Engineering-Based Methods for Affordable Housing and Sustainable Community Development

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I. Introduction

Housing is a key component of the U.S. economy: in 2001, housing comprised more than a third of the nation's tangible assets, and, in the form of home building and remodeling, housing consumption and related spending represented more than 21 percent of the U.S. gross domestic product. Since 2001, home sales, prices, equity and debt have all grown substantially, enabling millions of Americans to purchase ever-greater amounts of goods and services (Joint Center for Housing Studies 2006).

Housing that is decent-quality and affordable (generally defined as consuming less than 30% of a family's income) enables families to better enjoy a variety of life outcomes, such as family stability, good health, employment, education and recreation. Decent and affordable housing also contributes to the improved physical, economic, environmental and social health—the *sustainability*—of communities (Millenial Housing Commission 2002). These impacts are especially important for lower-income households and other underserved populations.

Despite the general strength of the U.S. housing market, the benefits of housing, and of stable, vibrant communities, are unequally distributed. Examples of these inequalities include: residential segregation, gaps in homeownership rates by race, sprawl-type development patterns and shortages in affordable housing. Most recently, in the wake of Hurricane Katrina, the challenges of securing basic shelter and rebuilding homes and communities have fallen disproportionately on minority and low-income populations (Millenial Housing Commission 2002, de Souza Briggs 2006, Joint Center for Housing Studies 2006). Such outcomes provide a justification for social interventions by government and non-governmental organizations.

The purpose of this chapter is to highlight new and creative research in a variety of disciplines—especially decision sciences—that help determine when, where, what type and by what means affordable housing and sustainable communities might be built, redeveloped and maintained. As a prelude, it is useful to draw a link between housing planning and supply chain management, the theme of the Frontiers of Engineering session in which this paper appears.

A *supply chain* is a network of facilities and transportation modes that uses production and logistics processes to transform inputs into finished goods and services, thereby integrating supply and demand management. Central to supply chain management is the temporal planning scope: strategic, tactical and operational, and a key technical process: location of facilities at which operations are performed. As a social enterprise, housing and community development is not literally an example of supply chain management. However, as in supply chain management, facility location—here, of housing—is central to this process. Also, the temporal scope of housing and community development planning similarly spans strategic, tactical and operational time horizons, as we will show below. Finally, effective housing and community development planning attempts, like supply chain management, to match supply and demand for goods and services—here, affordable shelter and sustainable communities.

Initiatives to improve access to affordable housing and sustainable communities address (cf. de Souza Briggs 2006): stakeholders (e.g. employers, housing developers, citizens, government agencies); policy objectives (minimize housing cost and environmental impacts, maximize deconcentration of poverty) and actions (create new housing alternatives, protect current alternatives, change attitudes and preferences). Engineering and related disciplines can influence all of these dimensions of housing policy.

Civil, environmental and mechanical engineering, for example, generates improved methods for implementing housing initiatives. The success of these methods is commonly measured by increased efficiency and effectiveness of construction outcomes. Urban and regional planning, especially land-use and transportation planning, in contrast, focuses on increased social efficiency and equity of development outcomes, given current or best-practice construction technologies. Decision sciences (e.g. operations research and management science) represent a link between engineering and planning methods. They generate specific, actionable strategies that jointly optimize social efficiency, effectiveness and equity. They may take as given current or best practices in construction technologies, or planning methods, or both, or neither.

In the remainder of this chapter, we present research results in engineering construction methods and urban and regional planning methods related to affordable housing development, and demonstrate the unique contribution of decision sciences in this domain. We conclude by presenting a number of promising research extensions.

II. Engineering-based methods for housing construction

Developing more cost-effective housing, and doing so efficiently, is a task well-suited to traditional engineering. Key goals of improved construction technologies include increased affordability, energy efficiency and structural integrity, and decreased negative environmental impacts. Recent European research addressing "sustainable" development from an engineering perspective (e.g. Priemus 2005) has focused more specifically on environmental impacts. Unfortunately, while construction techniques can be modified to decrease different ecological impacts associated with "flows" of energy, construction materials and water, the resulting innovations have been contradicted by increased resource usage by housing occupants and ineffective national policy. Ultimately, argues the author, the policy with the greatest impact on sustainability may be that which reduces new housing construction the most.

