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Interactive optimization for the planning of urban systems

S. Cajot[a,b,*], N. Schüler[a,*], M. Peter[b], A. Koch[b], F. Maréchal[a]

[a] IPESE, Ecole Polytechnique Fédérale de Lausanne, Sion, Switzerland
[b] European Institute for Energy Research, Karlsruhe, Germany

Abstract

This paper introduces URB[io], an interactive optimization framework for the planning of urban systems. Addressing the elusive nature of urban planning and its need to cope with more technical sectors, the framework allows urban planners to generate and evaluate many alternative urban configurations, while focusing their attention on the most promising ones. First, addressing the need for integrated urban modeling approaches, a Mixed Integer Linear Programing (MILP) optimization model representing both urban and energy system components was developed. Second, an interface based on parallel coordinates and georeferenced maps is proposed to effectively communicate the optimization results to decision makers, revealing tradeoffs and synergies between competing objectives. Interaction with the parallel coordinates charts further allows planners to steer consecutive optimization runs based on their preferences and experience. The framework is applied to an urban development project in Switzerland to demonstrate its usability and relevance.

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Keywords: urban planning; energy planning; urban energy system; optimization; parallel coordinates.

1. Introduction

In the last decades, urban planning has progressively shifted from the rather spatial-oriented task of accommodating social growth and economic development, to a more strategic and integrative process [1,2]. No longer confined to the role of technical experts who design cities based on assumed universal principles, urban planners must today involve and arbitrate the interests of various stakeholders [3]. Additionally, their strategic plans must bring together and coordinate different sectors, consider effects on multiple scales and cover long-term horizons. Given global concerns for the climate and the environment, the energy sector is in particular receiving attention as to how it might be better integrated in urban planning processes. By considering energy efficiency and renewable energy integration beyond the individual building scale, urban planning can effectively help reach energy and climate targets [4,5]. Such strategic tasks imply taking high-stake decisions in the earlier phases of a project, where precise information may be lacking, and feasible alternatives to choose from are plentiful. This holds true for both general planning approaches, although

* These authors contributed equally to this work. Corresponding addresses:
E-mail address: sebastien.cajot@alumni.epfl.ch, nils.schueler@epfl.ch

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to different extents: brownfield planning requires precise knowledge of the local existing infrastructure and actors, whereas greenfield masterplanning presents a very large solution space in which good, energy efficient solutions could easily be overlooked [6,7]. In either case, whether the planning is a government-led or more competitive and developer-led process, planners require both accountability and speed in the generation and evaluation of plans [7,8].

Many tools have been developed to support planners in these regards, ranging from GIS tools to detailed simulation models of the urban system [7]. Among these, optimization approaches are gaining momentum in the research community. They are believed to improve on traditional planning practices, by avoiding alternative-driven decisions, as opposed to decisions guided by the values at stake [9,10]. Some notable examples of optimization applications in urban planning contexts include the optimization of dwelling locations to minimize transport costs or flood event risks [11], or the search for land-use plans minimizing traffic congestion, costs and required change from status quo [9].

However, modelers striving to harness the benefits of optimization for urban planning face two key challenges. First, their models must overcome the inherent elusive and undefinable nature of urban planning, and avoid falling into a too narrow representation of the different sectors [7]. Second, they must ensure that the experience and knowledge of the planners are well integrated in the model, and not replaced by it. As Raphael[12] notes, very often designers are able to criticize specific designs, without being able to precisely state the underlying reasons. It is because of this difficulty to express such reasons that human-computer interaction is expected to play a central role in overcoming the divide between optimization techniques and urban planners, which has been lasting for decades [2,13,14].

An early example of an interactive tool for exploring optimization-based efficient plans is found in [15]. This however is not per say interactive optimization, which is defined as applications in which the decision maker's preferences are included *during* the optimization process [16].

Interactive methods are particularly relevant to address the difficulty in design problems to know preferences before understanding their interdependencies, and the high computational costs related to the optimization of large problems, such as when dealing with an entire neighborhood (>100 buildings) [12,17]. In that sense, interactive methods can be considered superior to *a posteriori* methods, which require the generation of the solution space before evaluating it, and to *a priori methods*, which require a clear understanding of the priorities and relationships between objectives beforehand. Various examples of interactive methods can be found in [16]. In particular, two studies have pointed out the advantages of relying on parallel coordinates (which will be introduced below) for inputting user preferences in multi-objective optimization [18,19].

A previous article documented the initial development and a first application of an integrated Mixed Integer Linear Programing (MILP) model for urban and energy planning [20]. Building on this, the current article's purpose is to describe how this optimization model is employed within an interactive framework based on parallel coordinates to support early-stage urban planning.

The remainder of this article is structured as follows: Section 2 describes the methodological aspects adopted in the study. After briefly introducing the basic notions of the optimization model and the parallel coordinates interface, their combination to form an interactive optimization framework, and its corresponding workflow, are presented. Section 3 demonstrates how the decision support tool can be used in practice and illustrates actual results obtained by application of the method to an urban development project in Switzerland. Finally, the article is concluded with a discussion on the significance of the framework to improve energy-oriented urban planning (Section 4).

2. Methodology

In this section, the main components of the interactive optimization framework URB^{io} are described (Figure 1). Its main aim is to support the early-stage planning of urban areas, by generating a large variety of urban and energy system configurations and revealing synergies and tradeoffs between decisions. The decision support framework consists of two main, iterative phases (Figure 1). The first phase is user-driven: the decision maker explores optimized results in parallel coordinates and geo-referenced maps, and requests additional solutions based on their preferences and acquired insights. The second phase is computer-driven: optimal urban configurations are calculated according to user-specified objectives and constraints in an MILP model, and the results are stored in a database.

URB^{io}'s first innovation compared to existing optimization-based approaches is an extensive integration of energy aspects with other more traditional urban planning concerns in a single MILP model. In addition, the decision maker is directly involved in the optimization process, allowing them to explore and learn from the intermediate so-