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Modeling algae powered neighborhood through GIS and BIM integration

Florina Dutt[a,b], Steven Jige Quan[a,b], Erik Woodworth[a], Daniel Castro-Lacouture[a], Ben J. Stuart[c], Perry Pei-Ju Yang[a,b]*

[a] *College of Design, Georgia Institute of Technology, Atlanta, USA*
[b] *Sino-U.S. Eco Urban Lab, College of Architecture and Urban Planning, Tongji University, Shanghai, China*
[c] *Department of Civil and Environmental Engineering, Old Dominion University, Norfolk, VA 23529, USA*

Abstract

This paper aims to propose a modeling method for algae powered neighborhoods through GIS-BIM integration. In the first part of the paper, the applicability of different types of algae systems in an urban neighborhood are studied. The various systems of algae provide different strengths and weakness that affect their performance and suitability for given urban scenarios. Through extensive literature review, the variables that affect the performance of the micro-algae in the built environment are identified, with a focus on flat-panel photo bio-reactors and tubular photobioreactors. A previous GIS model for data management, performance analysis and design of the algae systems is reviewed [1], which shows its limitations in managing fine-grained structures and functions of algae systems. A bottom-up BIM approach to deal with these limitations is further explored. The algae-embedded built environment can be modeled in the parametric 3D BIM and Rhinoceros with a set of building parameters for the roof, façade, window to wall ratio, etc. Subsequently, solar exposure on building surfaces, the use of the buildings and their respective façade types would be studied. Parametric 3D models of the buildings allows for faster design modification and the creation of multiple design options. These models can be used to perform energy analysis using the parametric energy analysis tool to check for building energy use intensity (EUI). The bottom-up approach explored in this research design aims to facilitate visualization and analysis of the built environment and gauge the productivity of microalgae. Finally, a platform for BIM –GIS integration and its possibility is explored in this paper.

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Keywords: Micro-algae; Parametric Model; Building Information Model (BIM); Geographic Information Systems (GIS)

1. Introduction

Different types of biofuel sources have been explored over the past two decades to reduce dependence

* Corresponding author. Tel.: +1-404-894-2076; fax: +1-404-894-1628.
E-mail address: perry.yang@design.gatech.edu

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on fossil fuels. Algae have been specifically investigated due to their high lipid content, rapid growth rate, and ability to capture atmospheric or waste CO2 [1]. Microalgae are photosynthetically more efficient with photosynthetic efficiency (PE) of 3-6% in comparison to typical plants where PE ranges from 0.1-2%. They can be cultivated continuously and produce 60-100 times more biodiesel than soybeans cultivated over the same acreage with very little environmental impact. Algae systems are primarily designed to reduce carbon emissions, reuse untreated wastewater, capture atmospheric carbon dioxide and to produce renewable fuels and clean water [2]. Algae can grow in nutrient-rich wastewaters, and reduce nitrogen (N) and phosphorus (P) content, thus reducing nutrient loads of the receiving water bodies [3]. Also, algae cultivation and the processes of managing liquid and solid waste in a neighbourhood allows carbon stream recycling into a useful source of energy [4]. The typical input for any algae system requires water, nutrients (nitrogen and phosphorus), carbon (primarily carbon dioxide), and sunlight. Biodegradable solid wastes from a neighbourhood are directed to biogas digesters where anaerobic bacteria convert the majority of the organic carbon into methane CH4 and carbon dioxide CO2. These gases are further combusted in a gas turbine where electricity and heat are supplied to the neighbourhood buildings. The flue gases produced as the result of a combination of CO2 and N2, as well as the nutrient-rich liquid waste from the combustion, can be further fed into algae cultivation ponds. Algal biomass can also be used as solid fuel and provide oil from high lipid strains. The biological processes involved in algae cultivation further generate biomass, oxygen, and water as outputs. Thus through these processes the algae systems are capable of producing renewable energy using the waste stream of an urban neighbourhood. This paper aims to propose a modeling method for such algae powered neighborhoods through the integration of GIS and BIM.

