Designing a combinatorial auction for Solids

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To raise a building that will last for at least 200 years, with its tenants deciding how to use the building. The Dutch housing corporation Stadgenoot (a non-profit private organization with strong links to local authorities) aims to make this happen in Amsterdam with so-called "Solids". A Solid is a sustainable building without predefined purpose; in fact, a Solid should accommodate any (legal) functionality. The construction of the first Solid, called Furore, was finished in April 2011. Two other Solids were delivered one month later, and there are plans to build others in Amsterdam. We will focus on Furore, which offers 7000 square meters of floor space in the west part of Amsterdam. This Solid features a spacious roof terrace with a splendid view over the city.

To allow maximal flexibility, it is up to the tenants to decide on the use, the size, the configuration and even the rent of their space in the Solid. Stadgenoot sees Solids as highly suitable for a large variety of tenants : (large) families, entrepreneurs, students, restaurants, etc. Furthermore, space in a Solid is delivered as a shell. This means that within a solid space, it is the tenant who decides where to place partition walls, interior doors, etc. This enables the rented space to be designed for a whole range of purposes : living, working, culture, or any combination of these. Stadgenoot remains the owner of the shell; the tenants rent solid space, and own the interior. If a tenant leaves, (s)he can sell the interior to a next tenant. Over time, solid spaces can grow (when merged with another solid space) or shrink (when split up), and be used in very different ways, depending on the needs of the time.

In essence, the challenge Stadgenoot faces is to allocate the space in their Solids to interested bidders. The main objective is not making profit, but to obtain a balanced functional mix of residential, commercial, and social tenants. The first group consists of people who plan to live in the solid, the second group plans to open a business, and people with a low income make up the third group. For social tenants, Dutch law imposes an upper bound on the monthly rent. Nevertheless, Stadgenoot wants the allocation to reserve at least 15% of the surface to social tenants. Residential bidders should get at least 25% of the surface, whereas commercial bidders should be allocated at least 30%. We divided the Furore building into 125 lots, distributed over 7 floors. Hence, any interested tenant can specify space in the Solid as a subset of these lots, together with the price (s)he

is willing to pay as a monthly rent. By choosing an appropriate set of lots (on a bidder's favorite floor, according to a preferred orientation), a bidder specifies the resulting solid space. However, each solid space should have a door to the central hallway, and have access to at least one utility shaft, from which it can get its utilities (ventilation, gas, electricity, water, etc.). The allocation should be such that the required capacities for each space can be accommodated by the shafts. Other constraints originate from municipal and building regulations. For instance, the stairs have a rescue capacity that should not be exceeded; the rescue capacity needed for each solid space depends on its surface area, and the function that the tenant has in mind.

We designed a combinatorial auction that maximizes total rent, while coping with Solid's various municipal and building regulations. A combinatorial auction is an auction where multiple items are auctioned simultaneously, and bidders are allowed to bid on one or more subsets of the items (see e.g. [1]). This is particularly useful in this case, because typically, bidders are interested in multiple lots, and may value some sets of lots higher than the sum of the values of the lots individually. A combinatorial auction allows bidders to express their preferences to a greater extent than for individual items only.

Every auction needs a set of rules that determine the course of the auction, the actions the bidders can take, and the feedback they will get. The design of the solid auction was settled in two steps. First, several meetings with Stadgenoot resulted in the decision to use a sealed-bid first-price auction. In a sealed-bid auction, the bidder communicates bids directly and solely to the auctioneer. In a first-price system, a bidder pays the amount (s)he bids for the solid space (s)he wins. Next, the design was fine-tuned based on a series of computer simulations and experiments with human bidders, in which we studied the effect of various auction rules.

Finally, we also needed to deal with the so-called winner determination problem, i.e. deciding which bidder is allocated which part of the solid. For general combinatorial auctions, the winner determination problem is NP-hard [2]. Rothkopf et al. [2] showed that the problem becomes easy if each bidder expresses only one bid, and all lots are arranged on a single row. We generalize this result, by showing that if all lots are arranged in two rows, the winner determination problem is still polynomially solvable. Finally, we provide an IP formulation to solve the winner determination problem for the solid auction, taking into account all allocation constraints and regulations. We conclude by discussing the outcome of the Furore auction, which used our design.

Références

[1] P. Cramton, R. Steinberg and Y. Shoham (2005). *Combinatorial auctions.* MIT Press.

[2] M.H. Rothkopf, A. Pekeç and R. M. Harstad (1998). *Computationally manageable combinational auctions.* Management Science, 44(8) pp. 1131–1147.