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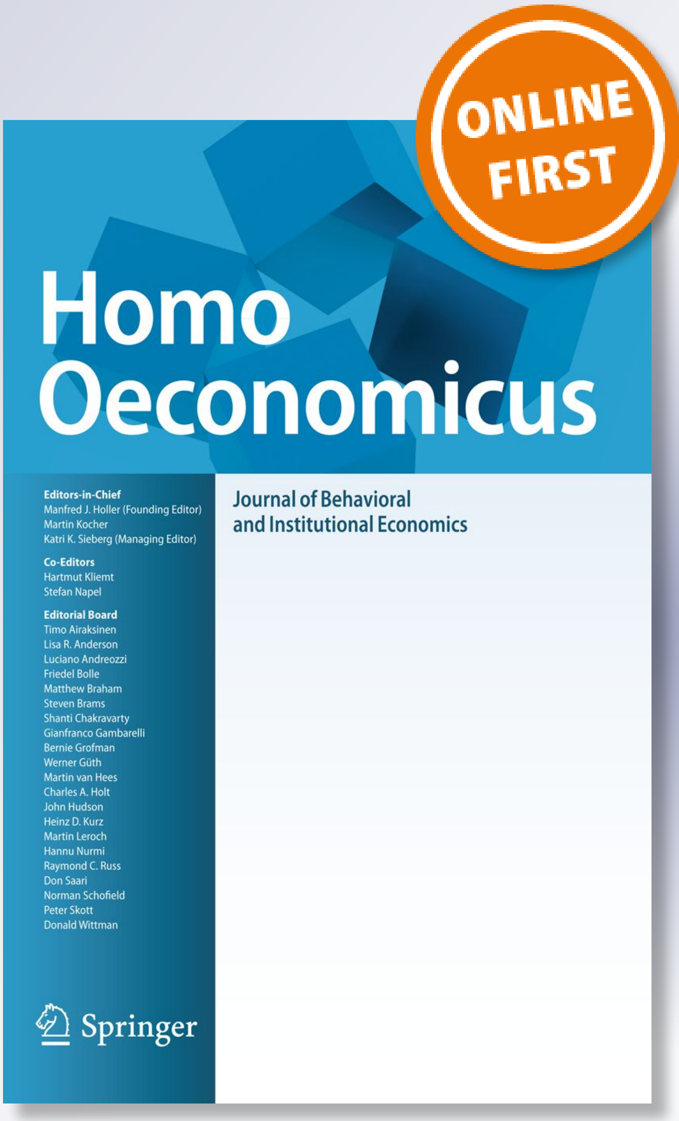

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RESEARCH PAPER

On the Process and Economics of Land Settlement in Oman: Mathematical Modeling and Reasoning in Urban Planning and Design

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Abstract The Sultanate of Oman organizes a peculiar land allocation system by lottery. Combined with governmental loans this system is intended to provide house ownership for male and female nationals. Active land-management measures such as incentives or taxation do not exist. The process can be described as an ideal market. As observed in empirical studies the resulting settlement remains incomplete and inefficient, which leads to an overall unsustainable land-use. The paper develops an agent-based land-settlement simulation based on cellular automata. The simulation describes the agents and their motivation. It is calibrated with a real-estate price index compiled for Muscat Capital Area for the first time. The simulation allows discussion of four scenarios: Status quo, negative, positive and combined land-management measures. The status quo scenario reveals that the original intention of the land allocation program as part of the welfare system in Oman is not attained. On the contrary, the present system without additional management fuels private land speculation that rapidly excludes those in need and benefits a few. The alternative

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scenarios of negative, positive and combined land-management measures support policies for a fair and sustainable settlement process.

Keywords Collective decision-making · Simulations in economics · Settlement dynamics · Housing in Oman

JEL Classification C630 · R310 · R380 · R520 · R580

1 Introduction

The Sultanate of Oman is facing a continuous and rapid demographic growth since the opening of the country in 1970. Fertility rates are still high and the population grew to over 4 million inhabitants by 2016 (Oman Census 2016). Reoccurring topics in the context of a sustainable urban planning of Muscat are higher gross residential density, higher achievement rates (proportion of allocated plots actually built on), and higher shares of residential land in the gross developed area, see (von Richthofen and Scholz 2013), (Nebel and von Richthofen 2016a, b), and (von Richthofen and Cummings, 2017).

