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Article

Building Mass Reconfiguration as an Energy-Sensitive Design Strategy for Green Campus Implementation

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Abstract: Universitas Gadjah Mada (UGM) is implementing the concept of green campus by various means including through elements in its sustainable campus development plan. With regards to several factors related to Energy and Climate Change indicators set by UI GreenMetric, this research examined the existing condition of the area of UGM which belongs to academic zone in order to construct a proposal based on a building mass reconfiguration. This proposal was aimed to improve the implementation of energy-specific green campus concept within the Forestry cluster area as a sample case study. This selection was based on the average value of the Building Coverage Ratio (BCR) values in all of the clusters; thus, the scenario was relevant for generalization and could be replicated in other clusters in the university. The study was done in three stages of simulation, and was based on a series of digital simulation of sunlight hour and solar radiation run in Grasshopper using Lady Bug environmental analysis plug-in for a period of five summer months during the building office hours. Following the reconfiguration, results had shown a similar downtrend between the amount of sunlight hour and solar radiation in the area (up to 49% and 45% respectively on building envelopes, and up to 44% and 42% respectively on landscaping surfaces). This reduction indicated a potential of energy efficiency by applying selective building mass reconfiguration as a passive design strategy that goes hand in hand with the campus's development policy to optimize the use of BCR for a greener UGM campus through its many undergoing and upcoming redevelopment projects.

Keywords: Green campus; Sunlight hour; Solar radiation; Building reconfiguration

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1. Introduction

Along with the raising awareness towards the pressing issue of environmental damage, green architecture has become more of a mandatory operational concept for current and future architecture. Within a vast scope of sustainable design, there is a rising of number research regarding topics related to green architecture, especially energy, in relation with housing, offices and other kind commercial buildings [1-4]. Nevertheless, this trend has not been the case in the educational building sector.

Globally, UI GreenMetric is one of the most widely referred references for green and sustainable campus rating system with a large number of growing participations from 95 to 407 in just 5 years [5]. It provides a set of indicators under six categories appropriate to be used as a framework to assess the readiness of a campus towards the implementation of green campus concept. Among the six categories, the most determining one is Energy and Climate Change (EC), comprised of 21% of the total calculation. Within this category, including as the indicators are: (1) energy-efficient appliances usage are replacing conventional appliances; (2) smart building implementation; (3) number of renewable energy sources in campus; (4) the total electricity usage divided by total campus population (kWh per person); (5) the ratio of renewable energy produced towards energy usage; (6) elements of green building implementation as reflected in all construction and renovation policy; (7)

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greenhouse gas emission reductions program; and (8) the ratio of total carbon footprint divided campus population [6].

To date, Universitas Gadjah Mada (UGM) is one of the largest universities in Indonesia to implement the concept of green campus through its progressive and sustainable campus development plan [7]. Studies on this ongoing process in UGM has cover various topics in regards to green campus concept implementation within the campus's existing condition, including the study of waste management [8], rainwater absorbent and inundation management [9], sound level mapping and analysis [10] and drinking water supply system [11].

However, surprisingly, there is a very limited number of research regarding the impact of green campus implementation in UGM with regards to the energy issue, whilst the aforementioned ranking system implies the high importance of such matter. In general, there has been several studies showing the relationship between the surrounding environmental conditions —as an built environment, and building's energy consumption in an area; from a direct connection between greeneries and cooling load [12-13] to a more indirect correlation between the placings of several urban elements and energy consumption [14]. Furthermore, with regards to other aspects of urban elements, previous studies also demonstrated the relationship between massing arrangements; which affected the urban canyon form; with outdoor thermal comfort along with other aspects including galleries, overhanging facades, and vegetation [15]. Nevertheless, when it comes to the specific case of UGM, a study conducted in 2018 only focused on analyzing energy consumption in one specific building [16].

