Sustainability in Energy and Buildings: Research Advances ISSN 2054-3743
Vol. 7. No. 1 : pp.1-9 : seb20s-005

Comparison of two approaches for evaluating a floorplan's ability to change: SAGA and AOM

Makenzie Wilson[1, 2]
Brandon Ross[2]
Pieter Herthogs[3, 4]
Zoraya Rockow[2]

1. *Brigham Young University*
2. *Clemson University*
3. *ETH Zürich, Singapore-ETH Centre*
4. *Singapore University of Technology and Design*

An open floorplan is often cited as a key factor in the ability to adapt a building. This paper compares and contrasts two recently created approaches for quantifying the adaptability of floorplans. The Spatial Assessment of Generality and Adaptability (SAGA) method is based on graph theory and can be used to calculate the "generality" and "adaptability" of floorplans. Generality is the passive ability to accommodate different programs, whereas adaptability is the ability to accommodate different programs through active change. SAGA focuses on the configuration of spaces in a floor plan and their relationships with each other. The second method, Areal Openness Model (AOM), utilizes basic arithmetic, geometry, and a set of user-defined value judgements to calculate the Openness Score (OS), Weighted Openness Score (WOS), and Openness Potential (OP) of floorplans. OS indicates the lack of obstructions (walls, columns, chases) in a floorplan. WOS is a composite indicator which considers the number of obstructions and the difficulty of removing them. OP is the arithmetic difference between OS and WOS and indicates the potential of a floorplan to become more open. The authors used five case study buildings from university campuses in the USA to compare and contrast the SAGA and AOM approaches. This paper's objective is to evaluate if the methods are complementary or redundant.

1. Introduction

While much has been written about adaptable buildings [2], modeling and quantification of adaptability are still in the nascent stage [9]. This paper reviews two recently emerged methods for quantifying the adaptability of floorplans. In particular, the Spatial Assessment of General and Adaptability (SAGA) method [5] and Areal Openness Model (AOM) [8] are compared and contrasted using five case study buildings from university campuses in the USA. Results from SAGA and AOM are compared to evaluate correlations, if any, between the two methods.

Presented at KES-SEB-20 9-11 September 2020

Floorplan layout and openness are often cited as key enablers of building adaptation [2, 10]. The notion is that floorplans that are free of obstructions and configurational constraints can be readily changed (adaptability) or used as-is (generality) to suit different occupant needs. Indeed, the link between floorplans and adaptability has been observed in empirical data from real-world building adaptation projects [1]. This short paper aims to compare and contrast SAGA and AOM, which are currently the only quantitative methods for analyzing floorplan layouts within the context of adaptability.

2. Spatial Assessment of General and Adaptability (SAGA)

The SAGA method [5, 4] evaluates the generality and adaptability of floor plans from a configurational perspective, representing and analyzing building layouts as graphs of connected spaces. The method is conceived as a suite of indicators to measure particular aspects of configurational generality and adaptability. The present paper discusses SAGA's *spatial configuration* indicators [5], which measure the permeability of existing and potential spatial configurations in a building. SAGA also has a set of *surface area* indicators, which categorize a floor plan's configured spaces according to the generality and adaptability of surface areas [4, 6].

SAGA uses *convex mapping* to represent floor plans as *plan graphs*: each space is represented as a graph vertex, connections between spaces are represented by (weighted) graph edges, and any non-convex space (e.g., an L-shaped room) is further subdivided into convex subspaces. SAGA's approach to convex mapping is similar to that of Space Syntax theory's Justified Plan Graph (JPG) method [3, 7], a graph analysis method to study correlational patterns of user behavior and floor plan configurations. As a result, SAGA indicators can be derived from JPG indicators. Figure 1 illustrates how SAGA represents floor plans as graphs of convex spaces.

SAGA's spatial configuration indicators measure the permeability of plan layouts. The method's premise is that highly interconnected spatial configurations can accommodate more types and variants of functional programs, as these are, in essence, spatial configurations of multiple interrelated functions. The permeability of a plan layout can be expressed by the *Aggregated Total Depth* (ATD) of its plan graph, which is the aggregate of the shortest paths from all convex spaces to all other convex spaces. The *Permeability* (P) of a *v*-node plan graph (see equation 1) is then defined as the ATD of that graph, normalized relative to the ATD of a *v*-node linear graph (the configuration with the lowest possible Permeability, equation 2) and that of a v-node wheel graph (the configuration with the highest feasible Permeability, equation 3).

