EnvironmentAsia

Simulation of Sustainable Habitat in Gajah Mungkur Reservoir Area Using Urban Modelling Interface (UMI)

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Abstract

The Gajah Mungkur reservoir (GMR) area is located in Wonogiri district. The reservoir was built to prevent flooding issues. There are some parts of the reservoir that function for nature tourism. This function has supported the development of other infrastructures and facilities. In addition, the development of Wonogiri district has promoted a variety of new growth centres. Therefore, sustainable development is urgently needed to minimize negative impacts on the environment both now and in the future. This study aims to assess the level of sustainability of the GMR area through a simulation method on the floor area ratio, operational energy, lifecycle, and design accessibility. The findings show that the GMR area had a sufficient sustainability habitat system based on the parameter standards value with various buildings intended for residential, retail, office, and hotel. This study suggested that GMR area had high sustainability habitat based on the standard of Operational Energy (OE), lifecycle of building, lifecycle of facade and glazing, and design accessibility. Meanwhile, based on the simulation, Floor Area Ratio (FAR) in the GMR area had a low value since the study area was dominated by green area. The low FAR value indicated a low building density in the GMR area, and it may be considered that there is a high possibility of improving the rural development of the area. The research results are expected to contribute to the sustainable development of the GMR area.

Keywords: Sustainability; Neighbourhood Scale; Simulation of Sustainable Habitat; Urban Modeling Interface (UMI)

1. Introduction

The Gajah Mungkur reservoir (GMR) is located in Wonogiri Regency, Central Java where the main function is as flood control (Utami and Trilaksana, 2015). Besides functioning as a disaster prevention infrastructure, GMR also functions as a nature tourism and tourist attraction. Population growth around the GMR area has increased the environment stress in the area, and reduce the environment sustainability (Hastono *et al.,* 2012).

To avoid environment degradation in the GMR area, a model called sustainable habitat system (SHS) is applied to assess the level of sustainability (Cook and Garret, 2014; Cook, 2011; Stang and Hawthorne, 2005). The concept of SHS is formulated by T = W - D, where T is throughput, W is welfare, and D is environmental damage. Ideally, to achieve the highest level of sustainability, an area should maximize the throughput (T) and welfare (W) while minimizing the environmental damages

(D) (Figure 1). Sustainable development is a guideline of development that aims to meet the needs of the current generation without neglecting the ability of future generations to meet their needs (World Commission on Environment and Development, 1987; Kusumawanto and Astuti, 2017). The prior studies have conduct research on sustainability in several analysis such as energy (Stambouli, 2011); life cycle assessment on the energy and carbon emissions on buildings (Chau *et al.,* 2015), and mobility assessment (Macedo *et al.,* 2017). However, there is a lack attention on the integrated analysis on the sustainability.
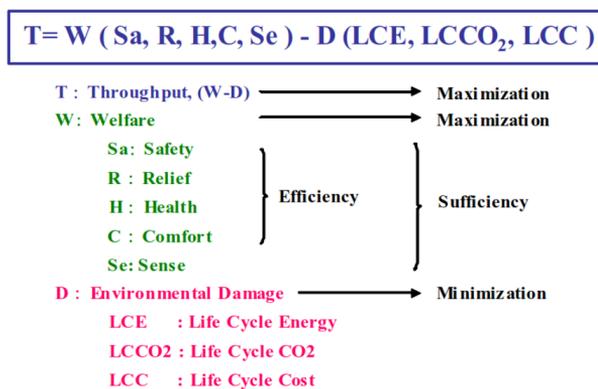
There are several methods to model the habitat system, such as system dynamic model (Nuryadin *et al.,* 2019; Moallemi *et al.,* 2021), and Environmental Niche Factor Analysis (ENFA) (Rosas *et al.,* 2017). Those model function is to support the decision-making analysis were tested in a laboratory to investigate and control through mathematical experiment. In this study, the Urban Modeling Interface (UMI) software is utilized to model the SHS in the GMR area. UMI is an integrated urban modelling platform used to evaluate the environmental performance of an area and city based on building density, the use of operational and life cycle, walkability, and daylighting potential (MIT School of Architecture and Planning, 2020). The parameters employed to simulate the SHS model are floor area ratio (FAR), operational energy, life cycle (embodied energy and embodied carbon), and design accessibility (walkability and bike-ability).

2. Methodology

2.1 Study area

This study focused on the GMR area as shown on the Figure 2. To simulate the environmental performance in SHS, this study utilized UMI to assess the land use, through Floor Area Ratio (FAR), Operational energy (OE), life cycle that consists of Embodied Energy (EE), and Embodied Carbon (EC), and design accessibility (walkability and bike-ability). A model of selected areas was made in Rhinoceros, and then its environmental performance was investigated using UMI. The steps in this research consisted of the following: created model of buildings and research object areas in Rhinoceros 6.0 software; entered the model of elements in the UMI layer type; made changes on building templates; identified the functions of buildings at UMI; input building data; and entered Yogyakarta's climate data to get the more accurate climate data due to the availability of more complete data.

