building Initiative, dedicates between 10-40 points depending on the amount of reduction in water use. It is important to note that although different weights and points are given to this category by the different rating systems, each considers water use reduction an essential component of green design.

2.2 Urban Water Use in Commercial Buildings

Reducing water use by installing efficient fixtures is a relatively simple criteria to follow in order to earn credits, for example, from a sample of LEED 2.1 Silver certified buildings in Pennsylvania, we found that 88% of the buildings achieved credits for water use reduction, and 56% of the same set achieved 4 out of 5 possible credits [19]. Figure 1 shows the samples, numbered from 1 to 25 on the x-axis, with the water efficiency credits on the y-axis, numbered from 1 to 5.

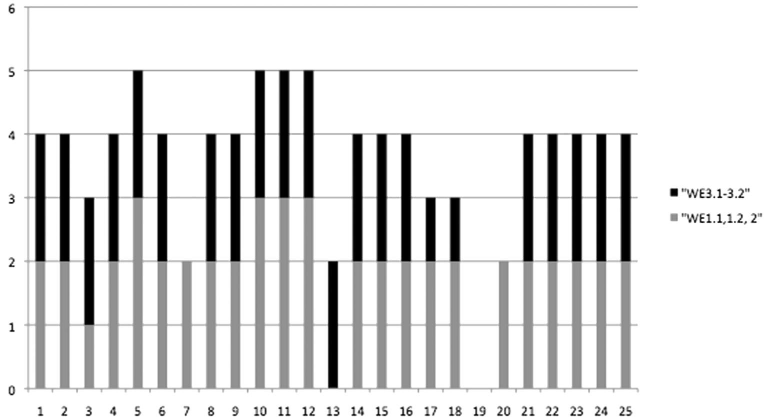


Fig. 1. Distribution of LEED water credits earned by certified buildings. The lighter and darker series respectively represents credits WE1.1, WE1.2 and WE2, and credits WE3.1 and WE3.2. These two kinds of credits essentially cover fixtures, water use and water use load calculations.

In a study of LEED certified buildings on the campus of Carnegie Mellon University, we found that all but one had acquired water reduction credits (Table 2). According to facilities management, the benefits can be seen not only in the use of less water but also in the overall operation and maintenance costs of the facilities. Although the campus has several differing types of buildings certified under LEED New Construction, calculations generally vary only in the allocation of types of fixtures, number of users and number of days in a year the buildings are used. The reason for the one of the buildings not having achieved LEED water credits can be attributed to the small footprint of the building. Water use reduction is reflected in the deployment of available efficient fixtures at the time.

Table 2. Water efficiency credits achieved for LEED certified buildings on the campus of Carnegie Mellon University

Project Name	Certification	LEED version	LEED water credits achieved
New House	Silver	LEED NC 2.0	WE 1.1, WE 1.2
Henderson House	Silver	LEED NC 2.0	WE1.1, WE 1.2, WE3.1, WE3.2
407 S Craig St	Silver	LEED NC 2.1	None
300 S Craig St	Silver	LEED NC 2.1	WE1.1, WE 1.2, WE 3.1
Collaborative Information Center	Gold	LEED CS	WE1.1, WE 1.2, WE2, WE 3.1, WE 3.2

3 Modeling Water Use

We employ two different methods to model water use in buildings. The first considers individual buildings to determine their water use. It is assumed that the number of occupants is known. Further, there is an urban information model containing the floor areas and numbers of floors in each building. Urban water use is then, an aggregation of water use by the occupants in each the selected buildings. The second approach works from 2D drawing of an urban area with known building heights. Numbers of occupants, fixtures and fixture flow rates are assigned and maintained in an external database.

We modeled the test case in a commercial design software, Revit® Architecture 2010 [13]. It provides designers with an architectural modeling environment, with a built-in collection of general objects or a family base of building elements such as walls, windows, floors, roofs, columns, beams, fixtures, zones, etc. Revit allows the user to parametrically manage, update and propagate changes in the model. It provides an Application Programming Interface (API) for writing specific functions according to need. It offers capabilities for ready design documentation with calculations that can be, ultimately, submitted for certification.

For water use requirements we employ criteria from LEED NCv2.2, and a building information model to make informed decisions on using certain fixtures for achieving sustainability goals set by LEED. The advantage in creating and using a building information model is its intrinsic characteristic of holding project information for all team members. This includes designers, planners, facility managers, and on a larger scale, policy and decision makers. To demonstrate the approach of designing towards specific LEED goals, we also employ Revit as the building information model. Figure 2 illustrates the test case, modeled in Revit® Architecture 2010.