The *Generality* (G) of a building layout is then defined as the Permeability of its *access graph* (Figure 1, 2nd from top), in which the graph edges represent existing connections between spaces (usually through doorways). The *Maximum Adaptability* (MA) of that building layout is the Permeability of its *adjacency graph* (Figure 1, bottom), in which graph edges represent shared walls between spaces (and hence all potential doorways that could exist). Finally, the *Adaptability* (A) of that building layout is the Permeability of the *weighted adjacency graph* (Figure 1, 3rd from top), with graph weights representing the difficulty of creating doorways between spaces that are not connected at present. Reference [5] provides a list of weights for different wall types; the example in Figure 1 weights existing openings at 1.0 and potential openings as 1.5.

As the Generality and Adaptability of a floor plan depend on the overall spatial configuration of the existing building, both values can be normalized relative to the plan's achievable maximum (MA), resulting in the indicators *Normalized Generality* (G_n) and *Normalized Adaptability* (A_n) - equations 4 and 5 respectively.

$$P_{plan\ graph,v} = \frac{ATD_{plan\ graph,v} - ATD_{linear,v}}{ATD_{wheel,v} - ATD_{linear,v}}$$ Equation 1

$$ATD_{linear,v} = \frac{(v-1)^3}{3} + (v-1)^2 + \frac{2(v-1)}{3}$$ Equation 2

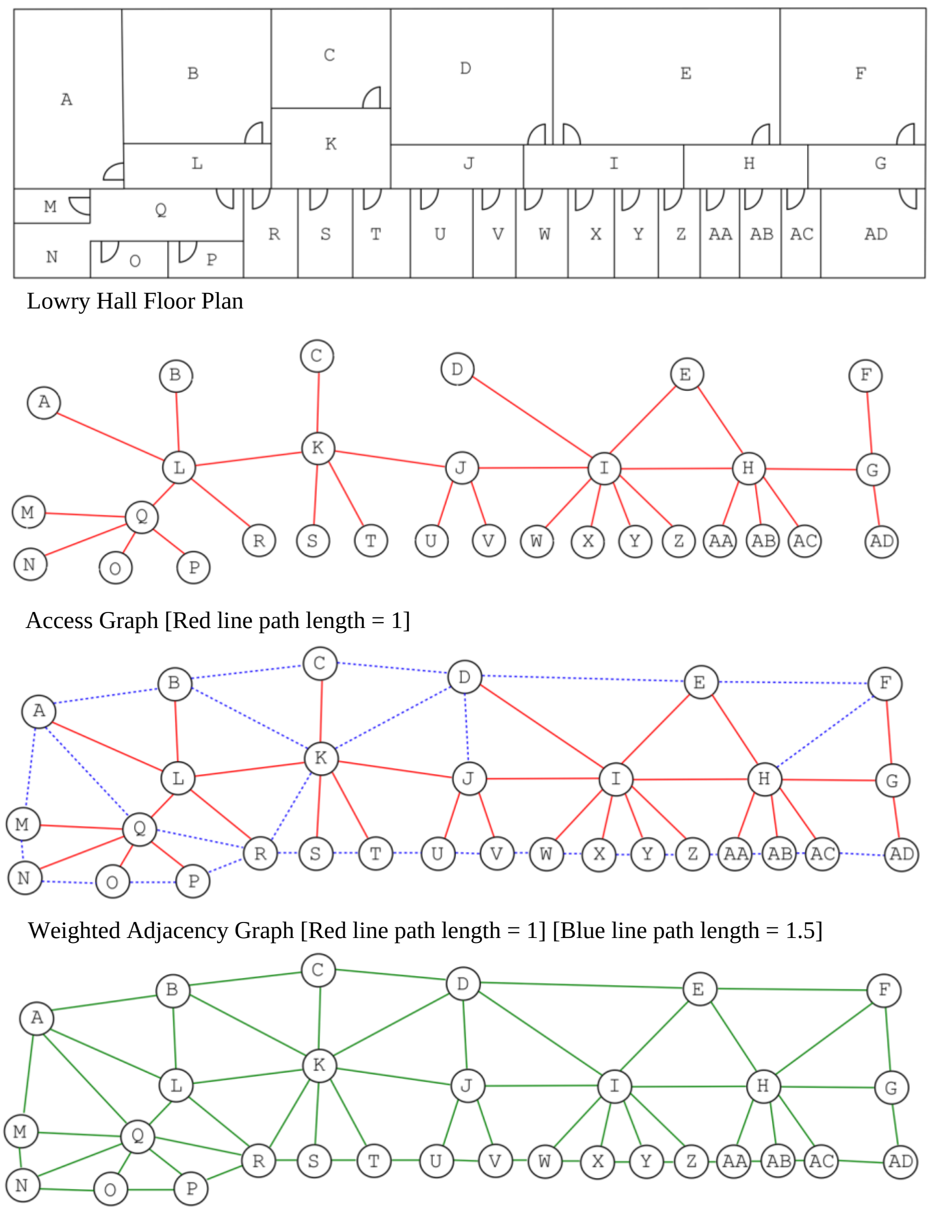
$$ATD_{wheel,v} = 2v^2 - 6v + 4$$ Equation 3

