Sustainable Housing Typologies - Planning and Development for Sustainable High Density Living: High Density Threshold Studies

The objectives of this research project are as follows:

- To develop a knowledge base of methods and standards relating to sustainable high density urban development through a literature review and case studies;

- To discern the relationships between density and environmental performance, and in the process, derive a range of optimal density parameters that can be tested in Singapore, and that can potentially be applied to other dense Asian cities;

- To study how high density living can be effectively integrated with micro-climatic responses particularly relating to use of natural light and ventilation, urban greenery, planning of urban spaces, and more sustainable transport systems, efficient resource use and recovery, to reduce overall environmental impacts while achieving highly livable environments.

Research Approach

The study is guided by a systematic research process that is composed of six components, namely, literature review, typology studies, environmental variable studies, environmental simulation using computational simulation tools, a high density living perception survey, and finally, design explorations where hypothetical design scenarios are evaluated to discern how various density and design options could affect environmental performance.

This is an empirical study. A total of 92 case studies were collected internationally and locally, representing a diverse range of relatively high density housing typologies, and the analysis was undertaken in the scale of the urban block or precinct. The study focuses on analyzing the environmental performance for building facades and un-built ground open spaces of the urban blocks/precincts.

Examples of the urban form/precinct cases as collected and modeled (Gross FAR (gFAR) and Net FAR (nFAR) are calculated based on remodeled urban form)
The spatial context within which a given case is situated is usually varied, so it is not appropriate to compare the environmental performance across different cases. Hence, for this study, we formulated the concept of a "theoretically homogenous context" by using a normalization process which sets the typology at the center of a 3 x 3 grid layout composed of the same form, and use this to analyze the “theoretical environmental performance”. This theoretical performance refers to the potential of the typology to perform in a context comprising similar built forms.

Through literature review, the key environmental variables identified for this study are daylight, insolation, sky exposure and wind flow. These variables are chosen as they may affect the thermal and energy consumption performance of buildings, as well as the physiological comfort and psychological wellbeing of people, and could potentially impact a city’s urban heat island profile and air pollution dispersion.

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<th>Implications</th>
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<th>Daylight</th>
<th>Solar Radiation</th>
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These environmental variables are analyzed against various geometric variables, including the Built Density (as indicated by Floor Area Ratio or FAR), site coverage, Open Space Ratio, Area-to-Perimeter Ratio (as an indicator of building depth), Compacity (as the ratio between building envelop area and building volume), Convolution Index (which is an indicator of the degree of convolution of a given built form, Average Building Height, Frontal Area Index and Permeability.

In parallel to the computer simulation study, a residential perception survey was conducted in three high density residential precincts in Singapore, namely Punggol, Toa Payoh and Bukit Panjang. The study includes detailed walkthrough Interviews, a questionnaire-based mass survey (of 1200 residents) and a focus group discussion. The purpose is to gain a better understanding of Singapore residents’ perception towards the performance of the physical environment of high
density neighborhood as well as how physical and social-economic factors could affect the residents’ perceptions.

### Key Research Findings

1. **The relationship between density and environmental performance**
   
The correlation analysis between density and environmental performance for the 92 cases shows that density is negatively and significantly associated with environmental performance in terms of daylight availability and sky exposure, whereas it is positively associated with performance in other areas such as solar radiation heat gain. These findings highlight that decision-makers need to be aware of the important implications for environmental quality and the potentially negative impacts to concerns such as energy consumption when increasing development density. Nonetheless, the impacts can be mitigated by manipulation of the various geometric variables, as shown below.
2. The relationship between urban form and environmental performance

The research affirms the significant relationship between urban form and environmental performance. Specifically, the findings suggest geometric variables such as site coverage, Open Space Ratio, Area-to-Perimeter-Ratio, average building height, Frontal Area Index, and permeability, could significantly affect environmental performances. Specifically,

- For facade sky exposure performance, it is found that average Area-to-perimeter Ratio (APR) and average building height are negatively correlated with the performance indicator, whereas Open Space Ratio (OSR) is positively correlated with the performance indicator.

Relationship between geometric variables and façade sky exposure performance indicator

- For view-weighted facade sky exposure performance, it is found that average Area-to-perimeter Ratio (APR) and site coverage are negatively correlated with the performance indicator, whereas Open Space Ratio (OSR) is positively correlated with the performance indicator.

Relationship between geometric variables and view-weighted façade sky exposure performance indicator
• For ground sky exposure performance, it is found that average site coverage is negatively correlated with this performance indicator, whereas Open Space Ratio (OSR) is positively correlated with it.

Relationship between geometric variables and ground sky exposure performance indicator

• For daylight performance, it is found that average Area-to-perimeter Ratio (APR) and average building height are negatively correlated with the performance indicator, whereas Open Space Ratio (OSR) is positively correlated with the performance indicator.

Relationship between geometric variables and façade daylight performance indicator
• For insolation performance, it is found that average Area-to-perimeter Ratio (APR) and average building height are negatively correlated with the performance indicator, whereas Open Space Ratio (OSR) is positively correlated with the performance indicator.