Other engineering approaches have focused on best practices to reduce energy consumption through energy-conserving materials such as windows, insulation and appliances, alternative energy sources such as solar power, improved construction methods for foundations and walls, and more efficient heating and air conditioning systems (Steven Winter Associates, Inc. 2001). Building design strategies use advanced computer simulation methods to compare energy savings from novel designs with actual outcomes, as well as architectural choices such as site selection and building orientation for maximum passive solar exposure and compact floor plans. Application of these technologies to a specially-designed house generated energy usage 46 percent lower than the U.S. average (Balcomb, Hancock and Barker 1999). These technologies are also available for rehabilitation of existing housing in low-income areas through retrofitting, improved gas metering and increased cooperation between stakeholders. Estimated energy cost savings for a low-income family resulting from these innovations are on the order of one month's rent per year (Katrakis, Knight and Cavallo 1994).

Engineering methods also influence construction processes. Examples include concurrent engineering to better reflect customer requirements for industrialized housing (Armacost *et al.* 1994) and knowledge management to increase coordination between owners, designers and developers for affordable housing (Ibrahim and Nissen 2003).

III. Urban planning for affordable housing and community development

Affordable housing and community design is a problem faced by American planners and analysts for over 80 years, with a very mixed record of accomplishment (von Hoffman 1996). In central cities, 1930's- and 1940's-era planners embraced vertical towers grouped in communities distinct from surrounding neighborhoods. The resulting social dysfunction and physical decay has only been remedied in a substantial way in the past decade, under the Federal HOPE VI program. On the other hand, planners designed post-World War II suburbs to be affordable, accessible to central cities via freeways, and uniform in appearance.

In recent years, trends in denser, transit-friendly mixed-use development, often on land that had been previously used for residential or industrial purposes, in the central city or in nearby suburbs, have converged with redevelopment of distressed inner-city neighborhoods into mixed-income, joint ventures (Bohl 2000). Though U.S. consumers still overwhelmingly prefer the traditional suburban model of detached, single-family owner-occupied housing, there is increasing market demand for housing units and communities that appear to be more sustainable socially and environmentally than the historical norm (Myers and Gearin 2001). However, recent stagnant levels of Federal funding for subsidized and affordable housing have limited the impact of assisted housing redevelopment.

Of increasing importance in planning research is the use of decision models and geographic information systems to generate alternative strategies to optimize social objectives (Ayeni 1997). However, there is very little work in this area, nor in traditional urban planning, that addresses decision modeling support applications designed specifically for affordable housing.

IV. Decision science methods for affordable housing policy and planning

Decision models can improve access to affordable housing and sustainable communities by explicitly and jointly addressing space, opportunity, design and choice. *Space* and *opportunity* jointly address the problem of the physical location of housing, and its proximity to community amenities linked to improved life outcomes. *Design* addresses the generation of policies that enable families to participate in housing programs, as well as setting development priorities and configuring communities composed of differing land uses and housing types. *Choice* confronts the challenge individual households face when choosing among alternative housing and neighborhood destinations the one that best balances different needs and preferences. In contrast to engineering construction and planning methods, decision models for housing development use quantitative models that are stylized; prescriptive and forward-looking, and multi-objective.

One type of strategic decision problem we consider is the choice and evaluation of housing and community development policies. A solution to this problem consists of program *types* (e.g. housing subsidies) and *intensities* (e.g. funding levels, or number of program participants). Caulkins *et al*. (2005) address the generation of long-term population outcomes associated with a stylized large-scale program in which low-income families use housing subsidies to relocate to low-poverty neighborhoods. The purpose of their model is to understand the circumstances under which a large-scale housing program might preserve the health of destination communities. The authors model changes in the stock of middle-class families in a typical region due to normal demographics, a large-scale housing mobility program resulting in low-income families who "assimilate" to the middle class and middle-class "flight" in response to in-movers. Figure 1 shows that for base-case values of structural parameters, a long-term equilibrium exists (near $X = 1$) in which a housing mobility program run at low intensities in a generic metropolitan area would reduce the size of middle-class communities by only a small amount.

Given support, in a strategic sense, for a particular housing policy, a tactical decision problem is to choose the amount and type(s) of housing to be provided in a specific region over a specific time period. Solving this problem requires specifying program *locations* (municipalities, neighborhoods or land parcels) and *configurations* (differing quantities of differently-sized rental- or owner-occupied housing units). Gabriel, Faria and Moglen (2006) solve a multi-objective optimization problem to identify land parcels for development to balance the needs of planners, developers, environmentalists and government. Johnson (2006) solves two complementary optimization models specifically for affordable housing: longer-range, for identifying regional investment levels to maximize social benefit, and shorter-range, for identifying specific locations and development sizes to balance social benefit and equity. Figure 2 shows Pareto frontiers from this paper associated with solutions to the multi-objective optimization problem for owner-occupied and renter-occupied housing using data for Allegheny County, PA. These curves provide evidence of a range of policy alternatives that support choice of a "most-preferred" solution.