1.1. Types of Algae Cultivation systems

Three types of algae cultivation systems have been studied in this paper: the open pond, closed systems-photobioreactors and hybrid system. The open pond algae cultivation system is one of the oldest systems for mass cultivation of algae. There are usually shallow algae ponds, usually a foot deep [5] and their sizes may vary from an acre to several acres. The source of water in these ponds is runoff from adjacent land areas and sewerage from the neighborhood. The ponds are exposed to sunlight to allow photosynthesis and are equipped with paddle wheels to allow continuous mixing of algae cells and nutrients [6]. The open pond system is very cost-effective, and they are being introduced in commercial scale to produce fuels. However, the downside of the open algae ponds is, they can easily get contaminated by parasitic algae. As such, routine cleaning and flushing is needed for the maintenance of the ponds. The closed system is much more effective and contains high potential yield oil. They typically consist of two different types of photobioreactors (PBR) flat panel and tubular. Photobioreactors are closed bioreactors with a light source and continuous source of nutrients, sterilized water and CO2 are needed to allow algae growth and cultivation within the closed system. Although the closed system photobioreactors are more expensive and require higher maintenance compared to the open pond system, they require less sunlight, have the least chance of contamination and are capable of producing high oil species of algae. Another advantage of closed system photobioreactors is that they require less land area compared to the open systems, and they can be installed as building systems leveraging the use of algae in high-density urban neighborhoods. The third type of algae cultivation system is hybrid algae production system (HAPS), which essentially includes both open pond systems and closed bioreactors to produce high-yielding algae strains in a more cost effective way. HAPS have covered ponds constructed with inexpensive construction materials. They are more expensive than open pond systems but less expensive than closed system photobiorecators. They are more expensive than open pond systems, but the chances of contamination are much less. The downside of HAPS includes excess oxygen accumulation that inhibits algae growth and maintaining the constant flow of nutrients and gas exchange.

Fig. 1. a) open pond system; b) closed system of flat panels and tubular photobioreactors (PBR); c) hybrid algae production system

2. Parameters that affect productivity of Algae Systems

There are several parameters that affect the productivity of algae systems. In this paper, we focused on both open pond and closed systems and their sizing. In the open pond systems, their location and sizing are important parameters of consideration. The urban waste stream from the activity of the residing population, land, solar and water resources can be used to estimate the energy generation potential of algae system and self-sufficiency of neighborhoods. Also, the outputs of the algae systems could be redirected to be a valuable input in the urban system and reused. Thus, the waste stream from the population, hydrological cycle and solar availability associated with the urban gradient are the three selected planning parameters for evaluating the potential impact on the operation, performance and feasibility of the algae-powered systems [4]. The closed algae system follows the same principal as the open pond systems; however, their applicability and control mechanism make their performance measure more complex than open systems. The performance measure for the closed algae systems depends on several factors beyond the waste stream, location and land area availability. In this paper parameters affecting flat panel PBR and tubular PBR are studied and presented from the literature review.

2.1. Parameters affecting Flat panel photobioreactor (PBR)

Studies have shown the productivity of flat panel PBR largely depends on the algae species used, the orientation of the flat panels, distance between the panels, varying light over the day and year, temperature and biomass concentration [7]. The biomass production at higher altitude with limited daylight over the year has relatively less biomass production. However, they might have a higher peak value of production on longer days in summer. The panel orientation is also correlated to the productivity of the system for a given altitude. For higher altitudes, south-north orientation produces up to 50% more biomass compared to east-west orientation. The productivity of the panel also decreases with the shorter distances between panels.

2.2. Parameters affecting Tubular photobioreactor (PBR)

Slight differences have been noticed with the tubular PBR in its reliance on different parameters and productivity. Other than altitude and location parameters, 25-75% higher biomass production is reached in vertical system tubular PBR [8]. The performance also varies with the horizontal distance between tubes. The critical performance distance varies between 0.25m to 0.15m at different altitudes. The performance improvement of PBR with ground reflectivity the transparency of the tubes does not affect the performance significantly

