Linking urban scenarios with energy simulations for dense urban planning under climate change

J Felkner¹*, B Marshall¹, S Richter¹, E Mbata² S Zigmund¹, Z Nagy²

¹School of Architecture, The University of Texas at Austin, Austin, TX 78712, USA
²Cockrell School of Engineering, The University of Texas at Austin, Austin TX 78712, USA

* juliana.felkner@austin.utexas.edu

Abstract
This research aims at linking Urban Planning, Energy Simulations and Climate Change projections into the year 2100 for hot climates. The workflow of going back and forth between urban and city scale plans and individual neighborhood parcels to building scale, for the sake of simulating energy demand for a given city into the future is complex. It is prone to rely on many assumptions and simplifications in order to aid the simulations. In this work, we streamline the process with new computational tools, with the goal of communicating a more precise impact of building scale and neighborhood morphological scale design and retrofit strategies in order to meet energy reduction and carbon emission targets focusing on 2030, 2050 and 2100. Urban scenarios are developed using Envision Tomorrow. The building archetypes used therein are associated with energy demand profiles which we simulate using EnergyPlus for various climate change scenarios to improve the forecasting ability of Envision Tomorrow. Denser developments yield far lower neighborhood energy use.

1. Introduction
Scenario planning refers to a set of techniques, methods, and strategies used to represent and assess different perspectives of plausible or possible futures [1]. Its primary value is its function as a heuristic device to identify and explore key assumptions, decisions, and impacts of how the future might unfold [2]. Additionally, its ability to bridge different epistemological approaches (e.g. quantitative and qualitative), stimulate collaboration, and motivate learning have made it an important technique for interdisciplinary studies required of climate change adaptation research and practice [3]. While there are many kinds of scenarios, they mostly conform to three basic typologies: predictive, normative, and exploratory [4]. Scenario planning is used here to explore the potential energetic impacts associated with changing urban morphology [5]. We use a scenario planning tool, Envision Tomorrow, to construct a reference case scenario that reflects current reality, as well as alternative high density and low density case morphological scenarios [6]. Future scenarios can combine assumptions about operational and embodied energy, as well as per capita energy use as a key metric [7], along with the transportation behavior associated with land-use patterns [8,9]. In addition to our reference case scenario based on existing land use and zoning regulations, the low density scenario envisions a “sprawl” future with redevelopment indicative of auto dependent urban patterns and consisting primarily of large single family homes and low density commercial land uses [7]. Finally, a high density scenario envisions a future supported by transit with high intensity, multi-story residential and commercial buildings along major streets and a reliance on multi-family redevelopment. Our results simulate total building energy use for a single neighborhood.
2. Methods
The study area is Montopolis, a neighborhood in Austin expected to undergo major changes to building morphology due to (re)development by the target year of 2100. The study uses a parcel-level dataset of the City of Austin (Texas) including address, current zoning and land use class, year of structure construction, and assessed property value. The dataset includes an improvement-to-land (ILR) ratio, which is a measure of the economic potential of a property [10]. We assume that all buildings will be developed by 2100 only once to assess the impact of morphology on future energy use. We evaluate the area based on per capita square footage. Parcels were initially classified based on their current land use and location and combined into three classes, representing similar energetic patterns for given building morphologies: small residential, large residential, commercial/mixed-use. Similarly, three categories to account for location were identified: along a major traffic corridor, within an identified transit-oriented development (TOD) area, or within the interior of the neighborhood. Major corridors and TOD areas were determined by the Imagine Austin Comprehensive Plan, which specially identified the locations as preferred “activity corridors” and “centers” for future growth [11].

We use Envision Tomorrow (ET) [6] to generate scenarios. ET utilizes a set of linked MS Excel spreadsheets with an ArcGIS extension to enable parcel-level land development to be mapped over existing neighborhood geographies, generating demographic, economic, transportation, and energy outputs. The software has two components, a “Prototype Builder” and “Scenario Builder”. The Prototype Builder uses basic spatial and financial requirements to create spreadsheet models of individual building types: from a single-family home to a multi-story mixed use building. This project created 25 residential and commercial buildings. These building types are loaded into the Scenario Builder spreadsheet which incorporates assumptions about streets, green space, and other public spaces to generate “development types”. For this project each building is used as a stand-alone development type. The Scenario Builder, via an extension, links to ArcMap where these development types are assigned to existing parcels in each neighborhood. Through ET’s Excel-based architecture, we build a redevelopment schedule into the dataset to explore the process of land use changes by decade. The redevelopment schedule is the percentage of parcels in the neighborhood considered to redevelop over the course of each decade from 2020 to the target year of 2100. Montopolis has large, undeveloped portions, and therefore a great percentage of parcel redevelopment occurs quickly. The redevelopment schedule implemented through a redevelopment rank determined by the ILR and broken out by the three locations (interior, corridor, TOD). The lowest ILR in each location is assigned the highest rank for each use class. Redevelopment is implemented using the percentage of all parcel land use ordered by max rank by decade. Of the 1,914 “small residential” parcels in Montopolis, 15% were scheduled to redevelop in the first decade, the model thus assigned redevelopment (an increased intensity of use) to the 287 parcels classed as “small residential” with lowest ILR. The specific type of redevelopment was assigned using parcel size and location as the factors limiting potential land use intensity. The combination of ET with the above redevelopment schedule enables multiple pathways for redevelopment depending on land use class and parcel location.