The last decision problem considered here, operational in scope, is that of a client's choice of a most-preferred housing program, neighborhood or housing unit, given defined affordable housing policy priorities. Solving this problem requires specifying detailed characteristics (*attributes*) of housing units and neighborhoods, decision models by which participants can rank potential destinations (*alternatives*) and information systems that may help standardize and automate this process (*decision support systems*). Johnson (2005) has developed a prototype spatial decision support system (SDSS) for tenant-based subsidized housing choice that addresses qualitative concerns ("what attributes of housing units and neighborhoods are important to me?") and quantitative concerns ("how can I rank a 'short list' of alternatives to maximize my satisfaction and minimize the burden of housing search?"). The SDSS uses geographic information systems to illustrate neighborhood characteristics, a relational database to store information on specific housing units, and a multi-criteria decision model to help clients make relocation decisions. Figure 3 illlustrates the application's spatial data interface with fair housing data for Allegheny County, PA.

V. Conclusion and Research Extensions

A number of analytical methods may be used to increase access to affordable housing and sustainable communities. One stream of current research uses civil, environmental and mechanical engineering to design housing units that improve on current practice according to energy-efficiency, cost, structural quality, and construction process efficiency. Another stream of current research uses urban and regional planning to help stakeholders define development strategies that reflect best knowledge of social science-based program evaluation, land-use and transportation planning standards and community-level partnerships. In contrast, decision sciences provide an opportunity to design housing and community development policies that improve on current practice in construction-oriented engineering and planning according to social outcomes, multi-stakeholder negotiations and housing program client choice.

Since affordable housing and sustainable community development are not at present top priorities for market-rate housing providers, government support for improved engineering of residential housing may increase environmental sustainability and reduce user costs. However, housing policies that optimize various social criteria must also address technology aspects of housing provision and use best practices in urban and regional planning to be considered sustainable and affordable.

There are a number of promising extensions to the decision sciences-oriented research described in this chapter. Of greatest importance is evidence that implementation of the decision models described in the previous section in actual affordable housing provider organizations results in improved community and individual client outcomes. Other research extensions include: (1) the choice of housing design and construction strategies that balance different housing unit- and community-level sustainability measures; (2) development of dynamic models for strategic housing policy design to address place-based housing strategies, i.e. new construction and rehabilitation of existing housing units, and (3) design of realistic yet tractable decision models to provide guidance to affordable housing developers who routinely choose among many potential sites a handful to develop with limited funding that maximize the probability of neighborhood revitalization.

As long as sprawl, environmental degradation and geographical barriers to affordable housing and opportunity remain policy problems, researchers have an opportunity to devise novel and creative solutions at the nexus of engineering, planning and decision sciences.

