A BIOCLIMATIC APPROACH TO THE INTEGRATED DESIGN OF TRANSIT STATIONS AND THEIR IMMEDIATE SURROUNDINGS

EXECUTIVE SUMMARY

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Executive summary of thesis

Objective

This thesis identifies and illustrates the potential contributions of good climate-responsive design to a rapid-transit rail system under construction in San Juan, Puerto Rico. It focuses on the application of climate responsive design guidelines to the design of stations and their immediate surroundings. The objective of doing so is to maximize the benefits to the owner, operator and users of Tren Urbano, a 12 mile-long rapid transit rail system.

1. Introduction

The introduction states my motivations for carrying forward the research and the methodology employed. The most important amongst my motivations are:

- **Economic:** Application of climate responsive design guidelines will make the stations and the system comfortable, leading to increased ridership and perception of safety. Puerto Rico imports all of its cars and energy. Studies have shown that street design and layout can play a critical role in improving pedestrian access to stations and reducing car dependency. Experimental monitoring of climate responsive buildings has shown energy savings in the order of 20%.

- **Environmental:** There are considerable environmental problems in the San Juan Metropolitan area. Most notably among them: heat island effect, pollution and deforestation. The current transportation network relies heavily on the private automobile. Capacity expansion comes at the expense of vegetation, which contributes enormously to create comfortable outdoor conditions. Predominance of automobiles requires large areas of asphalt surfaces. These surfaces create microclimates that feed a cycle: air conditioning is necessary to offset outdoor conditions yet air conditioning worsens outdoor conditions.

- **Educational:** Dissemination is critical for climate responsive design to become accepted in the architecture and engineering disciplines. This should be done by incorporating the concepts of climate responsive design into the architecture/engineering curricula and course offerings in architecture and engineering associations as well as into building and planning codes.

- **Opportunity cost:** if access to stations is not given due importance, a double opportunity will have been lost: to revert the negative connotation of public transportation in San Juan, with its potential increase in ridership, and to design in a manner that uses natural resources responsibly.

Methodology. The methodology of the thesis is as follows:

- Literature review: reviewed the main sources on climate responsive design and their contributions to the discipline.
- Climatic analysis: conducted an analysis of San Juan's climate. To better illustrate how to extract information from the climatic analysis, San Juan's climate is compared to that of another location, Mexico City.
- Identification of site-specific variations: impact of such variables as altitude, orientation of alignment, vegetation, topography, distance from sea, and urban/rural location upon climate responsive design.
- Identification of station specific characteristics: analysis of stations' components and their contributions or conflicts with respect to climate responsive design.
- Identification of guidelines: specific recommendations for three different scales of the design process: site planning, building design and design of building components.
- Identification of conflicts: obstacles, conflicts and barriers for implementation are identified.

These steps roughly reflect the content of each chapter of the thesis.

2. Definitions, literature review, history and overview of Tren Urbano.

Chapter two introduces the definitions that will be used throughout the thesis. It also highlights the principal contributions to the literature on climate-responsive design. This is followed by a brief overview of the history and policy-climate that gave birth to environmental/climate-responsive design. The chapter ends with a description of the Tren Urbano project.

3. Climate analysis

The objective of chapter three is to identify the appropriate climate-responsive design strategies that apply to a location[1]. The chapter begins with a discussion on comfort, the factors that affect it and attempts to measure it. Following this, a classification of tropical climates is presented in order to put San Juan's climate into context. To illustrate how to extract information from the climate analysis, San Juan's climate is compared to Mexico City's climate. San Juan is classified as a warm humid island climate and Mexico City is a tropical upland composite climate.

This is followed by a discussion about the basic climatic indicators necessary to analyze a climate. The four main indicators are temperature, humidity, winds and precipitation. Charts and graphs guide through the process of recording the climatic indicators and how some conclusions can be quickly drawn from them.

The chapter ends by identifying the appropriate climate-responsive strategies, which emerge out of the climatic analysis, and a discussion on their limits of applicability. The basic strategies for San Juan are cross ventilation and solar protection, whereas for Mexico a mix of solar gain, thermal mass and selective ventilation is necessary.

4. Geometric relationships and thermal properties

Chapter four introduces the basic geometric and physical principles that govern the relationship between climate and buildings. These include:

- Relationship between the earth and the sun and its influence on design: impact of latitude on solar radiation and angles of solar incidence.
- Wind geometry relationships and wind control/capture techniques and principles: distances between buildings, openings, height and how all these shape outdoor and indoor air movement.
- Noise geometry and control techniques.
- Causes, geometry and control of glare.

[1] A design strategy is a general principle that guides the design process such as ventilation or solar gain.

- Thermal properties of building materials and their implications for design: absorption, heat gain factor, conduction and delay of heat transfer are the main properties.

This chapter is a compilation of generic concepts not related specifically to San Juan. Methods for quick solar and wind verifications of design proposals are presented at the end.