FAR relates to land use and road networks, where land use and road networks affect environmental impacts such as carbon emissions. Land use patterns affect the choice of transportation modes between motorized and non-motorized vehicles (Rakha and Reinhart, 2012). Moreover, FAR is a measure of building density and height and the maximum area that can be built in an area (MIT Sustainable Design Lab, 2022). Operational energy (OE) is the energy used for the building during operation

$$T= W \, (\, Sa, \, R, \, H, C, \, Se \,) - D \, (LCE, \, LCCO_2, \, LCC \,)$$

T : Throughput, (W-D) ⟶ Maximization
W: Welfare ⟶ Maximization
Sa: Safety ⎫
R : Relief ⎪
H : Health ⎬ Efficiency ⎫ Sufficiency
C : Comfort ⎪ ⎬
Se: Sense ⎭ ⎭
D : Environmental Damage ⟶ Minimization
LCE : Life Cycle Energy
LCCO2 : Life Cycle CO2
LCC : Life Cycle Cost

Source: Matsufuji, 2004; Kusumawanto dan Astuti, 2017; Hayashi and Matsufuji, 2004

Figure 1. Theory of sustainable habitat system

or occupancy, including heating, cooling, lighting, equipment, and appliances. Each building material has different OE during the entire service. The life cycle calculation in UMI allows the calculation of basic embodied environmental impacts related to construction materials. There are two embodied calculations: (1) Embodied energy (EE) and (2) Embodied carbon (EC) (MIT Sustainable Design Lab Revision, 2017). EE represents the fuel consumption of non-renewable sources that occurs over the life span of the product or building (expressed in kWh or MJ). Embodied carbon (EC) is generated over the life span of the product or building. The term EC is sometimes used to refer to CO_2 emissions and ignore the effects of other greenhouse gases (expressed in $kgCO_2$ or $kgCO_2eq$), which is presented in $kgCO_2$ in UMI. Life cycle calculations focus on calculating materials and geometric components in buildings (MIT Sustainable Design Lab Revision, 2017).

2.2 Spatial Condition

The overall spatial analysis showed that the GMR area and its surroundings tended to have a low density of buildings, large open spaces, and green areas. The area also had various existing buildings, which function as residences, offices, hotels, and retails. Specifically, the analysis revealed that zone 1 had various functions of buildings, which were for residentials, retails, offices, and hotels. On the other hand, zones 2A, 2B, and 3 showed the dominance of residential functioned buildings while zone 4 showed the dominance of retail functioned buildings. Zone 4 was the area of GMR that was intended as a tourist attraction. In addition to being dominated by residential buildings, zones 2A, 2B, and 3 had a higher density compared to the other zones (Figure. 2)
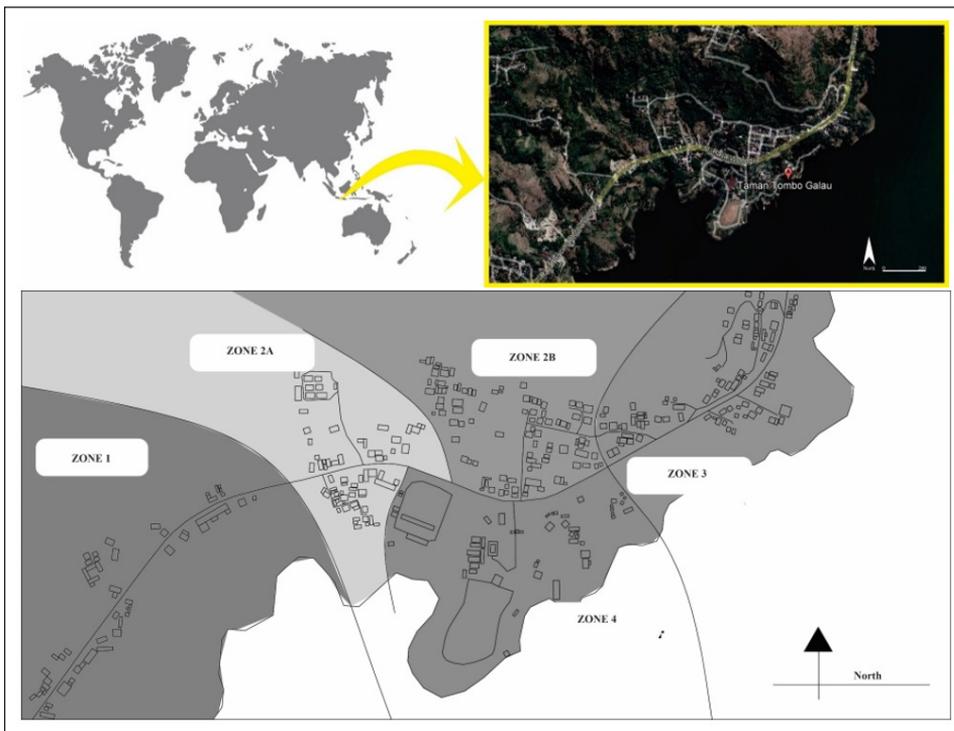

Figure 2. Research location

2.3 Simulation in Urban Modelling Interface (UMI) input parameter

Generally, the building materials commonly used in the research area were bricks, ceramic for the floors, roof clay tiles on the roofing, and glass for windows. Regarding the percentage of window-to-wall ratio (WWR), the buildings had a higher percentage of WWR on the front of the building. In contrast, the other sides of the building had a smaller WWR percentage (Table 1).

The windows on the front side can generally be operated either opened or closed. On the front side, the windows were usually opened in the morning until the evening, serving natural ventilation. The buildings operated between 7 am to 3 pm for offices, 8 am – 5 pm for retails, and 24 hours a day for residences and hotels. In terms of a cooling system, only hotel buildings used air conditioning. To calculate the operational energy in the GMR area, the numerous data input was set as shown in Table 1.