On the other hand, there is a continuous update on the campus's development policy and many major projects of redevelopment are already undergoing in several faculties' campus area in UGM [17]. Therefore, departing from a design perspective, this research was aimed to investigate the current environmental condition of the UGM campus area according to two aspects related to the previously mentioned UI Green Metric indicator. The two aspects were sunlight hour and solar radiation values. These aspects were employed as factors that indicates a higher Energy and Climate Change factor implementation on-site by two means, such as (1) less direct sunlight on building envelope potentially decreases energy consumption for the cooling load; and (2) less direct sunlight on landscaping surface potentially provides higher thermal comfort for outdoor activities. Then, this study was utilized as a reference to purpose an alternative design suggestion for a better implementation of green campus concept in UGM through building mass reconfiguration —a strategy that will go hand in hand with the progressing developments that will continue to take place on the site.

Considering the vast area of the campus, however, some limitations were set in order to make the research viable. Firstly, only the areas which belong to the 'Academic Zone' according to the UGM's 2010 Campus Development Master Plan were included. Secondly, although study regarding the overall existing condition covered areas of all of the clusters housed in the university, detailed study which lead to building mass reconfiguration was only conducted in one of the cluster areas as a sample study. Detailed explanations regarding the area delineation and the sampling method are provided in the following section.

2. Materials and Methods

In accordance with the related IU Green Metric indicator, the environmental performance of the selected UGM campus area was assessed through series of digital simulation run in Grasshopper using Lady Bug, a weather data analysis plug-in for Grasshopper plug-in in Rhinoceros. Lady bug is capable of simulating various environmental-related design process such as climate analysis, massing/orientation study, daylighting study and energy modelling for a specific area based on standard EnergyPlus Weather files [18]. However, among all solar-related factors that could be extracted through this digital simulation tool, only sunlight hour and solar radiation were analyzed in this research.

Sunlight hour analysis is a graphical analysis on the total amount of hours where sunlight directly falls on an input geometry of the surface, in this case, building envelope and inner court surface [19]. Then, solar radiation's analysis in this context was limited only to analysis on the solar

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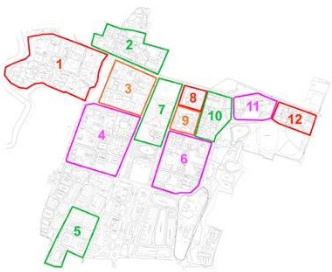
irradiation, the sun's irradiant energy incident on a surface of unit area, measured in kWh/m2 [20]. Technically, the simulations were set for five months during the summer season, dated from the 1st of March to the 1st of September from 8 AM to 5 PM every day. This time frame was selected as the simulation period to reconstruct the condition of building utilization under office hour during months of maximum exposure of the sunlight.

Furthermore, according to the aforementioned Energy and Climate Change implementation factors —the impacts of building mass reconfiguration on both of the building envelopes and the landscaping surface, the actual simulations and data presented in this paper were separated for the positive and the negative areas of the campus. In this context, the positive areas were defined as all the building envelopes enclosing the buildings and the negative areas were defined as the open space areas, including the inner court and the building canyon area or the area between buildings. Then, building envelope, in this case, was specified only to the wall surfaces of the building without the roof surface. This specification was based on the classification of building elements that could be considered for an Overall Thermal Transfer Value (OTTV), a value commonly used to measure the solar-related performance of building façade design [21]. In general, there were three parts of the study that were conducted. Detailed arrangements for each part of the study are as follows:

2.1. Study part one: existing condition

This first part of the study, the study of the existing condition of the academic zone, was based on the UGM's 2005-2015 Campus Development Master Plan. According to this database, among the six zones classified within the university area, the academic zone was the one with the highest real Floor-Area Ratio (FAR) [22]. Therefore, this zone was the most appropriate to examine with regards to building mass reconfiguration —as the approach would require some degrees of building 'cut and stack' strategy.

According to the original masterplan, there were five big clusters within the university. To provide a more comprehensive result, however, some of the clusters were redefined in details to provide a better context to how people perceive the campus area in real practice. Therefore, the new clustering arrangement adopted for this research is presented in the following Figure 1.



