Development of the layout method for a high-rise housing complex using parametric algorithm

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**ABSTRACT**
An algorithm-based parametric design method was developed to generate the layout of a high-rise housing complex with improved sunlight access and compliance with the relevant building code restrictions in South Korea. Integrated with computer-aided modelling and simulation, the algorithm automatically arranges multiple apartments according to their height, separation, the shaded area between adjacent buildings and setbacks from site boundaries. The algorithm was then implemented in three high-rise housing complexes across South Korea to validate its feasibility. In all three cases, the algorithm generated housing layouts that satisfied the considered building regulations and improved overall sunlight exposure conditions. Particularly, lower-density housing with fewer buildings or floors were found to be more effective in allowing sunlight access: more housing units were included in the longest sunlight exposure duration whereas fewer units were included in the shortest sunlight duration. The proposed parametric approach allows the effective execution of both diverse experiments in housing design layouts and assessments of layouts’ sunlight access conditions, enhancing sustainable decision-making in the design process.

1. Introduction

1.1. Backgrounds and theoretical review
Algorithm-based parametric design methods are useful in searching for various solutions to a specific design problem. Parametric algorithm design methods are used to explore diverse geometric forms of buildings and are often integrated with functional performance simulations of buildings including various environmental performances (Fesanghary, Asadi, and Geem 2012; Mark 2012). Additionally, algorithm-driven parametric design methods enable the evaluation of building performances while also generating and analysing multiple design alternatives catered to meet specific design goals (Shi and Yang 2013; Turrin, Von Buelow, and Stouffs 2011). One advantage of these algorithm-based parametric design methods is that the performance-evaluated design solutions can be easily adjusted in response to the changes that occur during the design process; this allows for significant flexibility and versatility (Caldas and Norford 2002). Additionally, the adaptability of parametric algorithm design methods enables the design process to be more efficient than conventional design methods with regard to the time, labour and cost required; this can be attributed to the parametric algorithm design methods’ use of automatic procedures for generating the most suitable performance solutions (Caldas and Norford 2003). Both of these advantages promote the implementation of the algorithm-based parametric design methods in pursuing sustainable design approaches for various building types (Shi and Yang 2013; Wang, Zmeureanu, and Rivard 2005).

In the field of housing design research and practice, parametric algorithm design approaches have been adapted in the exploration, simulation and evaluation of various housing design problems to search for the most appropriate performance solutions across a wide range of geographic and climatic regions. Several of these approaches include the following.

Caldas and Norford (2003) studied the multi-objective design optimization of buildings using algorithms to explore the trade-offs of between building construction operation costs and multiple design criteria. In particular, they experimented with a hypothetical apartment structure in Beijing, China to optimize the trade-off between energy consumption during building operations and the initial construction cost for materials on the exterior facades. Resultingly, they proposed exterior wall materials which can reduce both energy consumption and costs.

Tuhus-Dubrow and Krarti (2010) developed a computational tool to optimize residential building forms of standard shapes and envelope features and minimize their energy use. Energy use simulations of building forms with different envelope features were assessed in five major cities across different climatic zones in the United States. Subsequently, rectangular and trapezoidal residential building forms presented both lower-life cycle costs and the least variability of
their building forms in the energy saving value of building envelopes.

Chronis, Liapi, and Sibetheros (2012) analysed a student residence complex on the campus of the University of Paras in Greece. They developed an algorithm linking local climatic information such as solar geometry, wind flow and site topography with the basic geometric features of the residence, such as the shapes of a building profile, the roof shade and the overhang. Solar radiation and wind flow simulations were integrated into the algorithm and as a result, optimal housing forms and orientations were proposed for the considered location.

Nebia and Tabet (2017) employed an algorithm to predict and assess internal temperature and daylighting conditions for high-rise apartments in London, England. Single- and double-loaded plan types were compared to measure the impact of various performance criteria such as the glazing ratio, thermal mass, ventilation and orientation in relation to solar radiation and overheating. The apartment units with more exposure to solar radiation, due to either their orientation or floor level, were found more susceptible to overheating in the summer and exceeding daylight exposure standards.

The aforementioned studies demonstrate the use of algorithms for a wide range of housing types as well as the types of design problems investigated in varying locations worldwide, including building shape and size, floorplan type, exterior envelopes, HVAC system, etc. Various design alternatives were exploited and analysed especially in relation to diverse environmental performance criteria, for which algorithms were utilized to address objective performance goals. However, these studies are concentrated on the investigation of a single residential structure or housing type with identical buildings in size and shape. In most urban areas, numerous buildings with various designs, forms and functional properties are included in an urban block; this is especially true of the groups of high-rise apartments often found on large-scale residential blocks. Such diversity in housing configuration adds complexity in housing design and planning, requiring a more holistic design approach (Choi 2002).