Table 1. Operational energy input data set in UMI

DATA OF MATERIAL	UNIT	Ceramic	Cement	Clay Brick	Gypsum	Concrete	Clay Roof	Hard Wood	Clear Glass
Conductivity	W/mK	1.298 (1)	0.533 (1)	0.807 (1)	0.17 (1)	1.65 (1)	1.00 (2)	0.138 (1)	1.053 (1)
Density	Kg/m3	2640 (1)	1568 (1)	1760 (1)	880 (1)	2100 (1)	2000 (2)	702 (1)	2512 (1)
Moisture Diff. Resistance		50	50	50	50	50	50	50	
Roughness		rough	rough	rough	rough	rough	rough	rough	
Solar Absorptance		0.4	0.8	0.5	0.7	0.7	0.7	0.6	
Specific Heat	J/kgK	840	840	920	840	1040	800 (2)	1630	
Thermal Emittance		0.9	0.9	0.9	0.9	0.9	0.9	0.9	
Visible Absorptance		0.4	0.8	0.5	0.7	0.7	0.7	0.6	

Clear Glass								
Dirt Factor	Back-side IR Emissivity	Front-Side IR Emissivity	IR Transmittance	Back-side Solar Reflectance	Front-Side Solar Reflectance	Solar Transmittance	Back-side Visible Reflectance	Front-side Visible Reflectance	Visible Transmittance
1	0.84	0.84	0.01	0.07	0.07	0.83	0.08	0.08	0.89

ZONE INFORMATION DATA	UNIT	Residential	Retail	Office	Hotel
WINDOW-TO-WALL RATIO (WWR)					
Front Side	%	20 (3)	40 (3)	20 (3)	20 (3)
Other Side	%	10 (3)	10 (3)	10 (3)	20 (3)
LOADS					
Equipment Power Density	W/m2	6 (3)	4 (3)	7 (3)	4 (3)
Lighting Power Density	W/m2	1 (3)	1 (3)	1 (3)	1 (3)
Illuminance Target	LUX	250(4)	300 (4)	350 (4)	350 (4)
CONDITIONING					
Cooling Setpoint	degC				24
Max Cooling Capacity	W/m2				100
Max Cool Flow	M3/s/m2				100
Cooling CoP					3
VENTILATION					
Infiltration Rate	ACH	0.35	0.35	0.35	0.35
Nat Vent Min Outdoor Air Temp	degC	23 (5)	23 (5)	23 (5)	23 (5)
Nat Vent Max Outdoor Air Temp	degC	33 (5)	33 (5)	33 (5)	33 (5)
Nat Vent Max Relative Humidity		80	80	80	80
Nat Vent Zone Temp Setpoint	degC	22	22	22	22
WINDOW					
Operable Area		0.25 (3)	0.25 (3)	0.25 (3)	0.25 (3)

* (1) SNI Energy Conservation of the Building Envelopes; (2) Lubis and Koerniawan; (3) The Authors; (4) SNI Energy Conservation in Lighting System, 2011; (5) BMKG, 2021; MIT Sustainable Design Lab)

Table 2. Life cycle input data set in UMI

DATA	UNIT	Ceramic	Cement	Clay Brick	Clear Glass	Concrete	Clay Roof (1)	Hard-wood	Gypsum
Embodied Carbon	kgCO2/kg	0.59	0.18	0.22	5.06	0.24	0.22	0.45	0.24
Embodied Energy	MJ/kg	9	1.34	2.12	96.1	2.12	3	7.5	3.2
Substitution Rate Pattern			0.5,1	0.02, 0.01,1	0.2	0.2	1	0.2	0.1, 0.1,1	0.02,0.1, 1
Substitution Timestep			20	20	50	50	100	50	20	20
Transportation Carbon	kgCO2/kg/km	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067
Transportation Distance	Km	500	500	500	500	500	500	500	500
Transportation Energy	MJ/kg/km	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
BUILDING TEMPLATES	**UNITS**	**RUMAH**		**RETAIL**		**OFFICE**		**HOTEL**	
Partition Ratio		0.3		0.15		0.35		0.3	
Lifespan	Years	50 (1)		50 (1)		50 (1)		50 (1)	
CONSTRUCTION DATA INPUT – MATERIAL LAYERS …(2)									
FLOORS	**Thick (m)**	**WALL**	**Thick (m)**	**ROOF**	**Thick (m)**	**WINDOW**	**Thick (m)**	
Ceramics	0.01	Cement Mortar	0.015	Clay Roof	0.01	Clear Glass	0.005	
Cement Mortar	0.04	Clay Brick	0.1	Hardwood	0.15			
		Cement Mortar	0.015	Gypsum	0.009			

* (1) Attman, 2009; (2) the authors; MIT Sustainable Design Lab

In measuring the life cycle, the life cycle analysis (LCA) framework is needed to know the limits of the assessment. The LCA interface includes EE and EC of buildings. In this study, the calculation included a "cradle-to-site" of life cycle assessment. This stage was included in the initial impact boundary system or product stage of the life cycle assessment.

In UMI, mobility measures the level of sustainability of an area through the convenience of people to move between locations with non-motorized transportation, namely walking and biking. Walkability is a measure of how friendly an area is for walking (Reinhart *et al,* 2013). High density and diversity within an area is a strategy to reduce the use of motorized vehicles but encourage the use of more sustainable modes of transportation (human powered transportation) such as walking and biking, due to the close distances between building functions (amenities). An assessment of the friendliness of an environment for walking is calculated from a quarter mile to 1.5 miles walking distance from residential units to vital facilities (MIT Sustainable Design Lab,.2022).

3. Results and Discussion

3.1 Floor Area Ratio (FAR)

Based on the simulation results, the FAR in the GMR area was 0.04, which equal to 2.245.925 Ha. The total floor area of the residential, retail, office, and hotel buildings were 49,993 m², 20,042 m², 11,411 m², and 5,105 m², respectively (Table 4). The FAR value of 0.04 above indicated that the study area had a vast green area; approximately about 26 times larger than the floor area of the existing buildings. Based on the guideline of UMI, FAR is the ratio between the total floor area of the building and the land area. FAR relates to the density of human population and buildings, land use, and green spaces in an area. The ideal FAR value for a district or city is 4.0 based on the American Society of Planning Officials (American Society of Planning Officials, 1958). Meanwhile, according to Dawodu and Cheshmehzangi (2017), who studied the influence of FAR on energy consumption in the meso scale in China, it was revealed that the ideal value of FAR in an area is 2.5 – 3. The low FAR of the GMR compared to previous studies suggests that the current sustainability condition in the area need to be improved.