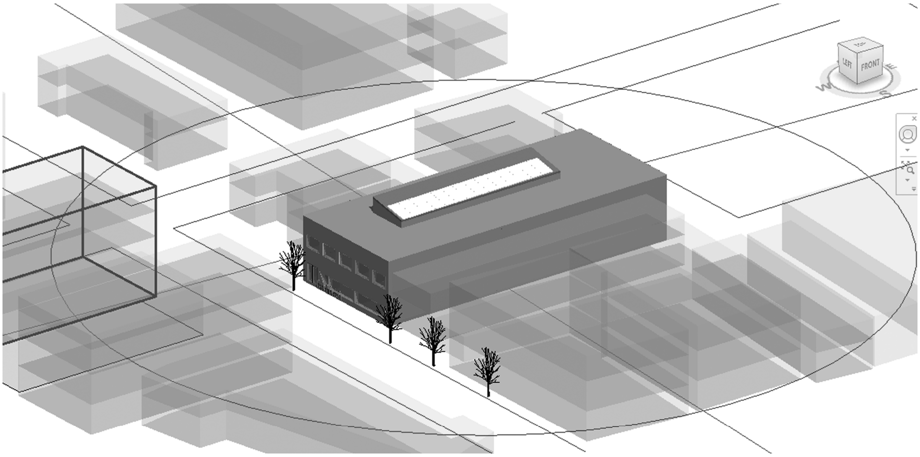


Fig. 2. Test case for modeling water efficiency for LEED

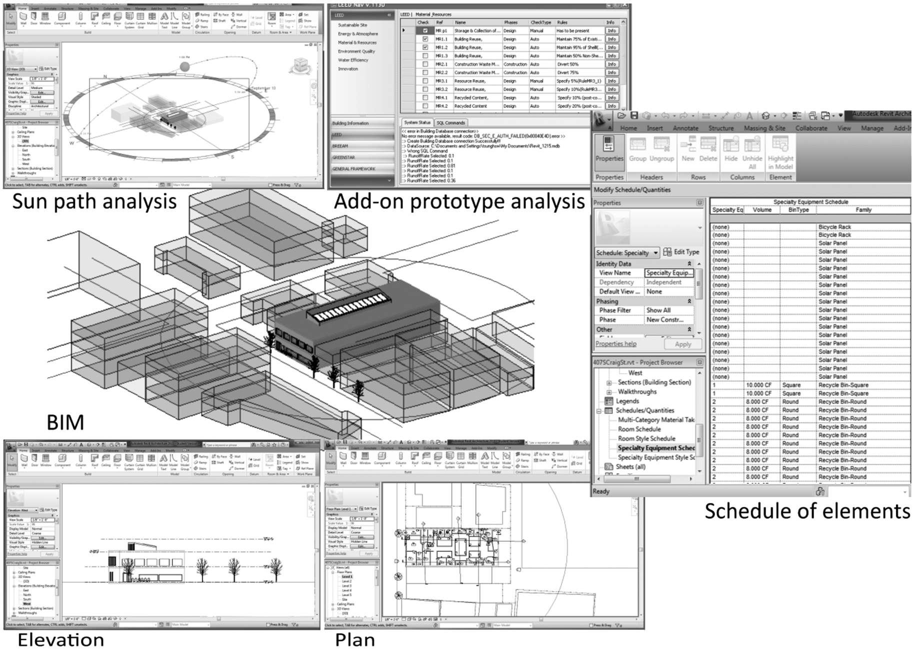
Building Information Model. There is no standard definition for a building information model (BIM). A BIM is a modeling technology with an associated set of processes to produce, communicate, and analyze building models [20]. From an information science perspective, a BIM is an instance of a populated data model of buildings that contains multidisciplinary data specific to a particular building, which can be described unambiguously.

According to Eastman [20], building models are made of

- Building components, (objects) that 'know' what they are, and can be associated with data attributes and parametric rules
- Components that include data that describe how they behave, as needed for analysis, e.g. scheduling, specification, and energy analysis
- Consistent and non-redundant data, such that component data are represented in all views such plan, section, elevation and schedules.
- Coordinated data, such that all views of a model are represented in a coordinated manner.

BIM has its roots in decades old computer-aided design research, but it is only recently that it is being adopted in different domains of the building industry. Some features sought in BIM software are the following—it must be digital, spatial (3D), measureable (quantifiable, dimensionable and queryable), accessible to the entire AEC/owner team; and durable (usable through all phases of the facility's life cycle).