Relationship between geometric variables and façade insolation performance indicator

• For ground level wind performance, it is found that area-weighted average wind velocity is positively correlated to permeability (measured for the range from the ground up to 4m above ground) and average floors, and negatively correlated to Frontal Area Index (measured for the range from the ground up to 4m above ground) and site coverage.

Relationship between geometric variables and ground level wind performance indicators
The results provided a good understanding of the relationship between environmental performance and geometric variables, such that planners and urban designers can use this understanding to work out different combinations of geometric variables for a given urban form in order to optimize its environmental performance. At certain desired densities, relevant geometric variables can be adjusted in order that environmental performance is not compromised.

3. **Multi-dimensional nature of urban environmental performance**

The multi-dimensional nature of the urban environmental performance and the difference in terms of the relationship between density and each of the performance domains as revealed in this research highlights the challenges in seeking to derive a range of optimal density. Hence, while the research did not specifically derive a range of optimal density, it establishes the important relationships between density, geometric variables and performance indicators. It applied Pareto Ranking Analysis to the case database to identify the cases that achieve relatively better balance in the various multi-dimensional optimization objectives. The overall results were able to rank the cases based on their ability to achieve the most optimum outcome between density and a desired environmental parameter. Bi-variant Pareto ranking studies to identify the range of performance outcomes for a given environmental variable within specified density bands also enables the diversity of building, urban forms and their geometric properties to be further studied for potential application in design exploration within the targeted density range.

![](image)

Bi-variant Pareto ranking

4. **Perceptions towards the physical and social environment of high density neighborhood**

The perception survey as a complement to the computer simulation studies shows that all the key environmental variables considered in this study are rated highly by the survey respondents, with air movement being the primary concern, followed by temperature, daylight, odours, humidity, noise and view to sky. The high perceived importance as assigned by the respondents to these environmental variables indicates that HDB residents do care about the environmental quality of their neighborhood. This affirms that importance of performance...
optimization in the planning and design process for high density residential neighborhood. On the whole, strong negative ratings are absent, which suggests that the physical environmental quality is generally regarded as acceptable to most of the respondents.

Importance of environmental aspects as perceived by HDB residents

There are some indications of slightly negative satisfaction ratings pertaining to temperature, humidity, air movement and daylight condition, which vary across the towns studied, the flat size and storey level of the apartment, age and years of residency of the respondents.

The implications from the survey are that 1) the environmental qualities may have significant impact on residents’ satisfaction, and design interventions at planning and urban design stage may serve as effective strategies to improve these environmental performances, and 2) attention should be paid to the specific needs or expectations from some of the user groups.

5. Relationship between simulated environmental performance and perceived environmental quality

From the research, we did not find significant correlation between the simulated environmental outcomes and the subjectively perceived environmental quality of the housing precincts. This could be due to two reasons. First, the limited scale of the survey could have resulted in insufficient variation to potential responses. Second, it also shows that there are many other factors that could affect people’s perception of their environment apart from those parameters included in this research. The same physical context with the same objective environmental conditions could be perceived differently by different people as they may relate to people’s socio-economic and cultural background, their previous and present experiences, expectations, prices paid for the apartments, all of which are beyond the scope of the current study.

6. Perceived qualities of the social environment

The survey also provided the opportunity to explore local residents’ perception towards the social environment, to seek a better understanding of the relationship between high density and issues such as social interaction, perceptions of safety, amenities, etc. Overall, respondent are satisfied with the quality of neighborhood facilities and feel that their neighborhoods are safe and most residents agreed that physical improvements could help
them meet their neighbors more, with the three top physical improvements suggested being recreational, retail and community spaces.

Other Research Outputs and Contributions
Apart from the above findings, the research has yielded other outputs in terms of concepts and tools, the most significant of which are:

- The simulation tool which is a customized Integrated Simulation Platform that combines different software for parametric modeling and simulation visualization. It encompasses a detailed workflow which will enable researchers and designers to conduct performance-optimization exploration by testing different urban form typologies or their combinations in a given design scenario in efficient and reliable manner. The usefulness of this tool to support performance-based planning and design exploration is demonstrated by applying it to evaluate potential environmental performance for different generic urban forms in a given context, such as in the Marina Bay project.

- The database of 92 case studies constitutes a comprehensive database of current design approaches to achieving high density housing precincts. It documents fully the key planning, design, geometric variables and the environmental performance for all the selected cases. It is thus an extensive reference and knowledge base to support planners and designers’ work when they are exploring design possibilities to attain particular density and environmental outcomes. It is also useful for comparative studies of environmental performance across different urban forms. This database is included as part of the final report of this research.
Conclusion

This research has developed an extensive knowledge base of concepts and methods relating to environmental performance of high density urban development. To our knowledge, this is the most comprehensive empirical research that discerns the multi-dimensional relationship between density and environmental performance. There is some scope for further research relating to density threshold development, additional environmental parameters and linkages to prevalent CAD software.

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