No	Cluster name	No	Cluster name
1	Engineering	7	University Central Building and Library
2	Graduate School	8	Forestry
3	Mathematics and Natural Science	9	Agricultural Technology
4	Medical	10	Agriculture
5	Vocational School	11	Veterinary Medicine
6	Social Humanities	12	Animal Husbandry

Figure 1. New clustering for the simulation

2.2. Study part two: a detailed study based on average Building Coverage Ratio (BCR) value

In the second part of the research, a detailed study was defined by the study of sunlight hour and solar radiation on the building envelopes of every building within the premises. Despite existing study on all of the cluster areas, however, only one cluster area was examined to this level to provide a base reference for the proposed building mass reconfiguration strategy. The arrangement of this specific cluster was based on the calculation of BCR value in each cluster —with one with BCR value closest to the average one was selected as the sample case study that could provide a generalized situation of the academic zone in UGM In particular, BCR was considered and appropriate variable as apart from BCR, other design variables such as building style and massing arrangement —in terms of the presence of inner court and its roles— throughout the UGM area were similar as they were regulated in the referred masterplan document. According to this calculation, the forestry cluster was selected as the study case. The BCR calculation is presented in Table 1.

Table 1. BCR calculation for all clusters

No	Cluster name	BCR (%)	No	Cluster name	BCR (%)
1	Engineering	26	7	University Central Building and Library	20
2	Graduate School	20	8	Forestry	26
3	Mathematics and Natural Science	33	9	Agricultural Technology	28
4	Medical	22	10	Agriculture	21
5	Vocational School	46	11	Veterinary Medicine	18
6	Social Humanities	25	12	Animal Husbandry	27
		Average BCR value			26

Considering the undergoing major project of redevelopment in several faculties' campus area in UGM, including in its Faculty of Forestry [23], the alternative design proposal which employed a building mass reconfiguration was designed as a passive design strategy to improve the overall potential of energy efficiency in term of energy for cooling load and to better reflect elements of green building implementation in the upcoming university's construction and renovation policy. By the time this research was conducted, the Faculty of Forestry's UGM campus area was comprised of 12 buildings with different sizes and orientation that were separated by inner courts and open spaces. Each building and inner court area were labelled uniquely with detailed measurement regarding each building's height and orientation as shown in Figure 2.

No	Building name	Number of floors	Maximum orientation	No	Building name	Number of floors	Maximum orientation
1	A	3	North - South	7	G	1	NSWE (All direction)
2	B	5	East - West	8	H	4	East - West
3	C	5	North - South	9	I	1	North - South
4	D	2	East - West	10	J	6	North - South
5	E	2	North - South	11	K	1	East – West
6	F	2	NSWE (All direction)	12	L	1	NSWE (All direction)