Current implementations of BIM do not meet these criteria within any single software [20]. Different BIM tools vary in their sophistication of their predefined objects; ease of use and learning; ease with which users can define and customize new object families; in their abilities to interface with other software. Figure 3 illustrates Revit as an example of a BIM where the software is used to generate different views-plans, sections, elevations, databases; and it is used for analysis and visualization.



LEED | Material_Resources

Check	Ref	Name	Phases	CheckType	Rules	Info
☑	MR p1	Storage & Collection of...	Design	Manual	Has to be present	Info
☑	MR1.1	Building Reuse,	Design	Auto	Maintain 75% of Existi...	Info
☑	MR1.2	Building Reuse,	Design	Auto	Maintain 95% of Shell(...	Info
☐	MR1.3	Building Reuse,	Design	Auto	Maintain 50% Non-She...	Info
☐	MR2.1	Construction Waste M...	Construction	Auto	Divert 50%	Info
☐	MR2.2	Construction Waste M...	Construction	Auto	Divert 75%	Info
☐	MR3.1	Resource Reuse,	Design	Manual	Specify 5%(RuleMR3_1)	Info
☐	MR3.2	Resource Reuse,	Design	Manual	Specify 10%(RuleMR3...	Info
☐	MR4.1	Recycled Content,	Design	Auto	Specify 10% (post-co...	Info
☐	MR4.2	Recycled Content	Design	Auto	Specify 20% (post-co...	Info

System Status | SQL Commands

```
<< error in Building Database connection>>
No error message available, result code: DB_SEC_E_AUTH_FAILED(0x80040E4D).error >>
:> Create Building Database connection Successfully!!!
:> DataSource: C:\Documents and Settings\tsunghow\My Documents\Revit_1215.mdb
:> Wrong SQL Command
:> RunoffRate Selected: 0.1
:> RunoffRate Selected: 0.1
:> RunoffRate Selected: 0.81
:> RunoffRate Selected: 0.1
:> RunoffRate Selected: 0.1
:> RunoffRate Selected: 0.36
```

Schedule: Specialty
Identity Data
View Name: Specialty Equip...
Dependency: Independent
Default View ...: None
Phasing
Phase Filter: Show All
Phase: New Constr...

Specialty Equipment Schedule

Specialty Eq	Volume	BinType	Family
(none)			Bicycle Rack
(none)			Bicycle Rack
(none)			Solar Panel
(none)			Solar Panel
(none)			Solar Panel
(none)			Solar Panel
(none)			Solar Panel
(none)			Solar Panel
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(none)			Solar Panel
(none)			Solar Panel
1	10.000 CF	Square	Recycle Bin-Square
1	10.000 CF	Square	Recycle Bin-Square
2	8.000 CF	Round	Recycle Bin-Round
2	8.000 CF	Round	Recycle Bin-Round
2	8.000 CF	Round	Recycle Bin-Round
2	8.000 CF	Round	Recycle Bin-Round
2	8.000 CF	Round	Recycle Bin-Round
2	8.000 CF	Round	Recycle Bin-Round
2	8.000 CF	Round	Recycle Bin-Round
2	8.000 CF	Round	Recycle Bin-Round
2	8.000 CF	Round	Recycle Bin-Round
2	8.000 CF	Round	Recycle Bin-Round

407SCraigSt.rvt - Project Browser
West
Sections (Building Section)
Walkthroughs
Legends
Schedules/Quantities
Multi-Category Material Tak
Room Schedule
Room Style Schedule
Specialty Equipment Schec
Specialty Equipment Style Sc
Sheets (all)

Fig. 3. Example of Revit as a BIM

3.1 Water Use Calculations

Water use calculations principally follow the LEED 2.2 method, which is outlined below. Water use reduction for a building/project corresponds to the difference between the *design* case and a *baseline* case.

In this methodology water use is calculated by estimating occupant usage and fixture flow rates. Occupants are determined by calculating full time equivalent (FTE) occupancy of a building. This is based on a standard 8-hour occupancy period, resulting in a value based on the hours per day divided by 8. In the case of transient building populations such as students, visitors, or customers, hours are estimated for a representative daily average. Table 3 illustrates the calculations for determining FTE occupancy.