5. Microclimatic, site-specific and train-specific variations

Chapter five addresses how different climatic, site-specific and transit station-specific conditions along the transit system in San Juan affect the design of stations. The objective of this is to make the guidelines in the following chapter, which are derived for the San Juan Metropolitan region in general, applicable to all of the stations along the alignment. The chapter begins by analyzing train stations' components and train operations in order to identify the impact of station configuration and station type on climate responsive design. Then, the effect of microclimatic variables of a site upon design is considered.

- **Train specific**

Central vs. side platform configurations: Central platform stations dissipate heat and noise better than in side platform stations because one side of the train faces the outside air. For the same reason, side platform stations can control noise to the outside better than central platform stations. In central platform configurations passengers are concentrated making it easier to provide comfort. Central platform stations create less visual impact on surroundings as stairs can be concentrated and hidden from view, whereas in side platforms, stairs normally protrude from the building.

Elevated, at grade or underground configurations: Elevated stations capture wind easier, yet are more intrusive in terms of visual and noise impact. At grade stations, especially stations in trenches need special configurations to capture wind: intermediate wind-exposed platforms, wind-deflecting mechanisms are some options to capture wind. Underground stations may justify using trainscreens to avoid escape of cold air and for safety.

Specific components: a table is presented with all the components of a station separated into entrance/lobby areas, platform areas and access/modal transfer areas. Their potential contributions to climate responsive design and each component's degree of flexibility are identified.

- **Site specific variables:**

Urban/rural location: affects temperatures. In warm humid climates it is usually some degrees colder in rural or suburban locations than in downtown built up areas especially where there is a lot of asphalt surfaces.

Altitude: altitude affects the amount of radiation received by a surface. At the same time temperatures drop at higher altitudes. Therefore, all else being equal, a higher altitude will imply a larger temperature range.

Distance from sea: sea bodies moderate temperature ranges. Differences in heat gain/loss rate between the earth and the water generate sea breezes in the morning and land breezes at night.

Topography: hills can create microclimates, changes in wind patterns and large changes in rainfall within short distances. In San Juan, at the airport there is a recorded average of 55-60 inches per year, and at nearby El Yunque annual average rainfall is above 200 inches.

Ground cover: the natural cover of a terrain tends to moderate extreme temperatures and stabilize conditions. Plant and grassy cover reduces temperatures and while other vegetation may still further reduce them, cities and man-made surfaces tend to elevate temperatures and reduce humidity.

Orientation of alignment: affects the amount of shade in the areas below the guideway and the design of sun protection devices.

6. Design guidelines

Chapter six describes how the design strategies identified in chapter three translate into specific design decisions. The chapter adopts a design-guideline format and illustrates the implication of each guideline upon design decisions with the aid of graphic representation.

First, a discussion of the design variables and their relevance for design, from a climatic point of view, is presented. Then, guidelines are presented for variables at three different scales in the design process for both San Juan and Mexico City: site planning, building design, and design of building components.

Lastly a step by step illustration of the application of the guidelines is presented. Using one station in the system, Hato Rey Centro, the same three scales of the design process are comparatively addressed for both climates. Table 1 presents a summary of the design guidelines for both climates at each of the three scales.

Table 1.

Design scale	Variable	San Juan	Mexico City
Site planning	**Topography**	• On northern or southern slopes • Windward slope of hills • Towards crest of hill	• in lower to middle part of hill • southern slope
	Orientation	• orient site and development to capture wind protect from sun	• south facing slope ⇒ benefit from winter sun • selective capture of wind
	Relationship between buildings	• scattered • staggered	• semi-compact ⇒ avoid excessive wind penetration in winter
Building Design	**Shape**	• elongated and narrow, 1:3	• semi-compact, patio house
	Surface-to-volume ratio	• maximum ⇒ maximize exposed surface so building can breathe	• average ⇒ allow for both types of seasons: allow building to breathe in summer and capture in winter
	Height	• medium ⇒ avoid excessive exposure to sun • detached from ground to capture winds	• can use ground for thermal inertia.
	Orientation	• oriented for wind • avoid west and to some extent east • long axis east-west	• oriented to capture sun • must be controllable in summer • avoid west
	Depth	• minimal ⇒ allow cross-ventilation • single banked buildings	• more compact than San Juan • capture sun and avoid its escape in winter • double banked building arrangement

Building Components	**Walls**	• light weight materials • some insulation	• materials with some heat storage capacity (thermal mass)
	Openings	• large and protected • on opposite facades • louvers and brise-soleil protect	• oriented to south (for north hemisphere) avoid overheating from west in summer • mid-sized ⇒ control ventilation
	Roofs	• pitched • insulated • lightweight materials	• can be flat ⇒ avoid concrete due to expansions • insulated
	Materials	• lightweight, • reflective ⇒ light colored materials no thermal mass nor time lag	• some absorption necessary • moderate time lag and thermal mass
	Vegetation	• canopy effect ⇒ tall with permeable foliage • evergreen ⇒ protect west • avoid wind blocking shrubs	• deciduous, moderate foliage density

7. Constraints/conflicts/obstacles

This chapter identifies the potential problems, obstacles, constraints and conflicts that stand in the way of implementing the design guidelines drawn in the previous chapters and suggests ways of overcoming these.