Figure 2. Aerial view of the Forestry cluster UGM with labelling

2.3. Study part three: building mass reconfiguration proposal

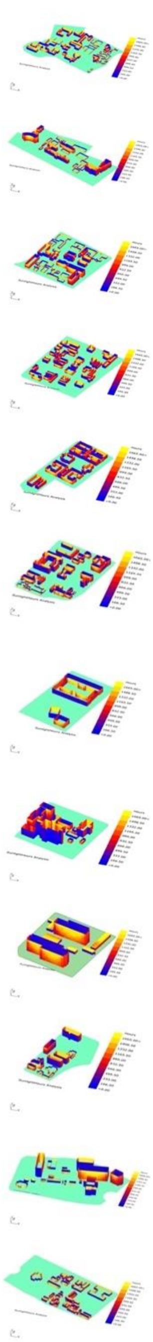
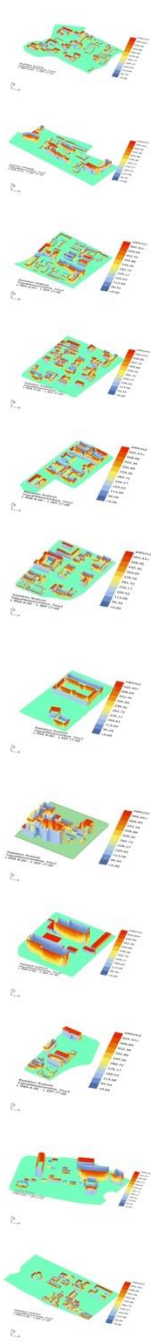
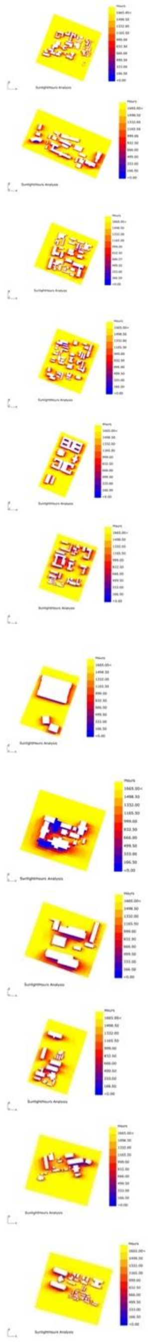
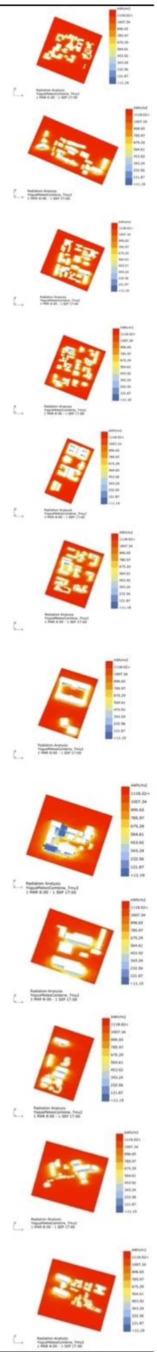
Following, a preliminary design proposal of building mass reconfiguration for the forestry complex area was also presented and then simulated to provide comparison on the impact of the passive design strategy towards sunlight hour and solar radiation values as the two factors that could increase the outdoor thermal comfort and the potential energy efficiency for cooling load to improve the indoor thermal comfort on the rearranged buildings. Moreover, the building mass reconfiguration was also proposed following the recommendations set up on Sekip – Bulaksumur – Boulevard's cluster Building and Environmental Planning (Rencana Tata Bangunan dan Lingkungan). This document set out regulation which required new buildings on the campus to be built with a minimum height of 5 floors to increase the effectiveness of land and space and to optimize open space or shared place to be integrated with the surrounding building functions [24].

3. Results

3.1. Study part one: existing condition

Detailed measurements and graphical result on the average sunlight hour and solar radiation analyses for each of all of the building envelope and the landscaping surface within each existing cluster area are presented in Table 2.

Table 2. Analysis result for existing building envelope in all clusters

No	Cluster name	Building envelope				Landscaping surface			
		Average sunlight hour		Radiation analysis		Average sunlight hour		Radiation analysis	
		Value (hr)	Graphical result	Value (kWH/m²)	Graphical result	Value (hr)	Graphical result	Value (kWH/m²)	Graphical result
1	Engineering	729.34		300.78		943.13		1117.01	
2	Graduate School	693.80		273.41		1495.68		1019.85	
3	Mathematics and Natural Science	672.41		268.88		1621.11		1072.04	
4	Medical	654.22		259.28		1233.89		835.16	
5	Vocational School	635.02		250.42		1305.20		888.45	
6	Social Humanities	667.76		266.08		1518.17		1010.05	
7	University Central Building and Library	698.86		303.59		1113.33		773.08	
8	Forestry	552.74		226.86		1647.16		1098.05	
9	Agricultural Technology	683.99		322.24		1384.28		968.95	
10	Agriculture	676.14		274.08		1404.56		965.73	
11	Veterinary Medicine	661.60		278.30		1519.03		1029.46	
12	Animal Husbandry	744.93		574.05		1243.93		855.08	

3.2. Study part two: detailed study case on Forestry cluster area

Graphical result and detailed measurements of sunlight hour and solar radiation on each building and surface area on the site of Forestry cluster under existing building configuration are presented on Figure 3 and Table 3.