3. Use of GIS-based analysis to measure Algae energy generation potential

The goal is to use algae technology as a design intervention in an urban neighborhood in order to promote energy performance and carbon reduction in urban systems. As we have seen, the three parameters of the waste stream from the population in the neighborhood, hydrological cycle, and solar availability are the primary factors of consideration, and GIS spatial analysis tools and associated data can be used to assess the energy production potential of the neighborhoods. For the sake of our study, we choose the Atlanta Midtown, a neighborhood in Georgia (GA) whereas the primary system inputs for algae energy production technologies include solar energy, water, and biomass, effective spatial analysis would have to account for these factors either directly or indirectly. For Midtown, Atlanta, the currently available and relevant GIS data accessible through Fulton County for this analysis includes building footprint data with height, year of construction, and use attributes. In addition to these, physical attributes, population characteristics of neighborhoods are available in the form of U.S. Census block data. Using GIS solar analysis tools, it is possible to calculate potential solar input on rooftops based on building orientation and height. With the DOE reference building dataset, the year of construction and the building function together can offer an additional layer of details related to HVAC systems and the window to façade ratio if window retrofits are to be considered for the implementation of flat panel algae solar capture. Population and worker density data can provide an indirect measure of biomass potential from household and commercial waste as an input to the algae system. Building use, geometry, and liveable unit data can be used to determine per area and per capita energy use intensity (EUI) for energy demand calculations to be assessed alongside potential supply from algae systems.

In addition to the usual calculations of EUI and energy production potential at the building and neighborhood scale, other calculations could include per capita solar energy potential, the ratio of per capita energy based on biomass (from waste) to per capita EUI, etc. In addition to providing insight into the energy balance potential for Midtown in its current configuration, these calculations can be used to establish energy optimization based on varied densities and building configuration. Whereas it is unlikely that entire solar facing façades in many pre-existing buildings can be converted for solar capture with flat panel algae systems, finer grained building information system modeling has the potential of more accurately measuring the performance of retrofitting such systems within pre-existing urban contexts.

4. Use of building information modeling (BIM)

The integration of the building information model using individual buildings in the urban system along with the GIS model will allow extensive use of the urban scale data as well as available building scale data. Existing GIS data for Midtown Atlanta such as building footprint, year of construction and building function can be used to create the primary building level urban model. Subsequently, the individual buildings can be categorized based on their use and year of construction into typical design categories to further develop the detailed models in the parametric 3D environment of Rhinoceros 5.0 and Grasshopper (parametric tool). The parametric model will allow quick design modifications through changes in certain building parameters. Fig 2 shows how these parameters are related to one another. For example, any change in building footprint will update the wall area, window sizes, roof and other façade systems simultaneously. The BIM models in the later stage will also include assigned building structure and material properties such as wall or slab thickness and materials can be assigned to the model. The algae systems designed for buildings will typically be a façade system using flat panel PBR or tubular PBR. Thus, algae systems can be designed as fenestration systems along the facades with maximum solar capture potential. The change in a single building parameter in a grasshopper based Rhinoceros model can quickly update itself and is capable of producing infinite iterations to check Energy Use Intensity (EUI) and energy performance of individual buildings and select the best option.

As examined in this paper the performance of flat panel PBR and tubular PBR depends on the orientation of the panels and spacing between them. The BIM and 3D parametric model can allow for such fine-grained changes and help to obtain a more accurate urban energy balance model. The 3D parametric model for buildings can also be tested for their energy performance, such as calculating heating or cooling loads, and other energy use based on their use, design parameters (such as window to wall ratio) etc. using Honeybee and Ladybug plugin for Grasshopper. The Ladybug primarily sets ups the model for energy analysis and the Honeybee plugin transfers model data from Grasshopper to the Energy Plus platform for energy analysis using energy plus engine. Honeybee retrieves the energy simulation results from Energy Plus and visualizes the output in grasshopper.