In urban housing development, the provision of sunlight access and ways in which it can be controlled has been a worldwide interest to ensure healthy residential environments (Choi 2015). For example, in England, sunlight access is controlled by building by laws, by which building heights are limited according to regulations that vary across building classifications and cities (Capeluto and Plotnikov 2017). To ensure adequate sunlight reception in residential buildings, a zoning ordinance can be used to control building height, the number of floors and the ratio between land area and built floor area (Department of City Planning, New York City 2011). The concept of an obstruction angle is also used to restrict the shadow cast by adjacent buildings. In Israel, the obstruction angle approach is used to limit the building height so as to not exceed the obstruction angle drawn from a neighbouring structure (Capeluto and Plotnikov 2017). In Japan, legal restrictions control the duration of shaded hours in buildings to ensure their sunlight reception. A minimum sunlight exposure duration (on the winter solstice date) is set according to the building height, its setback distance from the site property line and its surrounding climatic and geographic conditions (Ministry of Land, Infrastructure, Transport and Tourism, Japan 2018).

In South Korea, similar issues regarding sunlight access have caused constant disputes, especially in high-rise apartment neighbourhoods. To allow high-density urban housing development, the South Korean building codes have eased building spacing restrictions by means of controlling the height of the building; however, the code still aims to ensure sufficient sunlight in residential units (Kim 2001). Because of such strict restrictions on the height and the subsequent separation between residential buildings, many South Korean residential structures tend to exhibit similar building heights, plan types and orientations. Most facades face south and are arranged linearly for more daylight and improved through-ventilation. Such a uniformity presents a lack of diversity devoid of unique identities, creating monolithic urbanscapes throughout many South Korean urban cities (Yi and Kim 2015).

Thereby, some studies have paid special attention to the issue of sunlight access in a group of residential buildings by addressing their layout criteria. Some studies have further explored the relevant legal issues as well. With such aims, parametric computational approaches were adapted as a way to exploit various housing layout designs with regard to their sunlight access in the context of residential development. Several parametric computational approaches to jointly designing groups of buildings near each other are seen in the following works.

Mills (1997) studied the effects of sunlight exposure in a group of residential buildings with identical shapes in four different climatic zones of varying latitudes. Particularly, a computer model was implemented to simulate the heating, cooling and subsequent thermal stress in the group of residential buildings by controlling the height, size and spacing at different times of the year. Consequently, design of buildings as a group was found to be more beneficial to solar exposure in terms of heating and cooling loads on individual structures, especially in the mid-latitude zone.

Panão, Gonçalves, and Ferrão (2008) proposed a computational tool to exploit residential block forms based on their solar absorption and radiation for energy efficiency and improved thermal
performance in the mid-latitude climates. The study parameterized building forms, azimuth angles and the block aspect ratio to identify optimal basic urban forms in terms of solar energy performance potentials. The results indicated that design variations with certain block forms, azimuth angles and latitudes can generate a significantly enhanced sunlight reception and thermal performance.

Seong et al. (2011) investigated the geometrical elements of apartments and the design factors and regulations related to the solar right in South Korea. To satisfy the solar right regulations, a mathematical computational model and subsequent algorithm were developed to automatically adjust the height of apartments. Additionally, the developed algorithm was tested with case-study apartments, wherein the model and algorithm were verified as efficient tools to assess the solar right status of apartments.

Yi and Kim (2015) explored the optimization of the access to direct sunlight for apartment layouts in South Korea. They proposed an agent-based system to control building geometries more efficiently. Additionally, integration with computational simulation tools was proposed for a building layout with a more objective and accurate sunlight reception performance. Resultingly, the proposed method used the performance-driven measures to fulfil the minimum solar exposure hours enforced by the South Korean building code, while allowing more varied layout designs in tall apartments.

Capeluto and Plotnikov (2017) proposed a method and tool to explore the configuration of the parametric solar envelope which sets the maximum building height for the maximum solar access in an urban block. Particularly, their used the developed algorithm in a case study of a residential mixed-use block in the city of Tel Aviv, Israel; from this, they demonstrated the maximum developable volumes of buildings which can ultimately enhance the feasibility of the block’s overall development.