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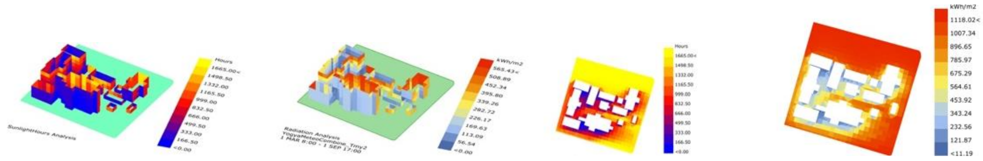
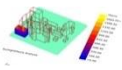
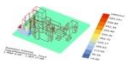
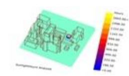
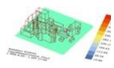
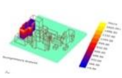
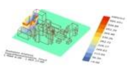
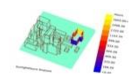
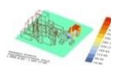
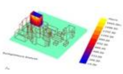
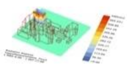
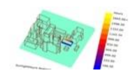
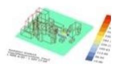
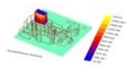
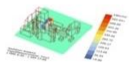
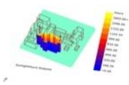
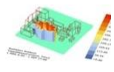
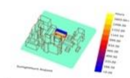
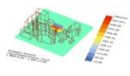
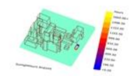
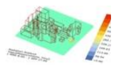
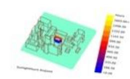
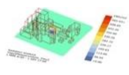
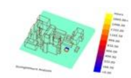
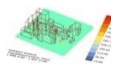
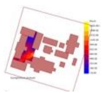
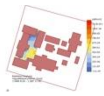
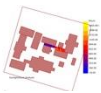
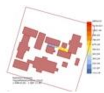
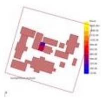
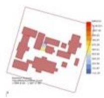
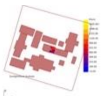
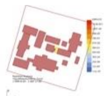
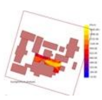
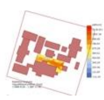
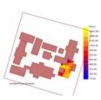
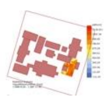


(a) (b)

Figure 3. Sunlight hour and solar radiation's graphical data of the existing Forestry's cluster area, (a) on the building envelopes, (b) on landscaping surface

Table 3. Sunlight hour and solar radiation data of the building area and landscaping surface area of the existing Forestry's cluster area

No	Building / Landscaping	Average sunlight hour (hr)	Graphical result	Radiation analysis (kWH/m²)	Graphical result	No	Building / Landscaping	Average sunlight hour (hr)	Graphical result	Radiation analysis (kWH/m²)	Graphical result
Building envelope area											
1	A	426.10		200.85		7	G	441.62		140.28	
2	B	438.57		157.17		8	H	755.213		356.66	
3	C	463.57		156.59		9	I	466.333		156.32	
4	D	514.21		181.39		10	J	597.36		268.94	
5	E	644.84		236.40		11	K	700.33		260.94	
6	F	591.53		193.51		12	L	653.37		244.89	
Landscaping surface area											
1	1	497.0		329.50		4	4	573.4		415.51	
2	2	471.0		362.44		5	5	591.2		436.68	
3	3	1029.73		681.85		6	6	1115.94		761.58	

From the simulation result, it could be seen that the solar radiation analysis result was in accordance with the sunlight hour analysis result. The south side of the building complex was the least exposed area due to its geographical condition in relation to the sun path diagram —as opposed to the inner court and open space area as the most exposed area with the highest amount of sunlight hour and solar radiation value. The Forestry's cluster is located on the south side relative to the equator line.