Figure 3. The area of Gajah Mungkur Reservoir

Table 3 shows that the occupancy density in GMR is low since the number of persons in each meter square is less than one person. Meanwhile, the population density in the study area was 1,595 people so that the housing occupancy density is 0.0222 people/m², 0.022 people/m² for retail, office 0.011 people/m², and 0.0115 people/m² as shown on the table 3, and the total population in residential, retail, office and hotel buildings were 1020 (64%), 406 (25%), 115 (7%), and 54 (4%), respectively (Table 4).

The total number of buildings was 276 buildings. In general, the existing building functions were: 61% or 170 residential buildings; 26% or 71 retail buildings; 9% or 24 office buildings; and 4% or 11 hotel buildings. Generally, most buildings in the study area had 1-level or 2-level buildings, with 97% or 267 of 1-level buildings and 3% or 9 of 2-level buildings. The distribution of these buildings in FAR simulation is shown in figure 4.

Table 3. Occupancy density of GMR area

Occupancy Density	HOUSING	RETAIL	OFFICE	HOTEL
People/ m²	0.0222	0.022	0.011	0.0115

Table 4. FAR in GMR area

Floor Area Ratio (FAR)		0.04				
Site Area(m2)					Floor Area (m2)	
2.245.925					86.553	
		RESIDENTIAL	RETAILS	OFFICE	HOTEL	
		49.993	20.042	11.411	5.105	86.553
Number of Building Mass		170	71	24	11	276
		61%	26%	9%	4%	100%
Occupancy Density		1020	406	115	54	1595
		64%	25%	7%	4%	100%
Number of Floor	1	168	66	22	11	267
						97%
	2	2	5	2	0	9
						3%
Max. Building Height (m)		10				

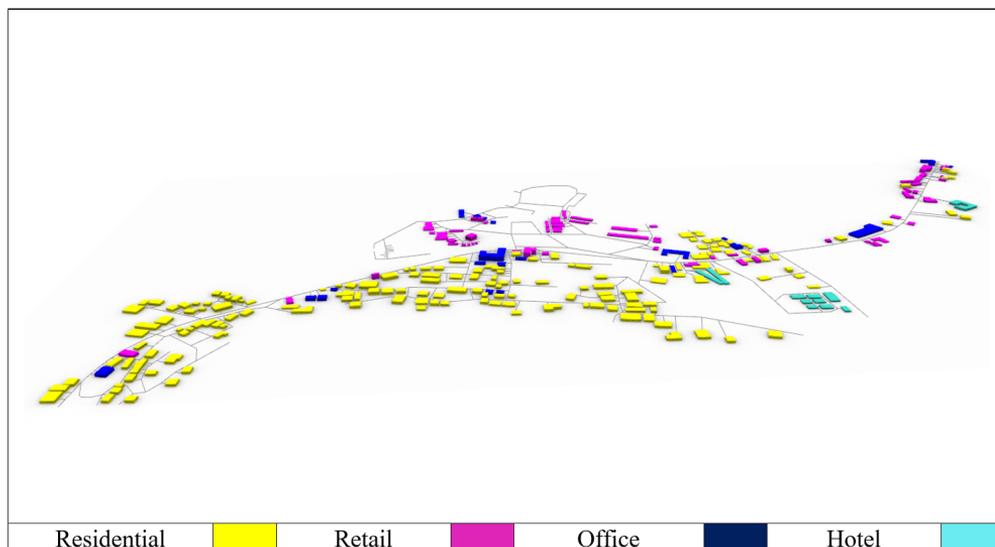| Residential		Retail		Office		Hotel	

Figure 4. FAR Simulation

3.2 Design Accessibility

Accessibility design in UMI takes into account walkability and bikeability. The average value of the easiness level of access in the study area were 41 and 45 on the walkability and bike-ability scores, respectively (Figure. 5 and Figure. 6). The low walkability and bike-ability scores are most likely due to the diversity of building functions (as shown in Figure 4) that were not spread out, where in general retails, offices, and hotels buildings were located near the main road, resulting a far travel distance for walking and cycling between residential buildings and other building functions.

Even though the travel distance was far, the residence still had access to the other building function as the main road was interconnected with roads to residential areas and tourist areas (Table 5). This score is lower than the study conducted walkability assessment in Thailand, specifically in Mahachai city. Tochaiwat *et al* (2022) conducts those studies and the neighborhood simulates receiving high walkscore as there are more amenities available within the neighborhood. In the same vein, Rakha and Reinhart (2012) also conduct experimentation related to walkability, and they find that walkability is considerably influenced by the diversity of land use.
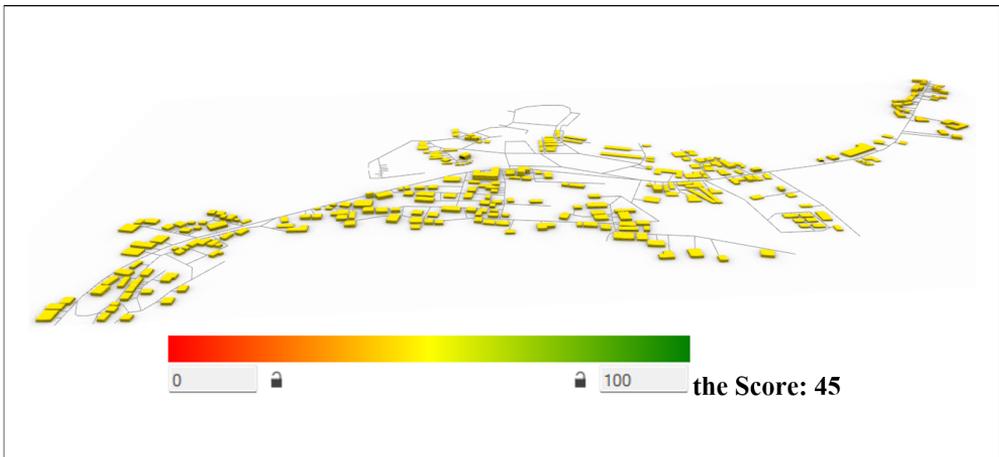