The aforementioned studies concern block-scale housing layouts using algorithm-based parametric methods in various context worldwide. These investigations concentrate on the morphology and size of urban block types, the manipulation of building geometries and their placement, pertaining to sunlight reception or absorption qualities. However, the practice of designing complex housing layouts while enhancing overall sunlight access requires the consideration of far more complex design parameters, including the various legal restrictions posed by building codes, as building codes substantially influence the outcome of housing layout configurations (Choi 2002; Lee 2011). Therefore, the housing layout design of multiple apartment buildings is an intensive process demanding the constant review and incorporation of the relevant building regulations (Seong, Yeo, and Kim 2005). As such, using an algorithm-based parametric design approach can be advantageous in designing a large-scale housing complex layout, as such an approach can automatically check designs’ conformity with legal issues and search for the most suitable design outputs. This has the potential to elevate the overall sustainability of the project in terms of resource allocation and management, particularly in the early stages of the design process (Attia et al. 2012).

1.2. Aim of study

As the design of housing layout configurations is a considerably complex process, designers and planners need a useful guide for proper decision-making. However, insufficient information is available to inform a design method which can assist in the navigation of the decision-making process. Thereby, this study aims to fill this gap by proposing an algorithm-driven parametric computational approach to aid in the design process of arranging a group of high-rise residential structures. First, this study aims to integrate the process of exploring, simulating and evaluating the design of housing layout configurations, with the aim of providing sufficient sunlight access to individual buildings. Second, this study aims to provide a useful tool to automatically generate design outcomes that conform to the complex building code restrictions pertaining to sunlight access in housing layout design. Third, this study aims to propose an accessible method that can, in practice, ease the decision-making process by incorporating publicly approachable computational tools.

With these aims, the present study is conducted with the following two process:

(1) Development of the algorithm: The algorithm is developed by reviewing the South Korean building code restrictions relevant to sunlight access in residential buildings. By integrating 3D parametric modelling and environmental performance simulations in the algorithm, the modelled and simulated results of housing layout designs are generated so as to satisfy the study aim of achieving improved sunlight exposure performance in residential buildings while complying with relevant building regulations.

(2) Feasibility study: To verify its usefulness in the layout design of high-rise housing complexes, the proposed algorithm is applied to existing high-rise housing complexes. Simulations of their sunlight exposure conditions are quantitatively analysed before and after implementing the algorithm to validate its effectiveness.

This computational parametric design approach is expected to facilitate the design decision-making process while providing more accurate performance
values of the design outcomes by integrating them with the computational simulation. Results and findings are discussed in the Conclusions, along with future issues of computational methods in housing layout design.

2. Methods

2.1. Design constraints

The design constraints explored in this study are the building form (i.e. height and wall type), setback, separation and sunlight exposure duration of residential buildings in relation to adjacent buildings and site property lines. Such constraints are regulated in the South Korean building code in order to secure adequate sunlight access for the health and well-being of building occupants (Choi 2002).

2.1.1. Building form

Tower-type high-rise apartments are the prevailing residential types in South Korea because higher density buildings can be effectively achieved in limited, urban residential plots. To enhance sunlight reception and ventilation, high-rise apartments are often designed with -, L, T or Y-shape forms (Lee 2011). In this study, an algorithm is developed to accommodate various building forms, especially allowing for changes in building height, as the South Korean building code regulates the building height as a way to control adequate separation or setback of buildings for sufficient sunlight reception (Kim 2001).

Another important constraint is the wall type of the apartment, which is determined by the presence and size of the daylight windows on the wall. The daylight windows should have an area of $\geq 0.5 \text{ m}^2$ according to the South Korea building code (Infrastructure and Transport, Ministry of Land, South Korea 2017a). The wall types are classified into those with daylight windows, those without and side walls based on the size of the windows (Figure 1). The presence or absence of daylight windows affects the separation distance between adjacent apartments.

2.1.2. Setback for open yards

A residential plot should provide an open yard around its periphery (Infrastructure and Transport, Ministry of Land, South Korea 2017b). For a multi-family apartment, the setback from its front property line should be between 2 and 6 m along the street to promote efficient traffic circulation and to protect the life and health of residents from traffic pollution or fire hazards; The setback from the property line to an adjacent plot should also be between 2 and 6 m to ensure passage and outdoor space, as well as to provide higher sunlight access, ventilation and visibility (Park 2003). Here, setback was measured (i) from the property line in contact with an adjacent street, and (ii) along the property line in contact with an adjacent plot (Figure 2).
2.1.3. Building height, setback and separation
The building code ensures the setback and separation of buildings from site property lines and between adjacent buildings, respectively (Infrastructure and Transport, Ministry of Land, South Korea 2017a) by regulating the building height, which poses a challenge for designing multiple apartments with varying heights. As a result, monotonous housing complex designs with similar apartments in height and orientation are used in many urban cities in South Korea (Kim 2001).