Then, based on the simulations of the Forestry cluster's existing building configuration, an alternative design proposal with building mass reconfiguration was presented. Overall, included in

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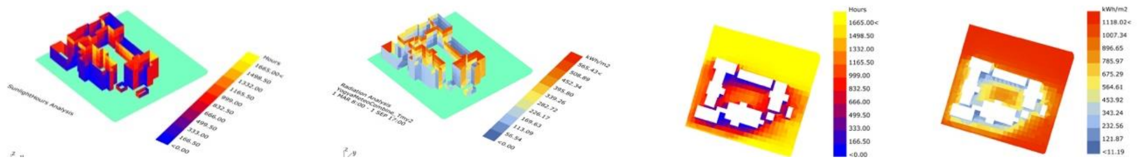
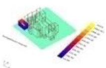
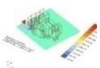
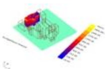
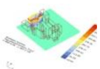
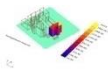
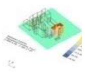
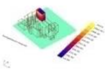
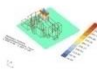
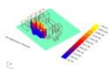
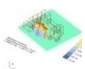
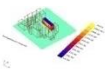
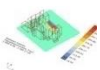
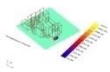
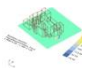
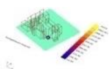
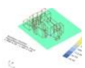
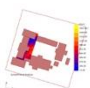
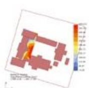
the proposal was efficiencies on the number of buildings by strategically relocating floor area from a certain building to another. Through selective building mass reconfiguration, two buildings in the central area were eliminated. Consequently, an additional volume was put to an adjacent building to compensate for the loss of spaces. Specifically, the height for the buildings located on the west and east side of the site was increased. Higher building masses cast larger shadows thus raised the number of shadowed spots in the inner court area and shorten the time for solar exposure in that area during the day. Furthermore, this reconfiguration was also a strategy to increase the amount of area available for the development of additional green and open spaces in the campus by minimizing the use of BCR. Following, another set of sunlight hour and solar radiation analysis were conducted. The graphical data and detailed measurements of total sunlight hour on the reconfigured Forestry's cluster area presented in Figure 4, followed by Table 4.



(a) (b)

Figure 4. Sunlight hour and solar radiation's graphical data of the reconfigured Forestry's cluster area, (a) on the building envelope, (b) on landscaping surface

Table 4. Sunlight hour and solar radiation data of the building area and landscaping surface area of the reconfigured Forestry's cluster area

No	Name	Average sunlight hour (hr)	Graphical result	Radiation analysis (kWH/m²)	Graphical result	Modification	No	Name	Average sunlight hour (hr)	Graphical result	Radiation analysis (kWH/m²)	Graphical result	Modification
Building envelope area													
1	A	392.56		193.99		-	7	G	-	-	-	-	Converted into an open space area
2	B	420.61		155.97		Moved towards the East side	8	H	686.405		313.68		Moved towards South-West side
3	C	454.75		154.88		Moved towards the East side	9	I	-	-	-	-	Converted into an open space area
4	D	-	-	-	-	Merged with Building E	10	J	523.259		226.80		-
5	E	572.68		194.91		Added mass	11	K	514.33		171.98		-
6	F	-	-	-	-	Merged with Building E	12	L	333.87		135.13		Moved towards South-West side
Landscaping surface area													
1	1	493.31		313.76		-	4	4	-	-	-	-	Merged with Inner court 3

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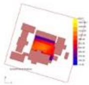
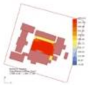
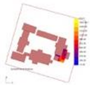
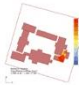
2	2	-	-	-	-	Merged with Inner court 3	5	5	-	-	-	-	Merged with Inner court 3
3	3	792.28		567.70		-	6	6	628.89		442.76		-

4. Discussion

Based on the comparative data of the simulation result, it is clear that following the building mass reconfiguration, along with the obvious reduction on the BCR by 4% —from 26% to 22%, there was also a decrease on the sunlight hour and solar radiation level on several buildings and inner court area. These declines were found by various percentage, with the number for the rest of the building was stable. The differences were caused by different mass reconfiguration strategies for each building; for example, some were heightened by additional stories substituting for removed buildings and some were not modified at all. The number of stories added for each relevant building was also varied.