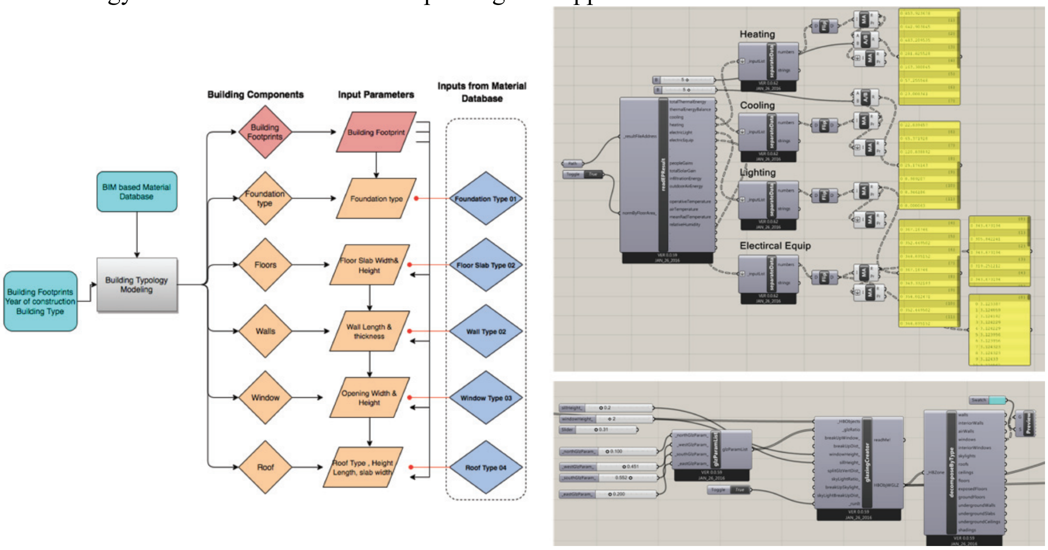

Fig. 2. Parametric 3D BIM model process model

5. BIM –GIS Integration

Both GIS and BIM have their strengths, yet they function in different scales and resolution of data analysis. Table 1 shows the major difference between a BIM and GIS system and its analysis potential. In this paper, we have studied and attempted to create a platform where the BIM data can be integrated with Urban Scale GIS data for comprehensive visualization of energy generation potential of Algae systems in a neighborhood. The integration system consists of several steps. In the first step, the GIS-based vector data and information systems such as building footprint and height for Midtown Atlanta are imported to the parametric 3D-BIM platform where a parametric model set up is created with an accurate information of Algae walls, and other building system information. The parametric 3D model can produce multiple iterations of design based on changes in certain parameters such as window areas, façade areas (wall and window), roof profile area, etc. Energy analysis can be performed using this model in the Energy Plus platform. The various analysis results and building information can be stored in the form of the data structure in a .csv or similar data structure which can then be linked to the corresponding building ID’s in the GIS platform. The data transfer can become an iterative process that continuously updates the GIS-model that captures and visualizes the urban scale information for algae powered neighborhoods.

Table 1. Gap between Macro scale (Urban System) GIS and Micro scale (Micro-scale) BIM data structure and analysis

	BIM	GIS
Data type	building level data	urban infrastructure (blocks , street , terrain etc.)
System boundary	Building	Earth / Specific Geographic Region
Model co-ordinates	Relative Co-ordinates	Geographic Co-ordinates
Dimension of consideration	Temporal dimension and emphasis on building construction and life cycle analysis cost	Spatial dimension and emphasis on socio- economic aspects
Network analysis	No large scale network analysis	Large scale network analysis to enable efficient distribution of resources
Energy analysis	Allow energy analysis through simulation tools	Solar radiation tools in GIS allow urban mapping and analysis of solar radiation

6. Conclusions

This paper presents a modeling method for algae powered neighborhoods through the integration of GIS and BIM, a potent model for multi-scale problems from algae cultivation to the fabrication of construction components, from buildings to neighborhood systems. GIS-based algae modeling takes into consideration various urban scale parameters such as population, waste stream flows and solar access in a neighborhood to determine important measures such as per capita energy use, the ratio of per capita energy production from algae systems and per capita EUI. The algae-powered building BIM system takes into account the finer grained details such as solar capture potential for building facades, minor parameter changes such as orientation and spacing of photobioreactors and integrating the performance analysis of algae to bridge algae component, building and urban scale systems. The integrated modeling method deals with both the demand and supply sides of energy systems, to capture the energy use intensities of building systems as well as the energy production from the algae cultivation systems that are embedded in urban climatic contexts. This article lays out a research design of an algae-power neighborhood model, which will be applied to a number of experimental test cases such as Atlanta, Tokyo and Shanghai for making connections between harvesting renewable energy and designing near zero communities in future research.

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