Table 3. Sample Occupancy Calculation for a College Building

Occupant Type	Number	Person- hrs/day	Subtotal FTEs
Full Time Staff (assuming 8hr/day)	8	64	8
Full Time Faculty	6	48	6
Part Time Faculty (assuming 2hrs/day)	24	48	6
Part Time Researchers	20	40	5
		Total FTEs	25
Transient Occupant	Peak Number	Occupant Values for LEED	
	320	320	25
		Total FTEs	345

Design Case. Annual water use is obtained by totaling the annual volume of water use by each fixture type and then, subtracting rainwater or graywater reuse. Actual flow rates and flush volumes for the installed fixtures are used in the calculation. For consistency, a balanced one-to-one ratio of male and female is assumed. Table 4 shows an example of a design case study for water usage from interior fixtures.

Table 4. Water use calculation based on flush and flow fixtures from a sample case study

Fixtures	Daily use	Flowrate	Duration	Occupant	H_2O use
Flush Fixture		*GPF*	*(flushes)*	*(gal)*	
Ultra Low Flow WC (m)	0	0.8	1	80	0
Ultra Low Flow WC (f)	3	0.8	1	80	192
Composting Toilet (m)	1	0	1	80	0
Composting Toilet (f)	0	0	1	80	0
Waterless Urinal (m)	2	0	1	80	0
Waterless Urinal (f)	0	0	1	80	0
Flow Fixture		*GPM*	(*minutes*)		
Conventional Lavatory	3	2.5	0.20	160	240
Kitchen sink	1	2.5	0.2	160	80
Shower	0.1	2.5	5	160	200
Total Volume (gal)					712
Work days					260
Annual volume					185120
Rain water or graywater reuse					0
Annual water use (gal)					185,120

Baseline Case. According to LEED methods, to create a baseline case the design case table is used to provide the number of male and female occupants, with fixture flush and flow rate values adjusted as per EPAct default specifications [9]. Table 5 shows the baseline case for the same design case study.

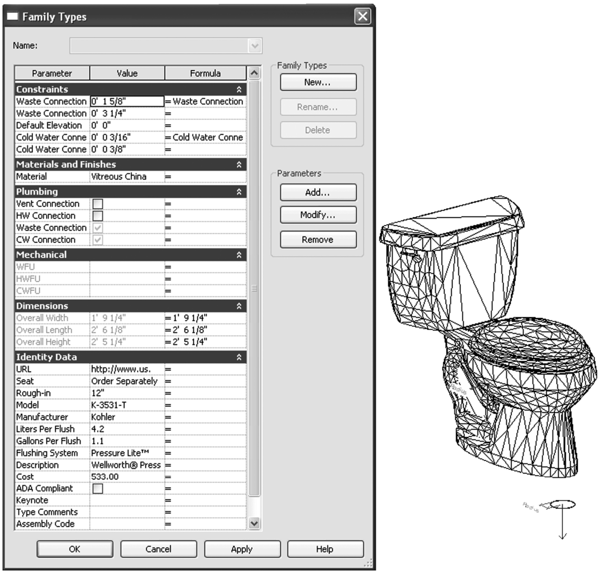
Table 5. Baseline calculations for the same case study

Fixtures	Daily use	Flowrate	Duration	Occupant	H_2O use
Flush Fixture		*GPF*	(*flushes*)	**(gal)**	
Conventional WC (m)	1	1.6	1	80	128
Conventional WC (f)	3	1.6	1	80	384
Conventional Urinal (m)	2	1	1	80	160
Conventional Urinal (f)	0	0	1	80	0
Flow Fixture		*GPM*	(*minutes*)		
Conventional Lavatory	3	2.5	0.25	160	300
Kitchen sink	1	2.5	0.25	160	100
Shower	0.1	2.5	5	160	200
				Total Volume (gal)	1272
				Work days	260
				Annual volume	330720
				Rain water or graywater reuse	0
				Annual water use (gal)	330,720

Water use calculations are straightforward. However, it can be problematical owing to missing data as a result of integrating requirements from a rating system with a particular building information model. As a model is only as complete as the information entered, designers must ensure that for water use calculations all pertinent information—occupant numbers, fixture costs and materials—are included within the model. There are always other required and pertinent information that are normally stored externally to any project for any building information model; these include rainfall data, plant water use data, etc. Such information is not expected to fall directly into a designer's purview, yet these factors have to be accounted for. Table 6 shows the objects required for calculating LEED NC 3.0 water related credits.

Water fixtures are components stored in the Revit library. As stored, when queried, only dimensions of instances are returned. Dimensions are incorporated into the object names; there is no other way of getting at object parameters, or other needed material properties from the objects, unless the information from manufactures specifications has been filled in.