The setback of a residential building in an exclusive or general residential zone should be at least 1.5 m from its property line facing north, when the height of the building is ≤ 9 m. For a height greater than 9 m, the setback should be more than half the height of each part of an apartment to minimize the shadow casted onto the adjacent buildings in the neighbouring northern plot (Figure 3).

When the walls with daylight windows in an apartment face the site property line, the height of each part of the apartment should be less than or equal to twice the horizontal distance to the nearest site property line perpendicular to the wall with daylight windows (Figure 4).

When more than two apartments are constructed and facing each other at a single site (Figure 5), the separation distance should be (1) more than half of the height of each part of the building facing the direction perpendicular to the wall with daylight windows; (2) ≥ 8 m when the wall without daylight windows and the side wall face each other; (3) ≥ 4 m when two side walls face each other. If none of the above restrictions are fulfilled, each housing unit may have the sunlight exposure of a minimum of 2 hours between 09:00 and 15:00 on the day of the winter solstice (on December 22, Korean Standard Time).

2.2. Study flow
The workflow of this study consists of two phases (also shown in Figure 6):

1. Development of algorithm:
   - Two-dimensional modelling: using a CAD tool (Rhino), the initial geometries of the building plan and site plan are modelled in 2D and imported to a visualized algorithm editor (Grasshopper).
   - Building layout: using an algorithm tool, various parametric constraints and their relations are defined for the housing layout with regard to the various building constraints addressed in Section 2.1.
   - Simulation: simulation of the environmental performance of the housing layout is integrated in the algorithm for the analysis of shaded areas. The algorithm automatically iterates the arrangement of buildings in accordance with the simulation results until all the required building constraints are satisfied.

2.2. Feasibility study:
   - The effectiveness of the algorithm is verified by implementing it in three case-study housing

Figure 3. Setback from the property line facing north.

Figure 4. Setback from the property line facing north with varying building heights.

Figure 5. Separation distance between apartments facing each other.

Figure 6. Workflow of the study.
complex developments. The housing layout generated by the algorithm for each case-study housing is transported to the simulation tool to check its sunlight exposure duration hours. The simulated results (i.e., improved sunlight exposure duration before and after using the algorithm), are then compared and analysed.

2.3. Tools

To integrate layout and environmental performance simulations into the algorithm, Rhinoceros (Rhino, v.5 SR4) and Grasshopper (v. 0.9.0076) were used. Rhino offers flexible expandability because it can accommodate plug-ins of various applications including Grasshopper, which is a graphics-based algorithm. As an algorithm-driven modeller, the combination of Rhino and Grasshopper is widely used by and accessible to architects and planners, especially in the early design stages (Capeluto and Plotnikov 2017). For an in-depth analysis of the areas shaded by residential buildings, GECO (v.1.0.44.0) was used to integrate Rhino/Grasshopper with Ecotect. To derive a housing layout that satisfies all design constraints defined in the algorithm, Hoopsnake (v.0.6.7) was used to generate iterations of the housing layout design in Grasshopper.

2.4. Variables

2.4.1. Building form

Based on the 2D building and site plan modelling in Rhino, Grasshopper was used to create the 3D building forms using variables, such as the number of

![Figure 4. Building height and setback for the walls with daylight windows.](image1)

![Figure 5. Separation distance between adjacent buildings on site.](image2)
apartment floors (n), height of a floor (m), positions of the wall with daylight windows, walls without daylight windows and side walls.

2.4.2. Separation between adjacent buildings
The separation between adjacent buildings was obtained by estimating the required separation distance area in relation to the building height, wall type and shaded area during the sunlight exposure hours. The related variables are the separation for the wall with daylight windows (%), separation distance for the wall without daylight windows (m) and separation distance for the sidewall (m). For the shaded area during the sunlight exposure hours, variables were the input date (month, day), starting and ending time of sunlight exposure, interval time (lapse) and shaded zone (per hour).

2.4.3. Setback from site boundaries
The setback from site boundaries is defined in three cases; the setback between the building and the site property lines to the adjacent streets and neighbouring plots (%), the setback distance for open yards from site property lines (m) and the setback for north sunlight exposure (%).

3. Algorithm development
The housing layout algorithm is based on the principle of redefining separation areas and setback distances that violate the building code restrictions. Therefore, the main procedure of the algorithm was structured around two fundamental aspects: (1) the separation between adjacent buildings and (2) the setback from site boundaries.