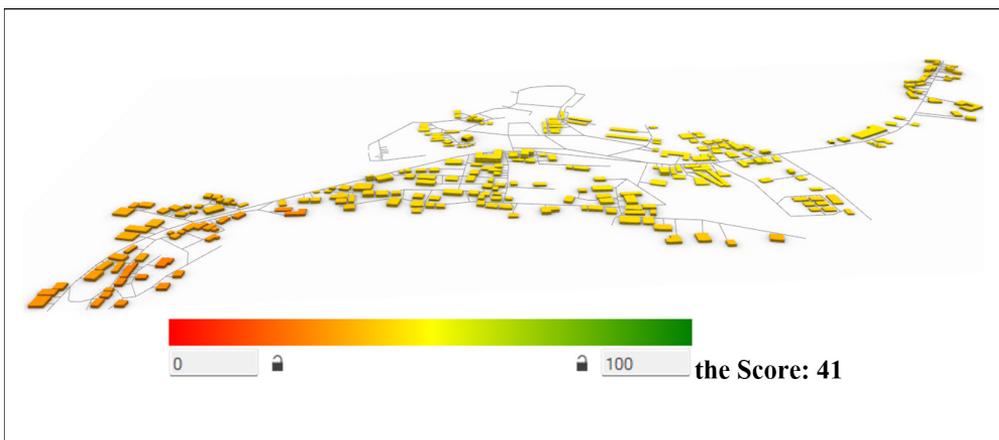**Figure 5.** Mobility simulation for bikeability

Figure 6. Mobility simulation for walkability

Based on the simulation result, the walkability had a score ranging from 25 – 46, 32 – 46, 31 – 46, and 42 – 46 for residentials, retail, offices, and hotels, respectively. The higher scores on retails and offices compared to residential functioned buildings indicated that the retails and offices were more accessible or closer as these buildings were mostly located on the main road. Hotels had the highest walkability score among the other functioned buildings because they were located in an area with various building functions and closed to the main road. Meanwhile, the bike-ability scores were 43 – 46, 42 – 46, 42 – 46, and 44 – 46 for residentials, retails, offices, and hotels, respectively. Most of the sites in GMR has low score on bike-ability, suggesting that the distance between one place to another is quite far and the infrastructure was not bikers friendly.

3.3 Operational Energy (OE)

Operational energy (OE) reflects the energy used for heating, cooling, lighting, and plug loading or electrical equipment in buildings when the buildings are operating or occupied. To determine the level of sustainability in terms of operational energy, the simulation results were viewed with reference to the energy consumption intensity (IKE) standard. Energy consumption intensity is the ratio of energy consumption used to building area (SNI 03-6196-200; Cahyanto *et al.,* 2021; Marzuki and Rusman, 2012; Raharjo and Riadi, 2016; Ikhsan and Saputra, 2016).

The OE simulation showed that the total OE in the GMR area was 1,831,000 kWh/year or 21 kWh/m²/year (Figure. 7), where the largest OE was in hotels because of the usage of air conditioners (AC) (Table 6). There were 11 hotel buildings in the research object area, which had OE of 4.14 kWh/m²/month. Nevertheless, this value is still classified as very efficient as it is still in the range of 4.17 – 7.92 when viewed from the standard value of buildings using AC. Meanwhile, 170 residential buildings had the second largest OE with a value of 1.83 kWh/m²/month. According to the energy consumption standards of buildings that do not use AC in Indonesia, this value fell into the efficient category, which was in the range of 1.67 – 2.50. Meanwhile, retails and offices had OE values of 1.17 and 1.58 kWh/m²/month, respectively.

Table 5. Score of walkability and bikeability (walkscore, 2021)

Category of walkability	Score	Score	Category of bikeability
Car Dependent (Almost all errands require a car)	0 – 24	0 – 49	*Somewhat Bikeable* (Minimal bike infrastructure)
Car-Dependant (Most errands require a car)	24 – 49	50 – 69	*Bikeable* (Some bike infrastructure)
Somewhat Walkable (Some errands can be accomplished on foot)	50 – 69	70 – 89	*Very Bikeable* (Biking is convenient for most trips)
Very Walkable (Most errands can be accomplished on foot)	70 – 89		
Walker's Paradise (Daily errands can be accomplished on foot, do not require a car)	90 – 100	90 – 100	*Biker's Paradise* (Daily errands can be accomplished on a bike)

Table 6. Operational energy

OPERATIONAL ENERGY	kWh/Year	kWh/m²/Year	kWh/m²/Month	CATEGORY STANDARD
RUMAH TINGGAL	1.076.610	22	1.83	Efficient 1.67 – 2.50
RETAIL	271.410	14	1.17	Very Efficient 0.84 – 1.67
OFFICE	213.624	19	1.58	Very Efficient 0.84 – 1.67
HOTEL	270.290	49.73	4.14	Very Efficient 4.17 – 7.92

These values were considered very efficient, which fell within the range of 0.84 – 1.67 (Table 6). The use of air conditioning to cool the room from hot weather makes the amount of energy higher for energy consumption. Perez-Lombard *et al* (2008) conducted a study associated with buildings energy consumption states that the utilization of air conditioning is one of the largest energy uses in the buildings whether residential and non-residential sector. In the same vein, Nasution *et al* (2014) found that air conditioning is one of the factors for reducing energy consumption.