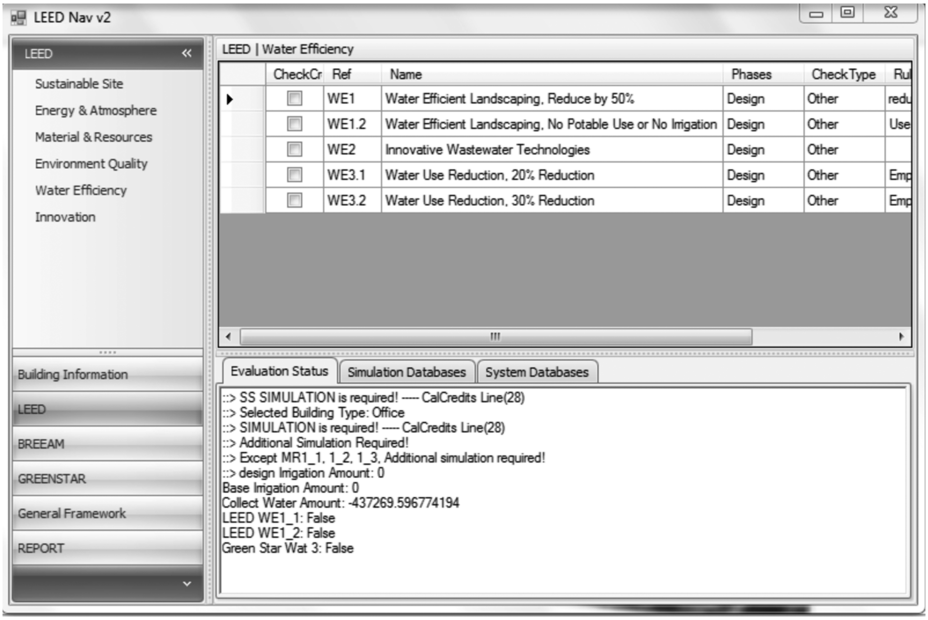
Figure 4 shows a family of fixtures in Revit with essential information pertaining to water use calculation such as flow rate. By default, flow rate is not specified as an attribute of a fixture; instead it has to be added as a customized parameter. Likewise, occupant data has to be added to the project. In the this release, Revit Architecture 2010, there is no standard way of specifying independent male and female occupant numbers. These are treated as separate attributes that can be aggregated.



Parameter	Value	Formula
Constraints		
Waste Connection	0' 1 5/8"	= Waste Connection
Waste Connection	0' 3 1/4"	=
Default Elevation	0' 0"	=
Cold Water Conne	0' 0 3/16"	= Cold Water Conne
Cold Water Conne	0' 0 3/8"	=
Materials and Finishes		
Material	Vitreous China	=
Plumbing		
Vent Connection	☐	=
HW Connection	☐	=
Waste Connection	☑	=
CW Connection	☑	=
Mechanical		
WFU		=
HWFU		=
CWFU		=
Dimensions		
Overall Width	1' 9 1/4"	= 1' 9 1/4"
Overall Length	2' 6 1/8"	= 2' 6 1/8"
Overall Height	2' 5 1/4"	= 2' 5 1/4"
Identity Data		
URL	http://www.us.	=
Seat	Order Separately	=
Rough-in	12"	=
Model	K-3531-T	=
Manufacturer	Kohler	=
Liters Per Flush	4.2	=
Gallons Per Flush	1.1	=
Flushing System	Pressure Lite™	=
Description	Wellworth® Press	=
Cost	533.00	=
ADA Compliant	☐	=
Keynote		=
Type Comments		=
Assembly Code		=

Fig. 4. Fixture information related to water use

To calculate Water Efficiency credits, we implemented external databases for fixtures and landscapes. In the prototype shown in Figure 5 there are two tabs under the Water Efficiency category. These contain the necessary tasks to be fulfilled when evaluating water efficiency credits.