We constructed 25 residential and commercial building model types for energy modelling using Rhino 6. Analysis was completed using the plugin Grasshopper. Running the energy analysis was done through the Design Iterate Validate Adapt (DIVA) plugin developed by Solemma LLC, using the EnergyPlus solver which is open source and funded by the Department of Energy’s (DOE) Building Technology Office [12]. Using this set of programs, the 25 buildings were modelled and analyzed using inputs from the following categories: ET Inputs, construction type, occupancy schedules, climate change predictive weather files, and population.

The building types chosen were: Duplex, 4 Plex, 8 Plex, Townhome Low, Medium, and High Density, Small Single Family 1-4, Medium Single Family 1-2, Large Single Family 1-3, Cottage, Mobile Home, Multi-Family Housing 2,3,5 stories, Multi-Use 2,3,5,8 stories, Large format retail.

The floor areas given were divided by a width of 7.6 m, except for a few cases where drawings were found that detailed another width. Using the length provided by the square footage from ET and the width of 7.6 m, the building footprint was found. A height of 3 m was given for each residential building
not counting the roof structure and a height of 6.1 m was given for the commercial buildings. The stories for each building were given by the file type from ET (ex. Multi-Use Residential 5 Story) or they were provided in the building outputs information from the program. The “build out” option from ET determines the amount of the building mass that is coplanar versus the amount that goes beyond the building plane (balconies, porches, and other extrusions). For the purposes of this study, a 100% build out was chosen which assumes the buildings are all co-planar with no overhangs or extrusions. The last shape decision that was made concerning the buildings was to make different versions of the buildings that were not strictly an extrusion of the length and width.

The next variable that was determined to be a driver for this study is the construction type of the buildings. During a previous study [13], series of wall sections were constructed for the purpose of energy analysis. These wall sections were compiled based on the building codes for the 1980s, 1990s, and 2000s. A 1990s wood framed wall was assumed to be the construction type for these buildings because of the prevalence of wood frame construction in Austin. The window type selected was a double pane clear window. The window to wall ratios for the buildings were a visual best guess. Schedules of occupancy were determined in a few ways. The first was to use the residential occupancy option built into DIVA. The second was a series of occupancies that were estimated based on the assumption that the building occupants were either staying home or leaving for work. The last version of the occupancy schedule was based upon the American Time Use Survey (Bureau of Labor Statistics). The Management and Service categories of the AMUS Table A-4 were averaged [14]. To simplify the data it was assumed that times spent not at work was time spent at home. These values were converted into a 0-1 scale and placed in DIVA’s schedule builder. The most recent data for the report were generated using this data.

Weather is at the center of this study. Since the study is about a changing Austin throughout time, one of the biggest factors that changes how much energy buildings use are the weather variables. We use weather data from Meteonorm, which estimates its data from mathematical models that are based on the International Panel of Climate Change (IPCC) emissions scenarios A1b. These weather files were generated for each decade from 2010 to 2100. We explore 2030, 2050 and 2100 in depth.

The last major area of input was the building occupancy. Two separate methods were used to determine the occupancy of the buildings. The first method was to use the DIVA population calculation tool which is based on the floor area of the building. After using this method it was determined that it biases the floor area of the building when calculating energy usage. The second method was to assume a certain number of occupants per dwelling based on the American Time Use Survey, in order to make DIVA’s population calculator tool reflect that number of people per dwelling. It is currently set at 2.5 people per dwelling unit. This method ends the area bias for calculations, however it now biases the smallest dwellings as the most energy efficient since a studio apartment is also assumed to have 2.5 people in it. These different variables all feed into the DIVA plugin to the Grasshopper extension of Rhino 6. With the current variables that can be selected, this will allow 2,940 different iterations of each of the 25 buildings. Assumptions have been made to prioritize different variables at this point. Our current outputs are to MS Excel where the data is post processed or straight to EnergyPlus where those files can be used by other compatible programs such as CityLearn. Figure 1 shows the combination of climate, building type and construction and occupancy for energy modeling.
3. Results

Based on development scenarios considering high and low density cases (Figure 2), energy consumption for Montopolis is significantly decreased starting at 2030, with increasing relative energy savings for high density, dense development scenario into 2100, even with changing climate (Figure 3). The scenarios were designed to account for multi-family housing along major transit lines for the high density scenario, and business as usual where mass-transit is seldom used, for the low density scenario.

**Figure 1:** Modelling impact of climate, building type, construction and occupancy on energy use

**Figure 2:** Per capita building floor area for high and low density scenarios (10 ft² ≈ 1 m²)
Figure 3: Average energy usage/building, high density vs. low density with the A1b climate scenario

From 2030 to 2050 and finally to 2100, total energy use per total building in the high density development is considerably lower than in lower density “worst case” development (Figure 3). We can also observe a higher change of average energy use before 2050 compared to after 2050. We speculate that this is the result of the changed interplay between the transformation of the building stock and the impact of climate change. Since there is only three datapoints (2030, 2050 and 2100) more research is needed to investigate this further.

4. Conclusion

This framework innovates by developing a methodology that links spatial planning (zoning policy) with parcel scale resolution for the energy demand under climate change, as well as a model for forecasting transformation of these parcels, e.g., from single to multi-family homes over the course of decades until 2100 including retrofit scenarios. This will allow for future study and implementation in terms of how individual buildings on these parcels, i.e., their inhabitants, make decisions to adopt certain energy systems. It further reveals the great extent to which denser urban development reduces building energy consumption at the neighborhood scale.

5. References

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