3.1. Algorithm for the separation between adjacent buildings
The separation area for each apartment building was generated by processing and integrating the following legal criteria, in turn; separation (1) for the wall with daylight windows, (2) for the wall without daylight windows, (3) for the side wall and (4) for the shaded area during the sunlight exposure hours. Based on the aforementioned procedure, all buildings were arranged at the site, excluding the instances in which buildings were located within the prescribed separation area.

3.1.1. Separation for the wall with daylight windows
The position of the walls with daylight windows was selected in the 2D building plan (Figure 7(a)). The separation area was projected perpendicular to the selected walls by a value obtained by the function of the building height and the separation distance ratio (Figure 7(b)). The measured separation area from around the building and the area of the 2D building footprint were combined to determine the separation area (Figure 7(c)).

3.1.2. Separation for the wall without daylight windows
The position of the walls without daylight windows was selected in the 2D building plan (Figure 8(a)). The separation area was projected perpendicular to the selected walls by a value greater than the minimum separation distance (8 m) (Figure 8(b)). The measured separation area from around the building and the area
of the 2D building footprint were combined to determine the separation area (Figure 8(c)).

3.1.3. Separation for the sidewall

The separation area for the sidewalls was configured to be smaller. Thus, instead of selecting the position of the sidewalks in the 2D building plan, a procedure projecting the separation area perpendicular to all walls was used to configure the area corresponding to the minimum separation distance for the sidewalks (4 m) (Figure 9(a)). The measured separation area from around the building and the area of the 2D building footprint were combined to determine the separation area for the sidewalks (Figure 9(b)).

3.1.4. Separation in relation to the shaded areas

The separation between buildings in relation to the shaded area was intended to generate the maximum number of housing units receiving at least two hours of sunlight between 9:00 and 15:00 on December 22 (on winter solstice date), as required by the building code. The separation area for the sunlight exposure hours was defined based on the 3D building form and the solar declination angle (Azimuth). The GECO plug-in in Grasshopper was integrated with Ecotect to analyse the shaded area per an interval hour (Figure 10(a)). The 3D solar shade simulation of the building was projected onto the ground plane with respect to the solar declination angle and the overlaps from each
interval per hour were measured (Figure 10(b)). The overlap areas were connected to generate the combined shaded area (shaded at least for two consecutive hours) (Figure 10(c)).

3.1.5. Combined layout corresponding to the separations between adjacent buildings

The overall layout corresponding to the separation between buildings was produced for all buildings...
simultaneously. The apartments were arranged reflecting the combined separation area for each building, which integrated separations for the walls with daylight windows, walls without daylight windows, side-walls and shaded areas. The completed location of each apartment falls outside the combined separation area.

Figure 11 demonstrates the layout process of each building in relation to the combined separation areas. For instance, a combined separation area was generated from around an examined building (Figure 11(a)). The combined separation area may initially include the footprint of other buildings (Figure 11(b)). To avoid others placed within the combined separation area, each building was moved away from the centre of the overlap between its footprint and the separation area. The examined building and others were moved in the opposite direction from each other to avoid others falling within the combined separation area (Figure 11(c)). Each building repeated its repositioning until the separation distance was satisfied (Figure 11(d)). Each building follows the aforementioned procedure simultaneously until all buildings meet the required separation distance from each other.

3.2. Algorithm for the setbacks from site boundaries

The procedure to determine the setbacks from site boundaries includes generation of the setback area (1) from site property lines, (2) for open yards on site and (3) for direct north sunlight exposure. Each step was applied in that order.

3.2.1. Setback from site property lines

The setback from site property lines was generated by the distance that is half of the building height in the perpendicular direction to the daylight window walls. The position of the walls with the daylight windows

Figure 11. Procedure to obtain a building layout in relation to the combined separation areas: (a) Generate the combined separation area around a building by integrating the separation areas acquired from Figures 7–10 (shaded in red); (b) Analyse the overlap (shaded in red) between the combined separation area and the footprints of buildings; (c) Move the buildings away from the centres of the overlap to avoid falling within the combined separation area; (d) Repeat (c) until all buildings meet the separation distance restriction (building footprints after relocation are indicated in bold lines); (e) Use the Grasshopper algorithm to generate the building layout by moving buildings to avoid falling within the combined separation area.
was selected in the 2D building plan (Figure 12(a)). The setback area was projected perpendicular to the selected daylight window walls by half of the building height (Figure 12(b)). The measured setback area from around the daylight window walls and the 2D building footprint area were combined to determine the completed setback area (Figure 12(c)).