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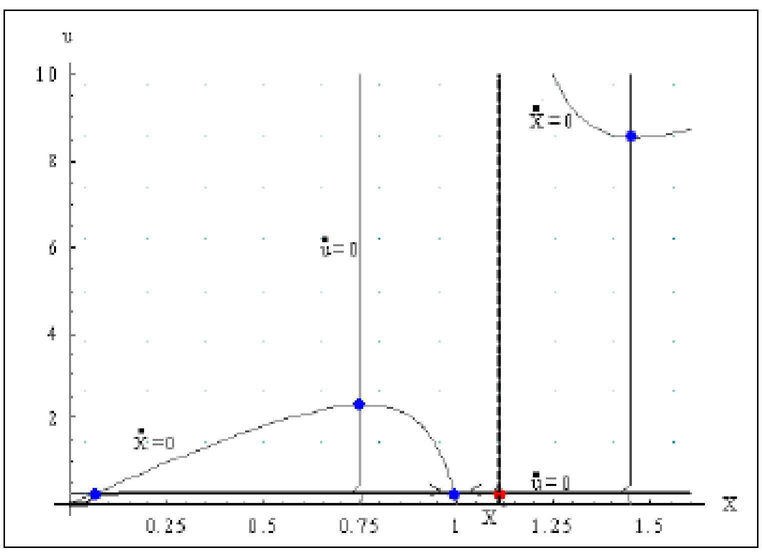
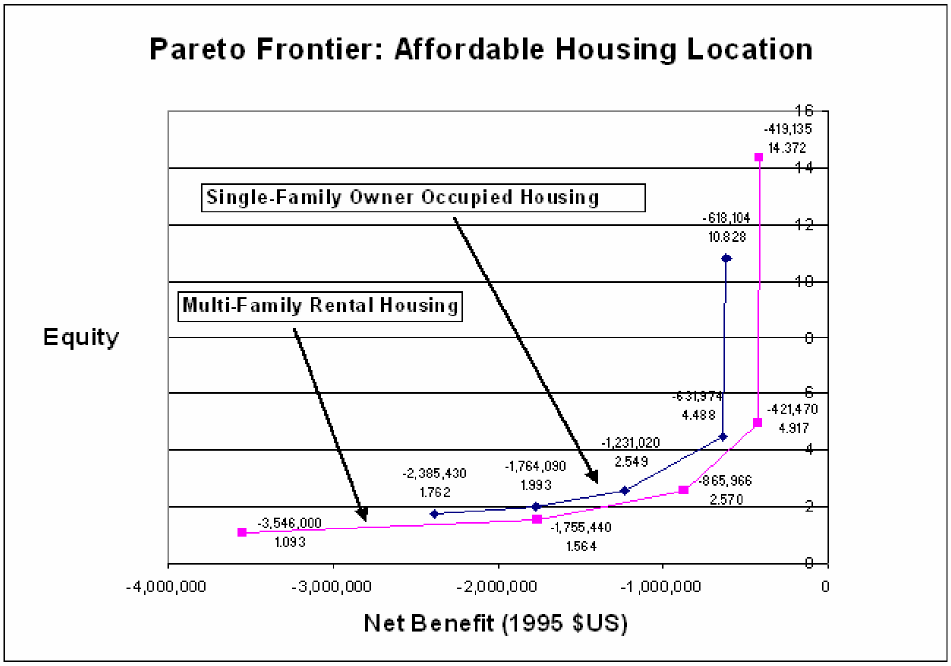
Figures



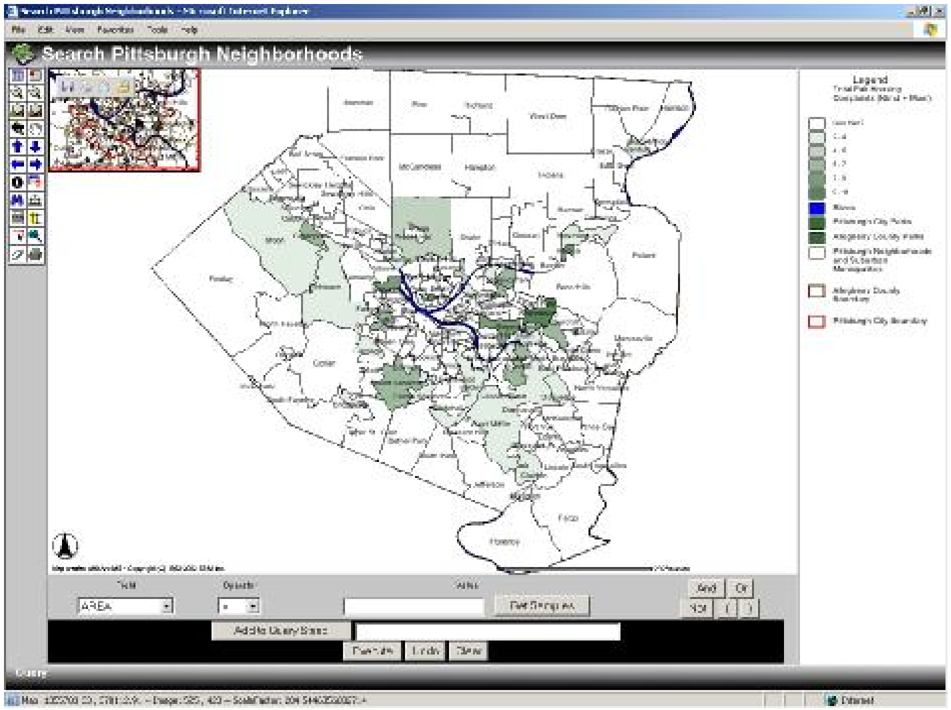
Source: Caulkins et al. (2005)

Figure 1: Dynamic Optimization Model Solution for Housing Mobility Program: Base-Case Parameters



Source: Johnson (2006)

Figure 2: Pareto Frontiers for Affordable Housing Location Problem Case Study



Source: Johnson (2005)

Figure 3: Spatial Data Interface for Counseling Support DSS