	CheckCr	Ref	Name	Phases	CheckType	Rul
▶	☐	WE1	Water Efficient Landscaping, Reduce by 50%	Design	Other	redu
	☐	WE1.2	Water Efficient Landscaping, No Potable Use or No Irrigation	Design	Other	Use
	☐	WE2	Innovative Wastewater Technologies	Design	Other	
	☐	WE3.1	Water Use Reduction, 20% Reduction	Design	Other	Emp
	☐	WE3.2	Water Use Reduction, 30% Reduction	Design	Other	Emp

```
::> SS SIMULATION is required! ----- CalCredits Line(28)
::> Selected Building Type: Office
::> SIMULATION is required! ----- CalCredits Line(28)
::> Additional Simulation Required!
::> Except MR1_1, 1_2, 1_3, Additional simulation required!
::> design Irrigation Amount: 0
Base Irrigation Amount: 0
Collect Water Amount: -437269.596774194
LEED WE1_1: False
LEED WE1_2: False
Green Star Wat 3: False
```

Fig. 5. Water efficiency tabs for rating credits, and various water related calculations

Table 6. LEED credit requirements for water efficiency calculations

Credit Name	Description	Existing objects in Revit™	Required Properties	New objects and required properties	Associated info	External info
WE pre	Water use reduction	Plumbing fixtures	Low flow fixtures, male and female; Kitchen, sink, shower		Number of male and female users	
WE 1.1	Water Efficient Landscaping Reduce by 50%	Plant	1. Species factor 2. Density factor 3. Landscape coefficient 4. Irrigation efficiency	Site area covered by specific plant		
WE 1.2	Water Efficient Landscaping No potable water use or no irrigation	Plant	1. Species factor 2. Density factor 3. Landscape coefficient 4. Irrigation efficiency	Site area covered by specific plan	Water harvested	ET rate database; CE value
WE 2	Innovative Wastewater Technologies	Plumbing fixtures	Water usage properties: flow rate, frequency used	Water treatment facilities and properties	Number of male and female users	
WE 3.1	Water Use Reduction 20% Reduction	Plumbing fixtures	Low flow fixtures, male and female; Kitchen, sink, shower		Number of male and female users	
WE 3.2	Water Use Reduction 30% Reduction	Plumbing fixtures	Low flow fixtures, male and female; Kitchen, sink, shower		Number of male and female users	

The overall workflow for wastewater management, firstly, retrieves information about the numbers of male and female occupants, which are specified in the building information section of the Revit building information model. Differences between the baseline and design cases are then compared to determine the number of credits that are earned at this stage. The comparison between the baseline and design case yields a percentage reduction of water use.

Most building information modelers usually offer the facility to calculate the areas covered by buildings, for example, site area. On the other hand, certain site-specific information such as ground cover type typically has to be manually specified. Additional materials and object parameters such as material porosity and fixture flow rates are also needed. Fixture cost values from manufacturers databases are used in the comparison for water use and for the ultimate savings in costs.

The prototype was implemented as an add-on to Revit Architecture 2010. It collects information such as flow rates from the fixtures placed in the model and calculates credits according to methods set out by LEED and the other standards. The application has the potential to be extended to accumulate information from multiple buildings and aggregate total water use. This approach, however, would work only when all pertinent information (number of occupants and fixtures allocated in all the buildings) are available.

4 Modeling Urban Water Use

In one sense, extending the water use model from the scale of a single building to the urban scale is straightforward; we simply aggregate single unit water use to multiple units. At the urban scale, we face the challenge of propagating results from one building to many, especially when each buildings' occupants and fixture type has to be specified by modeling. In this study we assume that the buildings are commercial office buildings.

Note that we have made assumptions. Firstly, the urban environment comprises many single unit buildings of the same type. Each building holds similar information on occupants and fixtures.

By using a building information model we can embed, store and query different kinds of information. In this case we are interested in information required for carrying out water use evaluation. We have already seen in section 3 that models only carry certain default values with their objects.

Assumptions and Challenges. In modeling for water use on a larger scale, we have far less information. Here, we adopt a slightly different approach, and employ a combination of different commercial software. The parameters that affect water use are similar to those seen in Tables 4 and 5. At this stage, graywater quantity and rainwater harvesting is not accounted for in the calculation.

As there are many buildings, assigning users to each individual building is difficult owing to lack of information; in this case, we have adopted the method of assigning occupant numbers used by Green Star's approach to space allocation [21]. In Green Star, the number of occupants in a building is allocated as a percentage of the net floor area. In contrast, there is no direct method in LEED to calculate occupants for a given area. As we have the floor area of all the buildings in the sample case study, we are able to allocate occupant number as a function of floor area.

Urban Case Study. The sample case study covers a total area of 17346.85 m^2, of which 11706.56 m^2 covers the building footprint. The remainder comprises roads, pavements and parking areas, which are assumed to have an impervious ground cover. There are also open spaces, which have potential for planning for rainwater catchments and water management. The model is generated from a 2D CAD drawing, and converted into a mass model for the purpose of calculating the total floor areas of buildings. Figure 6 shows the CAD drawing of a portion of the urban area modeled.