3.4 Lifecycle: Embodied Energy (EE) and Embodied Carbon (EC)

The life cycle EE in each stage, *i.e.,* initial, recurrent, and demolition, had different values. The range of values in the initial stage was $0.9 – 8.76$ GJ/m²; the recurrent stage was $1.22 – 23.1$ GJ/m²; the demolition stage was $0.108 – 0.144$ GJ/m²; or in other words, $1 – 3\%$ of the initial EE. Compared to other studies, EE in the GMR area had some differences since there were many regional complexities. Residential buildings with brick materials in the initial stage had a range of EE values of $0.9 – 16.3$ GJ/m², with an average of 25% of the initial EE value for the recurrent stage and $0.1 – 13\%$ for the demolition stage (Azzari and Abbasabadi, 2018). Several other studies have been conducted to determine the EE in residential areas. Ndudim and Nwanya (2016) found that the value of EE in a residential block was 2878.32 MJ/m², while the value of EC was 367.21 kgCO₂/m². Ding (2004) and

Aktas Bilec (2012) reported that EE values in the residential area were $3.6 – 8.76$ GJ/m² and $1.7 – 7.3$ GJ/m², respectively.

In UMI, the calculation of lifecycle could be conducted based on 3 lifecycle boundaries including cradle-to-gate which is only considering production and manufacturing processes, Cradle-to-site that is considering the transportation to site of use, and Cradle-to-grave that considering the use phase and disposal phase (MIT Sustainable Design Lab, 2022). This study calculates based on cradle-to-site lifecycle boundary. The calculation is in the initial embodied impacts ranging from raw materials to the site. Specifically, the cradle-to-site LCA in this study was calculated based on construction or material data of buildings within research objects including floors, walls, roofs, and windows. The buildings mainly use clay bricks for the building envelope, clay roof for the roof, and ceramics for the floor. Based on the life cycle simulation results for the building category at UMI, the value of the EE of the buildings in the GMR area was 1455.99 kWh/m², while the value of the EC of the buildings in the area was 112.78 kWh/m² in the span of 50 years. Meanwhile, when viewed from the Façade and Glazing category, the value of EE in the area was 204.02 kWh/m² or 0.73 GJ/m² or 734 MJ/m², and the value of EC was 16.07 kWh/m² in a span of 50 years. The range of EE value from similar research done previously was 222 kWh/m² – 4527 kWh/m². Meanwhile, the value of EC was lower in the range from 367.21 kgCO₂/m² – 405 kgCO₂/m² as the number of buildings are less dense.
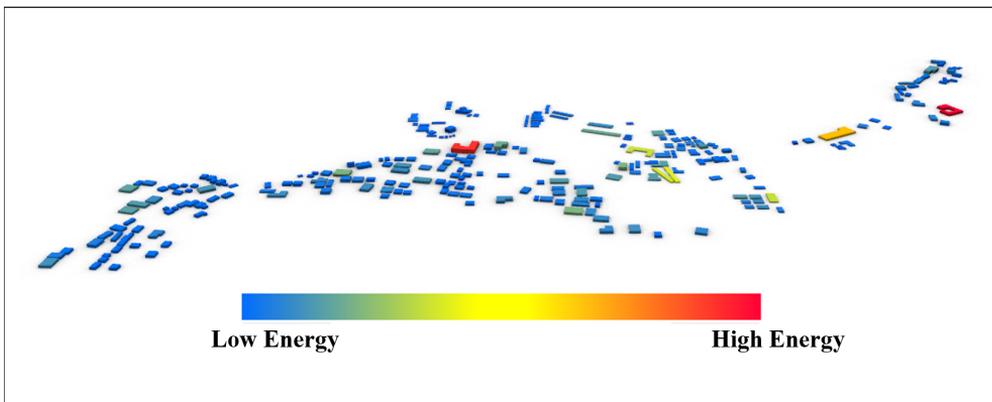

Figure 7. Operational energy map distribution in GMR area

Table 7. Value of embodied energy (EE) and embodied carbon (EC) in GMR area compared to previous studies

	EE			EC
	kWh/m2	GJ/m2	MJ/m2	kgCO2/m2
EXISTING(BUILDING)	1455.99	5.23	5238	112.78
EXISTING (FAÇADE- GLAZING)	204.02	0.73	734	16.07
Utama & Gheewala (2008)	222	0.8	837	
Dixit in Azzari & Abbasabadi (2018)	250 – 4527	0.9 – 16.3	900– 16.300	
Ndudim & Nwanya (2016)	777	2.8	2878.32	367.21
Ding (2004)	1000– 2433	3.6– 8.76	3600- 8760	
Aktas & Bilec	472 – 2027	1.7 – 7.3	1700 - 7300	
Monahan & Powell (2011)				405

Table 8. Lifecycle EE and EC

	BUILIDNG		FAÇADE & GLAZING	
	TOTAL VALUE	NORMALIZED	TOTAL VALUE	NORMALIZED
EE	126019914 kWh	1455.99 KWh/m2	17657797 kWh	204.02 KWh/m2
EC	9761126 kgCO2	112.78 KgCO2/m2	1391368 kgCO2	16.07 KgCO2/m2

Table 9. Simulation results with each parameter standard

SIMULATION RESULTS		UNITS	STANDARD	EXISTING
FLOOR AREA RATIO	FAR		2.5 - 4.0	0.04
OPERATIONAL ENERGY	Operational Energy (Bangunan Tidak Ber-AC)	kWh/m²/Month	0.84 – 4.17	1.17 – 1.83
	Operational Energy (Bangunan Ber-AC)	kWh/m²/ Month	4.17 – 36.50	4.14
LIFECYCLE OF BUILDING	Embodied Energy	kWh		126019914.35
		KWh/m²	222 - 4527	1455.99
	Embodied Carbon	kgCO₂		9761126.24
		KgCO₂/m²	367 - 405	112.78
LIFECYCLE OF FAÇADE AND GLAZING	Embodied Energy	kWh		17657797.46
		KWh/m²	222 - 4527	204.02
	Embodied Carbon	kgCO₂		1391368.93
		KgCO₂/m²	367 - 405	16.07
DESIGN ACCESSIBILITY	Walkability		0 - 100	41
	Bikeability		0 - 100	45

4. Conclusion

According to the simulation result, the GMR area had a sufficient sustainability habitat system based on the parameter standards value. Only one parameter fell below the standard, namely the FAR. As the GMR area was dominated by vegetation, there were fewer buildings. Additionally, since the simulation modelled the ability of an area to be occupied by buildings, it may also mean that the area was relatively unpopulated. The simulation used in this study also successfully revealed the proposed optimum parameters to increase the sustainability of the habitat.