$$G_n = \frac{G}{MA}$$ Equation 4

$$A_n = \frac{A-G}{MA-G}$$ Equation 5

Where:

$P_{plan\ graph,v}$	=	Permeability of a *v*-node plan graph
$ATD_{plan\ graph,v}$	=	Aggregated Total Depth of a *v*-node plan graph (computed)
v	=	Number of graph vertices
G	=	Generality = $P_{access\ graph}$
A	=	Adaptability = $P_{weighted\ adjacency\ graph}$
MA	=	Maximum Adaptability = $P_{adjacency\ graph}$
G_n	=	Normalized Generality
A_n	=	Normalized Adaptability



Lowry Hall Floor Plan

Access Graph [Red line path length = 1]

Weighted Adjacency Graph [Red line path length = 1] [Blue line path length = 1.5]

Adjacency Graph [Green line path length = 1]

Figure 1 – Lowry Hall Floor Plan and SAGA graphs

3. Areal Openness Model (AOM)

For AOM, openness is defined as the lack of obstructions (walls, columns, chases) that subdivide a floorplan. AOM utilizes basic arithmetic, geometry, and a set of user-defined value judgements to calculate the *Openness Score*

(OS), *Weighted Openness Score* (WOS), and *Openness Potential* (OP) of floorplans. Equations 6-8 are used in calculating these parameters. A derivation of the equations will be provided in a forthcoming work [8].

$$OS = 1 - \frac{\left(\frac{B_f}{4}\right)(2LI + LP)}{A}$$ Equation 6

$$WOS = 1 - \frac{\left(\frac{B_f}{4}\right)[\sum(2RF_i LI_i) + LP]}{A}$$ Equation 7

$$OP = WOS - OS$$ Equation 8

Where:

OS =	Openness score
B_f =	Baseline spacing factor (10ft, 3m)
LI=	Total length of interior obstructions
LP =	Total length of perimeter
A =	Floorplan area
WOS =	Weighted Openness Score
RF_i =	Removal factor of interior obstruction type i
LI_i =	Length of interior obstruction type i
i =	Index for obstruction type
OP =	Openness Potential

The physical interpretation of OS (equation 6) is based on the scale shown in Figure 2. A building is “completely open” (OS=1.0) if it has no interior walls. A “completely closed” (OS=0) building is defined as having an areal density of walls equivalent to walls spaced at 10 ft (3m) in orthogonal directions. This definition of closed was selected as it represents a very restricted floorplan with small rooms and many floorplans. The completely closed floorplan in Figure 2 is meant to demonstrate the baseline areal density of walls used in AOM and not represent any particular floorplan.

WOS (equation 7) is a composite indicator that considers the number of obstructions and the difficulty of removing them. Wall lengths are multiplied by a weighting factor based on how difficult they would be to remove (Table 1). The weighting factors are similar to the wall permeability factors in SAGA. Columns are also multiplied by a weighting factor such that a 1 ft (0.3m) wide column is equivalent to a 10ft (3m) length of structural wall.

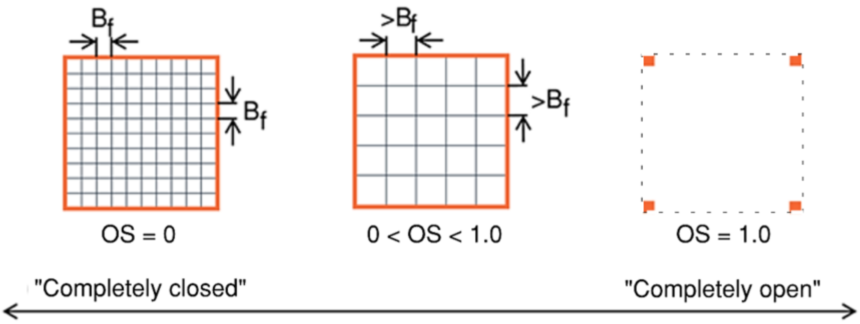


Figure 2 – Graphical definition of “completely closed” and “completely open” for AOM. Note that Bf = 10 ft (3m)

OP (equation 8) is the difference between OS and WOS and indicates a floorplan’s potential for becoming more open. A high OP occurs for floorplans with tightly spaced but easy to remove walls. A low OP occurs when a floorplan is already very open or that have walls and columns that are relatively difficult to remove.