Fig. 6. CAD drawing of the test urban area

In order to estimate water use on a larger scale we used Rhinoceros® (Rhino) [22] with Grasshopper™ [23] to generate the three dimensional model. Rhino is a commercial NURBS-based 3-D modeling tool. Grasshopper is a graphical constraint propagation editor and is mainly used for parametric generation. Rhino with Grasshopper offer a quick flexible way to visualize information from databases, which includes such building information as building footprints, heights, occupants, fixtures and parameters for calculating water use on a larger scale. Both Rhino and Revit are built on top of the .NET framework [24], thereby making communication of specific information between the softwares fairly straightforward. Figure 7 shows the mass model generated in Rhino. A CAD model of the site plan which included building footprints were imported into Rhino, each building footprint was identified by a unique number and corresponding height to generate the 3D massing. The Grasshopper definition file in Figure 8 shows the connection between the model geometry and the external databases that contain fixture information to generate the water use model for the urban area.

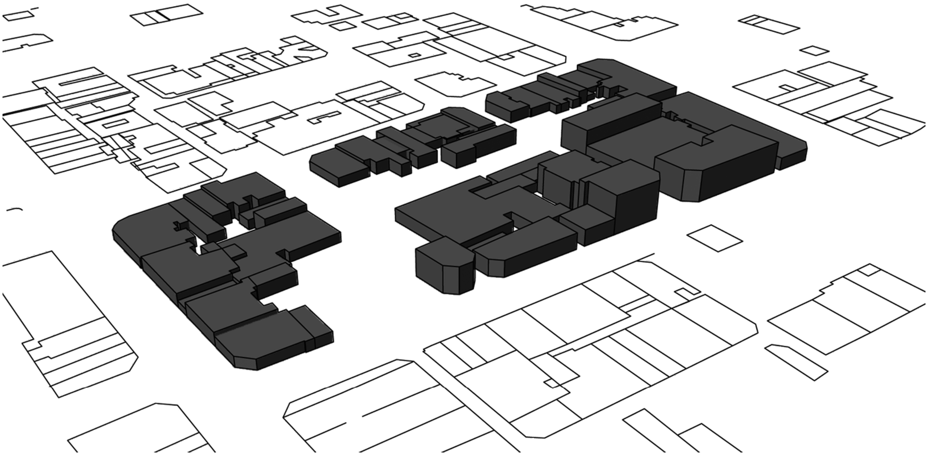
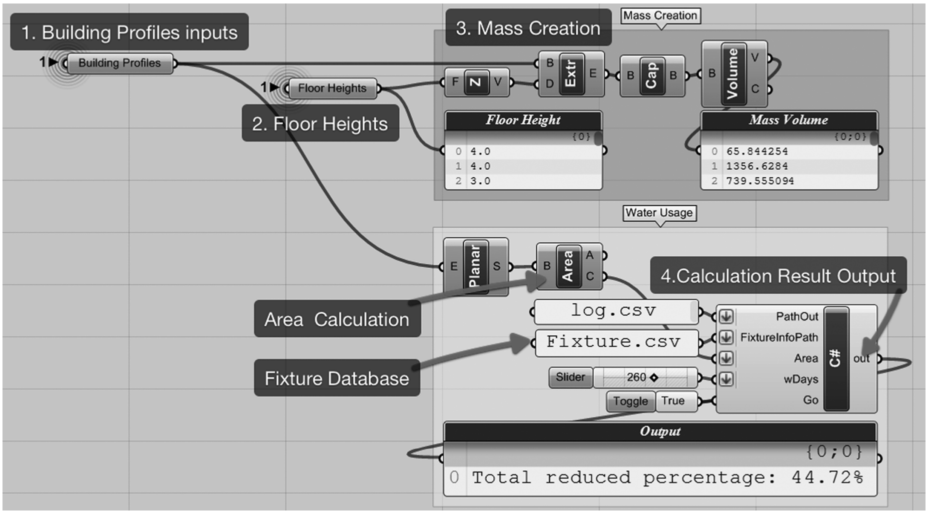


Fig. 7. Modeling the urban area



```
Floor Height
{0}
0 4.0
1 4.0
2 3.0
```

```
Mass Volume
{0;0}
0 65.844254
1 1356.6284
2 739.555094
```

```
Output
{0;0}
0 Total reduced percentage: 44.72%
```