There are two main categories of obstacles: those internal to the climate-responsive guidelines and those related to institutional/implementation conflicts.

- **Internal to design guidelines:**

Driving rain (need to protect from horizontal rain) - wind capture (need to capture to fullest extent possible): requires the use of special shading devices that keep the rain out and deflect the air flow back to human level.

Optimal orientation for solar protection (N-S) – optimal orientation for wind capture (NE-SE): compromise solution to maximize both variables. Each case should be analyzed particularly to identify the critical conditions that should determine weights in the compromise solution.

Use of vegetation for solar protection (dense foliage) – wind penetration (no obstructions): use of tall, thin vegetation that produces a canopy effect without obstructing the wind.

Noise protection - wind capture: selective use and location of absorptive materials that reduce noise impacts and do not obstruct air movement.

Daylight - rain and sun protection: reduce view angles to avoid glare using galleries, overhangs and intermediate spaces.

Site development constraints: surrounding structures may obstruct winds. Use of wind-deflecting mechanisms, both horizontally and vertically.

- **Institutional/implementation**

Implementation of design guidelines is a complex issue. Many hurdles must be overcome for effective implementation. Some of the most commonly mentioned problems in implementation are lack of institutional capacity to implement, inadequate incentives, politicization of guideline management/evaluation. This is an area for future study, especially given the unique contractual arrangement under which Tren Urbano is being built. I discuss three possible directions: an incentive-based mechanism for motivating guideline compliance, a mandatory and gradually more stringent implementation scenario and the inclusion of climate responsive design in architecture curricula.

8. Conclusions

This thesis described the concept of climate-responsive design, its methodology and framework. It also identified design guidelines and various reasons for which their application can be of particular interest and use in the context of transit station design and design of immediate surroundings in a warm-humid island climate such as San Juan's. The main reasons are:

- the natural shape of stations, which is long and narrow, allows the building not to store heat.
- the fact that many of the stations will be elevated, favoring wind capture.
- the climatic conditions throughout the year are relatively comfortable.
- the potential for a city like San Juan, where climate responsive design is not disseminated

and where there is considerable ground for improvement.

- the immediate need to address environmental problems in a city increasingly congested.
- potential cost savings: all autos and energy are imported in Puerto Rico.

The thesis also identified certain hurdles that must be overcome for these recommendations to be implemented. Two sets of hurdles were identified: internal conflicts within design guidelines and implementation/institutional/social obstacles.

The first set can be dealt with using discretion in making design decisions: when conflicts internal to guidelines arise, the designer should weigh all the indicators and variables to come up with a compromise solution as was shown in previous chapters. This is not a hurdle yet: there is no widespread dissemination of climate-responsive design and therefore these conflicts, which require greater study, still need to be identified and refined in practice.

Institutional hurdles can be seen at two levels. In the short run, the issue is to implement guidelines for the Tren Urbano project extensions. This presents challenges due to the unique contractual arrangement employed for the construction of Tren Urbano. Who should enforce? Who should set standards? Or should standards be set? Should there be an incentive-based system in order to motivate designers to consider climate?

In the long run, the practice of climate-responsive design should be required for all major infrastructure and design projects. There are various options for doing this. Initially standards may be set low to gradually build them up as the architecture and engineering professions incorporate the concepts into their curricula and a pool of qualified designers can practice and evaluate design proposals. Dissemination in school and professional organizations is a necessary step. Gradual incorporation of climate responsive-design concepts into building and planning codes is also a necessary step.

Yet, from the author's perspective, the single most important hurdle is social acceptance. Recent urban expansion in San Juan has followed a single-family, low-density suburban pattern so predominant in many urban areas in the United States. Coupled with a considerable shortage of public transportation, this has created a dependence on private automobiles, which has created important environmental problems. Congestion is out of control and road expansion has come at the expense of natural resources. Incorporation of design guidelines alone is unlikely to radically modify the way the city grows. Accompanying policy changes that promote and/or mandate energy efficiency will also be necessary. Puerto Rico must take advantage of the challenges and opportunities offered by the construction of this major transportation investment.

Future research

- Analyze/survey conditions around stations in the extensions of Tren Urbano. Would refine knowledge of conditions and make design of stations more responsive to specific microclimatic conditions.
- Research on implementation strategies: how does the existing contractual arrangement facilitate or conflict with implementation? What are the right incentives and who would be in charge of enforcement? How does this affect the future operation arrangements of Tren Urbano? What needs to be done for more widespread inclusion of these concepts in design and engineering disciplines?
- Produce examples of application of guidelines in university exercises. Incorporation of literature into the architecture curriculum.