### 3.2.2. Setback for open yards on site

To generate the setbacks for open yards, the setback distance equivalent to the open yard distance at the site was drawn around the building footprint (Figure 13(a,b)).

### 3.2.3. Setback for direct north sunlight exposure

The setback from the site property line to the direct north direction was generated by defining the setback distance, which is half of the building height to the direct north for buildings over 9 m in height. The position of the building footprint was selected (Figure 14(a)) and moved to the direct north by a distance greater than half of the building height (Figure 14(b)). The setback area was determined by conjoining the area from the original building footprint to the relocated building footprint in the direct north direction (Figure 14(c)).

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**Figure 12.** Procedure to generate setbacks in relation to the site property lines: (a) Select the position of the daylight window walls on the building plan (indicated in red lines); (b) Project the setback area (shaded in red) perpendicular to the selected daylight window walls by half of the building wall height; (c) Complete the setback area (shaded in red) by adding the building footprint area; (d) Use the Grasshopper algorithm to generate the setback area for the daylight window walls in relation to the site boundary.

**Figure 13.** Procedure to generate setbacks in relation to open yards on site: (a) Select the position of the building walls (shaded in red); (b) Project the setback area equivalent to the open yard distance at the site (shaded in red); (c) Use the Grasshopper algorithm to generate the setback area for open yards on site.
3.2.4. Combined layout in relation to the setbacks from site boundaries

In the algorithm, the movement of each building occurs independently; the layout is influenced by the site boundary conditions such as adjacent streets and the configuration of site property lines. Each building proceeded to be adjusted according to the objective of eliminating the setback area in non-compliance with the building code restrictions. Additionally, each building was set to move towards the centre of the site to get rid of the setback area falling beyond the site property lines; an offset area (half of the building height from the site boundaries and 2–6 m for the open yard setback depending on the local zoning ordinance) from the building footprint was measured (Figure 15(a)). A building footprint moved a distance, more than the building height, to the direct north was projected on the ground plane (Figure 15(g)). Any area extending beyond the site boundary was eliminated by moving the building towards the centre of the site. The distance of moving the building towards the centre of the site was obtained by creating a vector line between the centre of the excessive area and the centre of the site (Figure 15(b,c,h,i)). As a result, the completed building relocation satisfying the building setback restrictions was obtained (Figure 15(d,j)) by repeating the movement process indicated in Figure 15(b,c,h,i).

4. Feasibility study and discussion

4.1. Context

For the feasibility study of the proposed algorithm, three multi-family high-rise housing complexes across South Korea were selected. The case-study housings are recently built developments involving linear “—” and “L”-shaped apartments that are typical in South Korea. Each housing complex has a different number of apartment buildings, floors and residential units. The architectural design summary of the three case-study housings is presented in Table 1.

4.2. Application of algorithm

The algorithm was applied to the layout of the existing case-study housing complexes. The automated iterations of the algorithm produced a resulting layout that fulfils the building code restrictions and provides sunlight exposure in the apartments. The movement of the buildings in the Case 1 housing complex stopped at the 100th iterations, Case 2 at the 80th and Case 3 at the 100th. The comparison between the original and finalized layouts for the three case-study housings is shown in Table 2.

4.3. Simulation of sunlight exposure

The housing layout result was transmitted to Ecotect, which was set to analyse the sunlight exposure of the housing layout model per one-hour intervals between 9:00 and 15:00 on December 22 (the winter solstice) in South Korea. To measure the sunlight exposure condition in the building quantitatively, the building exterior surface area exposed to sunlight was measured based on the number of residential units (a function of the number of units per floor and the total number of total floors in the building). To analyse the change in the sunlight exposure duration in the hour before and after applying the algorithm, the number of housing
Figure 15. Procedure of obtaining the completed layout in relation to the setbacks from site boundaries: (a) Analyse the setback area in relation to the site boundary, open yard to find the excessive area (shaded in red) beyond the site property line; (g) Analyse the setback area in relation to the direct north to find the excessive area (shaded in red) beyond the site property line; (b, h) Produce a line connecting the centre of the excessive area with the centre of the site; (c), (i) Deduce a vector to move the building from the centre of the excessive area towards the centre of the site; (d, j) Move the building along the vector from steps (c and i) to eliminate the excessive area beyond the site boundaries (the relocated building footprint is indicated in bold lines); (e) Use the Grasshopper algorithm for the setback from site property lines; (f) Use the Grasshopper algorithm for the setback for open yards on site; (k) Use the Grasshopper algorithm for the setback from the direct north direction.
units exposed to sunlight per one-hour interval was counted and grouped into three sunlight exposure duration zones (short duration zone: less than 2 h; medium duration zone: 2–4 h; long duration zone: 4–6 h) as presented in Table 3.