Next, following the building mass reconfiguration plan, along with a reduction in the number of buildings, there were larger ground areas available. Thus, the grouping for landscaping surface was consequently modified. The inner courts, which were previously including several smaller building canyon areas, had been converted into a large one in the centre area of the site. Nevertheless, some separations or groupings within the large inner court were still allowed although the number has greatly reduced from 6 to 3. Referring back to the research goal, it was clear that with a decrease on the sunlight hour and solar radiation number on the building envelope and landscaping surface, selective building mass reconfiguration could work as a potential passive strategy to limit the energy consumption for building cooling load on the Forestry cluster's area. Detailed data on the decreases are shown in Table 5.

Table 5. Decrease on sunlight hour and solar radiation data on building

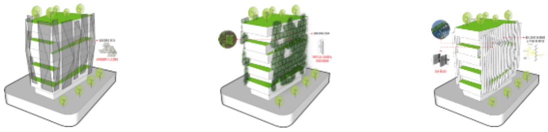
No	Building / landscaping surface name	Sunlight hour	Solar radiation	No	Building / landscaping surface name	Sunlight hour	Solar radiation
		Decreased by (%)				Decreased by (%)	
Building envelope area							
1	A	8%	3%	5	H	9%	12%
2	B	4%	1%	6	J	12%	16%
3	C	2%	1%	7	K	27%	34%
4	E	11%	18%	8	L	49%	45%
Landscaping surface							
1	1	1%	5%	3	6	44%	42%
2	3	23%	17%				

5. Conclusions

Concluding, with regards to other factors affecting energy consumption and urban outdoor thermal comfort, both of the downtrends for sunlight hour and solar radiation analyses for building envelope and landscaping surface area had shown the potential of building mass reconfiguration not only to reduce the energy consumption for building's cooling system but also to provide higher thermal comfort for outdoor activities in the inner court area. This conclusion was based on the context of the Forestry cluster as a study case, where the largest decreases for both factors were found on building L and in inner court 6 —by nearly 50% and more than 40% respectively. Finally, it is imperative to test this strategy in other clusters within the UGM's academic zone to obtain a detailed result of its effectiveness. However, considering the similar BCR —and the similar sunlight hour and solar radiation analyses for all the clusters' existing condition, analysis on the digital simulation of sunlight hour and solar radiation on the existing and reconfigured campus area of the Forestry's cluster area presented in this paper had successfully shown the potential impact of building mass reconfiguration to reduce energy consumption for a greener UGM campus.

5.1. Future research

Furthermore, to investigate additional strategies that could be adapted to increase the implementation of green campus concept in UGM's construction and renovation policy, building skin management strategies of Double Skin Façade will be examined in the next research as a continuation upon this study. This study will utilize three alternatives of DSF models that are commonly adapted for reducing energy consumption for building cooling load in academic buildings in UGM such as (1) andesite cladding, (2) vertical garden and roof garden, (3) external shading and wind trapper, as shown in Figure 5.



(a) (b) (c)

Figure 5. DSF alternatives (a) andesite cladding, (b) vertical and roof garden, (c) shading and wind trapper

Author Contributions: Conceptualization, Nabila Afif, Agus Hariyadi and Nedyomukti Imam Syafii; methodology, Agus Hariyadi, Nedyomukti Imam Syafiirv; software, Esti Setyaning Jati; validation, Agus Hariyadi; formal analysis, Nabila Afif; investigation, Nabila Afif; resources, Nabila Afif and Esti Setyaning Jati; data curation, Agus Hariyadi and Nabila Afif; writing—original draft preparation, Nabila Afif; writing—review and editing, Nabila Afif; visualization, Nabila Afif and Esti Setyaning Jati; supervision, Agus Hariyadi and Nedyomukti Imam Syafii; project administration, Nabila Afif. All authors have read and agreed to the published version of the manuscript.

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