The GMR area in Wonogiri Regency has become a new tourism attraction not only because of flood control infrastructure but also the rise of supporting infrastructures and facilities constructs. However, the rapid development of the area will threaten the sustainability of local environment. The simulation showed that the GMR area had five zones, where each zone consisted of buildings intended for residential, retail, office, and hotel. The materials of the buildings were dominated by bricks. This study suggested that GMR area had high sustainability habitat based on the standard of OE, lifecycle of building, lifecycle of facade and glazing, and design accessibility. Meanwhile, based on the simulation, FAR in the GMR area had a low value since the study area was dominated by green area. The low FAR value indicated a low building density in the GMR area, and it may be considered that there is a high possibility of improving the rural development of the area.

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References

Aris RM, Riadi S. Audit Konsumsi Energi Untuk Mengetahui Peluang Penghematan Energi pada Gedung PT Indonesia CAPS and Closures. J Chem Inf Model. 2013; 9(9): 1689–99

Aktas CB, Bilec MM. Impact of lifetime on US residential building LCA results. The International Journal of Life Cycle Assessment. 2011; 17(3): 337–49. doi:10.1007/s11367-011-0363-x

American Society of Planning Officials. Floor Area Ratio. Information Report No. 111. 1958. [Internet]. Illinois: American Society of Planning Officials [cited 2023 March 15] Available from: https://www.planning.org/pas/reports/report111.html.

Azari R, Abbasabadi N. Embodied energy of buildings: A review of data, methods, challenges, and research trends. Energy and Buildings. 2018 Jun 1; 168: 225-235. doi: 10.1016/j.enbuild.2018.03.003

Badan Meteorologi Klimatologi dan Geofisika (BMKG). Weather forecast of Sendang Wonogiri. [Internet] [updated 2022 March 23; cited 2022 March 23]; Available from: https://www.bmkg.go.id/cuaca/prakiraan-cuaca.bmkg?Kota=Wonogiri&AreaID=501270&Prov=11.

Boudghene SA. Algerian Renewable Energy Assessment: The challenge of sustainability. Energy Policy. 2011; 39(8): 4507–19. doi:10.1016/j.enpol.2010.10.005

Cahyanto A, Nisworo S, Pravitasari D. Analysis of electrical energy audit in multi-story residential buildings with lighting load. In: 2021 Proceeding of Applied Research Technology Seminar, 2021 Oct 16; Magelang.

Chau CK, Leung TM, Ng WY. A review on Life Cycle Assessment, life cycle energy assessment and life cycle carbon emissions assessment on buildings. Applied Energy. 2015; 143: 395–413. doi:10.1016/j.apenergy.2015.01.023

Cook GM. The zero-carbon house. Marlborough: The Crowood Press Ltd; 2011.

Cook M, Garret D. Green home building: money-saving strategies for an affordable, healthy, high-performance home. Gabriola Island, Bc: New Society Publishers; 2014.

Dawodu A, Cheshmehzangi A. Impact of Floor Area Ratio (FAR) on Energy Consumption at Meso Scale in China: Case Study of Ningbo. Energy Procedia [Internet]. 2017; 105(i): 3449–55. Available from: http://dx.doi.org/10.1016/j.egypro.2017.03.789

Ding G. The development of a multi-criteria approach for the measurement of sustainable performance for built projects and facilities [Ph.D Dissertation]. Sydney, NSW: University of Technology Sydney; 2004.

Fajar DH, Bambang S, Bandi S. Identifikasi daerah resapan air dengan sistem informasi geografis (Studi kasus: Sub DAS Keduang). Jurnal Geodesi Undip. 2012 Oct 1; 1(1). https://doi.org/10.14710/jgundip.2012.2232

Hayashi T, Matsufuji Y. Life Cycle Assessment of "Architecture of Habitat System for Sustainable Development". 2004 First International Workshop on Sustainable Habitat Systems

Ikhsan M, Saputra M. Audit Energi Sebagai Upaya Proses Efisiensi Pemakaian Energi Listrik Di Kampus Universitas Teuku Umar (UTU) Meulaboh. J Mekanova Mek Inov dan Teknol [Internet]. 2018; 2(1): 136–46. Available from: http://jurnal.utu.ac.id/jmekanova/article/view/846

Kusumawanto A, Astuti ZB. Green architecture in city innovation. Yogyakarta: Gadjah Mada University Press; 2017.

Lubis IH, Koerniawan MD. Reducing Heat Gains and Cooling Loads Through Roof Structure Configurations of A House in Medan. IOP Conference Series: Earth and Environmental Science. 2018 May; 152: 012008.https://doi.org/10.1088/1755-1315/152/1/012008

Macedo J, Rodrigues F, Tavares F. Urban sustainability mobility assessment: indicators proposal. Energy Procedia. 2017 Oct; 134: 731–40. https://doi.org/10.1016/j.egypro.2017.09.569

Marzuki A, Rusman. Audit Energi pada Bangunan Gedung Direksi PT. Perkebunan Nusantara XIII (Persero). Vokasi. 2016; 8(3): 184–96.