In Case 1, after applying the algorithm, the number of units in the short duration zone, receiving less than 2 hours of sunlight, decreased by 3.3%, and the number of units in the medium duration zone, receiving 2–4 hours of sunlight, decreased by 2.62%; in comparison, the number of units in the long duration zone, receiving more than 4 hours of sunlight, increased by 5.91%, suggesting an overall improvement in the sunlight exposure conditions in the long duration zone. In Case 2, the number of units in the short duration zone decreased by 1.36%, and the number of units in the medium duration zone decreased by 4.68%; in comparison, the number of units in the long duration zone increased by 15.02%, suggesting an overall improvement of the sunlight exposure condition in the long duration zone.

Applying the proposed algorithm to three housing complexes resulted in design layouts which were in compliance with the building regulations for all three cases. Additionally, the overall sunlight exposure conditions improved for all three cases, although the extent of improvement differed depending on the size of the housing complex: The number of residential units in the short and medium sunlight exposure duration zones decreased, whereas the number of units in the long duration zone increased, for all three complexes. This indicates the overall enhancement of the sunlight reception condition in all three cases.

Considering the size of the housing complex, the housing complex units with fewer number of floors (Case 1) or of buildings (Case 2) showed a decrease in the short and medium sunlight exposure duration zones, whereas the number of units in the long duration zone increased significantly. This indicates an effective improvement in the sunlight exposure condition, as the sunlight exposure condition was

### Table 1. Design summary of the case-study housings.

| Case | Location | Floor area ratio | Building coverage | Number of buildings | Number of units | Number of floors |
|------|----------|------------------|-------------------|---------------------|----------------|-----------------|
| 1    | 1–1 Goun-dong, Sejong-si | 134% | 14% | 14 | 667 | 8F, 18F |
| 2    | Guwoll-dong, Namdong-gu, Incheon-si | 196% | 10% | 7 | 850 | 28F, 29F |
| 3    | Jangyoo-dong, Ginhae-si, Gyeongsangnam-do | 194% | 16% | 13 | 1052 | 19F–25F |
increasingly characterized by the long sunlight exposure duration zone following the application of the proposed algorithm. For the housing complex with a greater number of residential units (Case 3), the short and medium sunlight exposure duration zones decreased, whereas the number of units in the long duration zone increased slightly. However, these changes were very small, indicating that applying the algorithm had little effect on the sunlight exposure condition in this case.

5. Conclusions

The focus of this study is two-fold; first, an algorithm-based parametric design approach is provided to generate complex housing layout designs that enable sufficient sunlight exposure while conforming to the relevant building regulations. Second, the robustness of the developed algorithm is demonstrated with case studies. The proposed method expands upon previous research by focusing on the challenge of layout design for a group of high-rise apartments, with regard to the sunlight access of each, on a residential block scale. The findings from this study are as follows:

1. Application of the algorithm led to the automatic generation of complex housing layout designs that satisfied the building code restrictions of height, separation, shaded areas between adjacent buildings and setbacks from site boundaries. Therefore, as initial overall building forms and densities are conceptualized and planned, the algorithm can be effectively implemented to generate a housing layout design that meets the building regulations concerning sunlight access. Furthermore, the algorithm allows for the design experiments to be flexibly conducted by enabling the modifications of the input design.
parameters such as the building plan form and height, choice of wall types (in terms of window types), separation and setback distance and the configuration of the site property lines.

(2) The results of the housing design layout generated by the proposed algorithm was found to be effective in terms of improving the overall sunlight reception status in the residential units for all three case-study housing complexes. However, the degree of improvement differed by the size (density) of the housing complex; the smaller housing complexes with relatively fewer buildings or floors presented better results; i.e. they exhibited an increase in the number of housing units characterized by longer sunlight exposure duration hours. Additionally, the number of housing units with less than two hours of sunlight exposure were significantly reduced. Conversely, the larger housing complex with a higher building coverage ratio, more apartment buildings and more housing units presented a lesser improvement in the number of housing units that shifted towards longer sunlight exposure duration hours; additionally, the number of