Fig. 8. Grasshopper definition file for water use model generation

As the scale changes from building to urban, we begin to notice that water use reduction is only a piece of the overall water management scheme. The model reveals potential spaces for artful rainwater catchment areas [25]. Rainwater management, collection and reuse in buildings, and for community activities, rely not only on individual buildings and their storm water collection strategies, but also become part of urban planning, as this is not always cost effective to do so for smaller projects. Information for groundcover type, vegetation, rainfall data for the area are critical to calculating rainwater runoff and collection potential. This is information that is not originally part of the building information model; however, such data needs to be supplied whether calculations are done either in Revit or Rhino, or some other combination of commercial building/urban information models.

5 Analysis

Our sample model for urban water use considered a total building area of 52439m^2 and 3516 occupants. By changing design cases we were able to see explore variations in water use reduction rates. Tables 7 and 8 depict a portion of the sample urban area. For both design cases the number of uses of the fixtures was the same and distribution of male and female were evenly balanced at a ratio of 1:1.

Table 7. Water use reduction: design case 1

Building No.	Case 1	Area (m^2)	Occupant	Water Use
Building_000	BASE	1174.0848	79	617247.540
Building_000	DESIGN	1174.0848	79	340844.868
Building_001	BASE	1356.6284	91	711006.660
Building_001	DESIGN	1356.6284	91	392618.772
Building_002	BASE	153.9494	11	85945.860
Building_002	DESIGN	153.9494	11	47459.412
Building_003	BASE	1001.68	67	523488.420
Building_003	DESIGN	1001.68	67	289070.964
Building_004	BASE	739.5551	50	390663.000
Building_004	DESIGN	739.5551	50	215724.600
Building_005	BASE	65.8443	5	39066.300
Building_005	DESIGN	65.8443	5	21572.460
			Total reduced percentage	44.78%

Table 8. Water use reduction: design case 2

Building No.	Case 1	Area (m^2)	Occupant	Water Use
Building_000	BASE	1174.0848	79	617247.54
Building_000	DESIGN	1174.0848	79	298918.62
Building_001	BASE	1356.6284	91	711006.66
Building_001	DESIGN	1356.6284	91	344323.98
Building_002	BASE	153.9494	11	85945.86
Building_002	DESIGN	153.9494	11	41621.58
Building_003	BASE	1001.68	67	523488.42
Building_003	DESIGN	1001.68	67	253513.26
Building_004	BASE	739.5551	50	390663
Building_004	DESIGN	739.5551	50	189189
Building_005	BASE	65.8443	5	39066.3
Building_005	DESIGN	65.8443	5	18918.9
			Total reduced percentage	51.57%

With the tool it is possible to vary the number and type of fixtures, change the ratio of male and female occupants, and also allocate different design cases to different parts of the urban area in order to parametrically model various scenarios for water use. The two design cases shown have different fixture flow rates; the resulting water reduction savings for design case 1 is 44.78%, and 51.57% for design case 2. Case 1 also has a savings of 12.3 million liters of potable water annually.

6 Conclusions

We have hinted at a fraction of the possible calculations that stem from combining a rating system requirement (in this case, LEED) with capabilities provided by a specific commercial building information modeler (in this case, Revit). We have also given an alternate approach, based on a combination of commercial software, that is, Grasshopper and Rhino, external databases and rating system requirements, to illustrate how information (in this case, for modeling water use) can be gathered and processed on a larger scale. These methods can be used to both pre-certify a building for sustainability, and on a larger scale, to project the effects on environmental resources. Through the use of different parameters, generally simple calculations, and by augmenting extant databases of materials and objects, we show how current commercial tools can be used to model environmental resources at both the building and urban scales.

There is also no technical reason to suppose that the approach will not work with other green rating system requirements, other commercial building information models and software, or for other environmental resource related calculations. The process used for modeling urban water use, prepares the groundwork for implementing other water resource management tools, for example, for graywater and rainwater collection, design of green roofs and water runoff calculation from different surfaces. The prototype described in this chapter was developed primarily for research purposes. It was implemented as a plug-in module on top of Revit. Currently, it is based on a simple water use model. It would require a more sophisticated water use modeling before it can be employed for non-research use.

The findings described in this chapter lead to the conclusion that strategies, which focus on water use reduction from the scope of the individual building to the urban scale, are among the components required for water management that have to be cohesively integrated to create a 'Green Urbanism' [26].

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