Matsufuji Y. Sustainable Habitat System. 2004 First International Workshop on Sustainable Habitat Systems.

Moallemi EA, Bertone E, Eker S, Gao L, Szetey K, Taylor N, et al. A review of systems modelling for local sustainability. Environ Res Lett. 2021; 16(11). https://doi.org/10.1088/1748-9326/ac2f62

MIT School of Architecture and Planning. Urban Modeling Interface. [Internet] 2020 [cited 2023 March 7]; Available from http://web.mit.edu/sustainabledesignlab/projects/umi/umi_about.html

MIT Sustainable Design Lab Revision. Modeling low carbon energy systems. [Internet] 2010 [cited 2023 March 6]; Available from: https://energy.mit.edu/wp-content/uploads/2016/05/LCW-Final-Report_v4-Affliation-changed.pdf

MIT Sustainable Design Lab. Umi Documentation Release 3.0. [Internet] 2022 [cited 2023 June 4]; Available from https://umidocs.readthedocs.io/_/downloads/en/latest/pdf/

Nasution, H., Sumeru, K., Aziz, A, A., and Senawi, M, Y. Experimental Study of Air Conditioing Control System for Building Energy Saving. Energy Procedia, 61, 63-66. https://doi.org// 10.1016/j.egypro.2014.11.907

Salehi M, Filimonau V, Asadzadeh M, Ghaderi E. Strategies to improve energy and carbon efficiency of luxury hotels in Iran. Sustainable Production and Consumption. 2021 Apr; 26:1–15. https://doi.org/10.1016/j.spc.2020.09.007

Moazzen N, Ashrafian T. Embodied Energy and Carbon of Residential Buildings. CLIMA 2022 Conf [Internet]. 2022;6495(8). Available from: https://proceedings.open.tudelft.nl/clima2022/article/view/290

Monahan J, Powell JC. An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework. Energy and Buildings. 2011 Jan; 43(1): 179–88. DOI:10.1016/j.enbuild.2010.09.005

Ndudim OH, Stephen N. Embodied Energy and Carbon of Residential Buildings. Int J Adv Eng Res Sci [Internet]. 2016; 3(8). Available from: https://proceedings.open.tudelft.nl/clima2022/article/view/290

Nuryadin D, Saleh S, Hardi AS, Pangaribowo EH. Developing a Dynamic Model for Sustainable Development in Yogyakarta City. The Indonesian Journal of Planning and Development. 2019 Oct 31; 4(2): 57–68. https://doi.org/10.14710/ijpd.4.2.57-68

Osman Attmann. Green architecture: advanced technologies and materials. New York: Mcgraw-Hill; 2010.

Perez-Lombard et al. A Review on Buildings Energy Consumption Information. *Energy and Buildings*. 2008, 40(3), 394-398. https://doi.org/10.1016/j.enbuild.2007.03.007

Rakha, tarek and Reinhart, Christoph. Generative Urban Modeling: A Design Work Flow for Walkability-Optimized Cities. Proceedings of Simbuild, 2012, 5(1), 255-262

Reinhart, Christoph F dkk. UMI-An Urban Simulation Environment for Building Energy Use, Daylighting, and Walkability. International Building Performance Simulation Association, 2013. Chambery, France

Rosas YM, Peri PL, Huertas Herrera A, Pastore H, Martínez Pastur G. Modeling of potential habitat suitability of Hippocamelus bisulcus: effectiveness of a protected areas network in Southern Patagonia. Ecological Processes. 2017 Aug 17; 6(1). https://doi.org/10.1186/s13717-017-0096-2

Santoso AA, Sudarsono B, Sukmono A. Analysis of the effect of erosion hazard levels on the Bengawan Solo watershed on total suspended solid (TSS). Journal of Geodesy University of Diponegoro. 2017 Nov; 6(4): 463-473. https://doi.org/10.14710/jgundip.2017.18179

National Standardization Agency. SNI 03-6196-2000: energy audit procedures in buildings.

National Standardization Agency. SNI 03-6389: conservation of building envelope energy in buildings.

National Standardization Agency. SNI 6197. 2011: Energy Conservation in Lighting Systems.

Qeisi S Al, Al-Alwan H. Generative Urban Design Concepts and Methods: A Research Review. IOP Conf Ser Mater Sci Eng. 2021; 1090(1): 012085. https://doi.org/10.1088/1757-899x/1090/1/012085

Stang A, Hawthorne C. The green house: new directions in sustainable architecture. New York: Princeton Architectural Press; 2005.

Tochaiwat et al. Walk Score Assessment using Urban Modeling Interface in Mahachai City, Thailand. Journal of Hunan University. 2022; 49(3). https://doi.org/10.55463/issn.1674-2974.49.3.19

Utama A, Gheewala SH. Life cycle energy of single landed houses in Indonesia. Energy and Buildings. 2008 Jan; 40(10): 1911–6. https://doi.org/10.1016/j.enbuild.2009.07.025

Utami, S and Trilaksana, A. 2015. Pembangunan Waduk Gajah Mungkur 1976-1986. Avatara. 2015 March; 3(1): 82-90.

World Commission on Environment and Development. Brundtland report. [Internet]. New York: World Commission on Environment and Development, 1987 [cited 2023 March 7]. Available from https://www.are.admin.ch/are/en/home/media/publications/sustainable-development/brundtland-report.html

Walk Score. Walk score methodology. [Internet] 2021[[updated 2023 March 7; cited 2023 March 7]]; Available from: https://www.walkscore.com/methodology.shtml.

Wang Y, Yang X, Hou Q, Tao J, Dong J. Quantitative Study on the Life-Cycle Carbon Emissions of a Nearly Zero Energy Building in the Severe Cold Zones of China. Sustainability. 2022 Jan 27; 14(3): 1448. https://doi.org/10.3390/su14031448