| Sunlight exposure duration (h) | Original layout, n (%) | Final layout, n (%) |
|-------------------------------|------------------------|---------------------|
| Case 1                        |                        |                     |
| Short zone                    |                        |                     |
| < 1                           | 1 (0.14)               | 31 (4.26)           | 0 (0.00)           | 7 (0.96) |
| 1–2                           | 30 (4.12)              | 7 (0.96)            |
| Medium zone                   |                        |                     |
| 2–3                           | 92 (12.64)             | 134 (18.41)         | 63 (8.65)          | 115 (15.79) |
| 3–4                           | 42 (5.77)              | 52 (7.14)           |
| Long zone                     |                        |                     |
| 4–5                           | 105 (14.42)            | 563 (77.33)         | 122 (16.76)        | 606 (83.24) |
| > 5                           | 458 (62.91)            | 484 (66.48)         |
| Case 2                        |                        |                     |
| Short zone                    |                        |                     |
| < 1                           | 0 (0.00)               | 12 (1.48)           | 0 (0.00)           | 1 (0.12) |
| 1–2                           | 12 (1.48)              | 1 (0.12)            |
| Medium zone                   |                        |                     |
| 2–3                           | 110 (13.55)            | 243 (29.93)         | 62 (7.64)          | 205 (25.25) |
| 3–4                           | 133 (16.38)            | 143 (17.61)         |
| Long zone                     |                        |                     |
| 4–5                           | 73 (8.99)              | 557 (68.60)         | 98 (12.07)         | 606 (74.63) |
| > 5                           | 484 (59.61)            | 508 (62.56)         |
| Case 3                        |                        |                     |
| Short zone                    |                        |                     |
| < 1                           | 0 (0.00)               | 59 (5.48)           | 0 (0.00)           | 49 (4.55) |
| 1–2                           | 59 (5.48)              | 49 (4.55)           |
| Medium zone                   |                        |                     |
| 2–3                           | 168 (15.61)            | 325 (29.2)          | 135 (12.55)        | 316 (29.37) |
| 3–4                           | 157 (14.59)            | 181 (16.82)         |
| Long zone                     |                        |                     |
| 4–5                           | 172 (15.99)            | 692 (64.32)         | 180 (16.73)        | 711 (66.08) |
| > 5                           | 520 (48.33)            | 531 (49.35)         |
housing units with less than two hours of sunlight exposure duration hours reduced only slightly.

Based on these results, the limitations of the present study and the proposed agenda for further research are as follows:

(1) The input design parameters need to be diversified, as there are many other design criteria to consider in relationship to sunlight access for the layout design of urban residential blocks; these include the design, location, and material properties of building envelopes, including windows, facility types (i.e., commercial building, school, kindergarten, etc.), outdoor spaces (i.e., road, playground, garden, park, etc.), forms and locations of neighbouring buildings, etc. However, here such parameters are not included and the design results are based on the automated generation of the housing layout design controlled by the prescribed input values that are based solely on the legal building regulations pertaining to sunlight access. Hence, it is worthwhile to expand the design input parameters to include real-world requirements and produce more comprehensive design outcomes.

(2) The feasibility of the algorithm needs to be verified further by using a bigger pool of housing and site samples in the case study; housing samples can be selected based on the morphologies of different floorplan types, housing types such as low-rise walk-ups vs. high-rise apartments, and layout configuration types such as linear vs. courtyard housing, etc. Additionally, diverse site samples can be selected, such as low-density vs. high density block, singular-use block vs. mixed-use block, etc. As such, the versatility and effectiveness of the algorithm can be further enhanced to accommodate the housing layout design, with regard to its sunlight access, for a wide range of residential building types and block configurations.

(3) In the continuing development of the algorithm, the integration of modelling, simulation and evaluation of environmental performance needs to be seamlessly conducted with the help of other computational tools (i.e. Ladybug and Honeybee tools) and to provide 3D visualization of environmental simulation and data transfer between simulation engines in Grasshopper (Sadeghipour Roudsari and Pak 2013). Additionally, the optimization process of design outcomes needs to be further articulated by utilizing other computational approaches (i.e. generative algorithms) that facilitate an evolutionary process to identify the most fitted outcomes based on the objective performance values set by the designer (Caldas and Norford 2002). Furthermore, a set of multiple possible optimum solutions can be provided enabling designers to choose the preferred trade-off among them (Capeluto and Plotnikov 2017; Vieringer 2019). However, such capabilities are limited in the algorithm proposed herein. Therefore, conducting housing layout design investigations based on such computational approaches may enhance the feasibility involved in integrating the proposed algorithm into the design process, while also allowing opportunities for design selection based on the designers’ discretion.

To bridge the gap between research and practice, the presented findings are expected to provide a useful and accessible method for architects and planners to easily conduct design exploration, as well as to accommodate the complexity involved in the process of housing layout design in large-scale residential projects. This may also inform a sustainable approach for decision-making in the practice of housing design and planning.

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