Table 1 - Removal Factors for calculating WOS

	Obstruction Type	**Removal Factor, *RF***
Interior	Open	0.00
	Removable Wall	0.10
	Light-framed Partition Wall	0.25
	Other Partition Wall	0.50
	Chase Wall	0.75
	Fire Wall	0.75
	Structural Wall	1.00
	Columns	10.0

4. Comparisons of SAGA and AOM

Comparisons between SAGA and AOM are shown in Figure 3. The data points are based on five university campus buildings:

- Barnes Center, Clemson University
- Clemson House, Clemson University
- Graham Hall, Western Carolina University
- Natural Science Building, Western Carolina University
- Lowry Hall, Clemson University

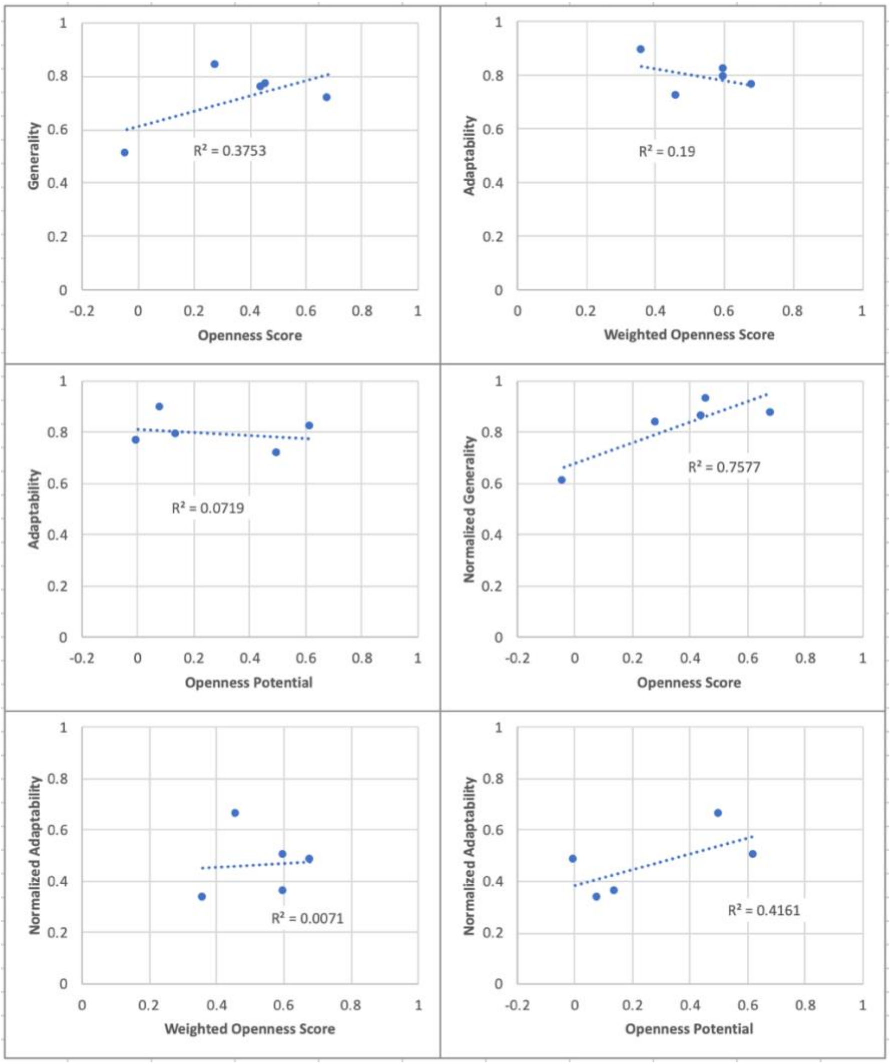


Figure 3 – Comparisons of SAGA and AOM methods

Figure 3 compares metrics associated with the in-situ condition of a floorplan (G, G_n, and OS) separately from those associated with potential changes (A, A_n, WOS, and OP). The sample size used for comparisons is limited; however, the comparisons do provide some insight into the relationship – or lack thereof – between SAGA and AOM.

In all but one of the comparisons, there is little linear correlation between the methods. This observation suggests that the two methods are complementary. The lack of correlations is attributed to the different formulations and scopes of the methods. SAGA is based on graph theory and considers the relationships between spaces in a floorplan, whereas AOM is derived from basic geometry and directly considers the floorplan size and length of walls.

The only pair of metrics that show a degree of linear correlation (R_2=0.76) is normalized generality and openness score. A possible explanation for this observation is as follows: Large values for normalized generality are associated with floorplans having adjacent and well-connected spaces. It takes relatively few walls to separate floorplans with adjacent and well-connected spaces; consequently, such floorplans are likely to have a high openness score. Conversely, fragmented floorplans have spaces with few interconnections and adjacencies and small normalized generality. Walls that separate the fragmented floorplans contribute to low openness scores.

5. Summary and Conclusions

In this paper, the SAGA and AOM methods were briefly introduced and were compared to determine if their associated metrics are complementary or redundant. The comparisons were made for five university campus buildings. Most of the compared metrics were not linearly correlated (R_2<0.41), suggesting that the models are complementary and provided distinct information about a given floorplan. The sample size for comparison was small, and additional studies are recommended to confirm the observations of this paper. Additionally, it is recommended that AOM be compared to SAGA's surface area indicators; the current paper only compared with SAGA's spatial configuration indicators.

6. Acknowledgements

Makenzie Wilson's effort on this paper was funded through the US National Science Foundation (NSF) Research Experience for Undergraduates program. Brandon Ross and Zoraya Rockow were supported by NSF grant # CMMI 1553565. Pieter Herthogs conducted part of this research at the Future Cities Laboratory at the Singapore-ETH Centre, which was established collaboratively between ETH Zürich and Singapore's National Research Foundation (F1370074016) under its Campus for Research Excellence and Technologies Enterprise program. Clemson University and Western Carolina University provided building plans for the case study buildings.

7. References

1. Black, A.K., Ross, B., and Rockow, Z.R. "Identifying Physical Features that Facilitate and Impede Building Adaptation," in Proceedings of the 10th International Conference in Sustainability in Energy and Buildings, Gold Coast, Australia, June 2018 (2018)
2. Heidrich, O., Kamara, J., Maltese, S., Re Cecconi, F., and Dejaco, M. "A critical review of the developments in building adaptability", Int. J. Build. Pathol. Adapt. Vol 35, 284–303 (2017)

3. Hillier, B. and Hanson, J. The Social Logic of Space; Cambridge University Press: Cambridge, UK, 1984.
4. Herthogs, P. Enhancing the adaptable capacity of urban fragments. A methodology to integrate Design for Change in sustainable urban projects. Doctoral thesis, Vrije Universiteit Brussel. (2016)
5. Herthogs, P., Debacker, W., Tunçer, B., De Weerdt, Y., and De Temmerman, N. "Quantifying the Generality and Adaptability of Building Layouts Using Weighted Graphs: The SAGA Method", Buildings, Vol. 9, No. 4 (2019)
6. Herthogs, P., Paduart, A., Denis, F., and Tunçer, B. (2017). Evaluating the generality and adaptability of floor plans using the SAGA method: A didactic example based on the historical shophouse and gentry house types. In UIA 2017 Seoul World Architects Congress. Seoul, South Korea, September 2017.
7. Ostwald, M.J. The Mathematics of Spatial Configuration: Revisiting, Revising and Critiquing Justified Plan Graph Theory. Nexus Netw. J. 2011, 13, 445-470
8. Rockow, Z.R. "Qualitative and Quantitative Analyses of Existing Buildings' Adaptability" Clemson University, PhD Dissertation, forthcoming 2020
9. Rockow, Z.R., Ross, B., and Black, A.K. Review of methods for evaluating adaptability of buildings. Int. J. Build. Pathol. Adapt. 2018. doi:10.1108/IJBPA-01-2018-0013.
10. Ross, B., Chen, D.A., Conejos, S., and Khademi, A. "Enabling Adaptable Buildings: Results of a Preliminary Expert Survey", Procedia Engineering,145(Supplement C), 420–427 (2016)