Since the 1980s the government has implemented a lottery system to distribute land in order to avoid illegal land grabbing, but also to contribute to the development of a modern Capital Area. Land for building homes is provided by the state through a lottery system where adult males (since 1981) and females (since 2008) can participate pari passu.[1] The land transaction fees for empty plots, only introduced in 2014, are negligible and there is no taxation system to regulate the market for plots. National banks allocate low-interest loans to willing nationals to build upon the allocated plots. The size and shape of plots is a uniform rectangle of 20 m × 30 m (600 m^2) for which a typical "Omani Villa" has been developed. The consequences of this de facto free land allocation process at the hands of Omani nationals including urban sprawl and generally wasteful use of land, energy, material and social resources have been described by (Al Gharibi 2014), (Al Shueili 2015), and (Nebel and von Richthofen 2016a, b). Once the land has been allocated, the winners obtain a random plot within a given larger plot of land, that they are allowed to use for their own buildings or to sell.[2] Due to the demographic pressure, the land is developed further and further away in remote areas. Typically, just the claims for the plots and main roads exist physically at the time of the lottery results. Since the applicants need to be just 21 years old to apply, not all of the lottery participants are in immediate need of starting construction, and additional infrastructure gets into place only once enough houses are being built. Even though the land allocation process organized by the Omani government is accessible to all Omani citizens and

[1] See Royal Decree Oman (1981) No. 5/81 "To Organize Usufruct over the Sultanate's Lands" and amendment in 2008 on http://eservices.housing.gov.om for the details of this lottery.

[2] Besides fairness amongst the applicants to the lottery this system also breaks-up the traditional tribe structures and allows a mixing of people from different tribal backgrounds.

national banking loans are granted under very favorable conditions, not all citizens actually claim the plots and not all plots are developed. The overall system of land allocation as a governmental process and construction of houses as a subsidized, yet private initiative seems to be inefficient. The incremental growth process and the problems associated with it have been studied by (von Richthofen and Scholz 2013).

Land management measures by a government can have the character of incentives or taxes. The feudal state character of Oman has, since the 1970s, led to an underlying social contract where the government redistributes wealth to its citizens (Valerie 2013). This principle also implies the absence of direct taxation. Taxation in democratic societies is a key for political representation and has thus not been introduced in Oman so far. Incentives, on the other hand, can guide agents to change their behaviors. Possible remedies based on the results of this simulation may include: (1) the *development of a land monitoring system based on the simulation results*. Currently, the Ministry of Housing has the sole authority to distribute land and has not yet installed an effective land monitoring system. Next to a Geographic Information System (GIS) database, an urban simulation can lead to an evidence-based urban design and ultimately improve the current land allocation system. (2) *Modification of the pricing policy for land allocation and the introduction of variable pricing to steer land use and counteract land-speculation*. In principle, the pricing policy has not changed since 1990, and land is still allocated by the lottery system to all Omani citizens. The fees paid by the applicants do not currently cover the development costs incurred by the government nor do they reflect market prices. The simulation results question the efficiency of the system and reveal negative side effects such as land-speculation. (3) *Procedure to identify and predict genuine demand and suitable prioritization of allotment based on the simulation results*. The pricing policy drives an excessive demand for land, making it impossible to identify genuine demand. (4) *Coordination with other agencies responsible for the provision of infrastructure*. Coordination with other agencies has not significantly improved since 1990. The asynchronous development has many causes that defeat the goal of higher achievement rates. (5) *Strengthening housing finance institutions based on an economic simulation model*. This is evident in the wide range of low-interest mortgage schemes in operation. (6) *Creating provisions for re-acquisition of plots by the Ministry of Housing*. Provisions for re-acquisition of plots have been created and the land granted to residents can be reclaimed with appropriate compensation. Finally, one may (7) *consider individual household preferences and resident satisfaction*. The master planning does not take into consideration individual household preferences nor resident satisfaction. Residents are gradually losing touch with traditional ways of life and local customs as they move into newer neighborhoods.

In order to predict the effectiveness of these remedies a much deeper understanding of the actual land settlement process is needed, in particular with respect to timelines, the evolution of house prices and social fairness of the process.

Hence, in this land allocation system several questions arise that shall be studied here:

- What is the actual process of plot settlement, i.e. what patterns can be observed on a timeline?

- Is this system inherently able to efficiently and completely realize the full housing potential of a development area for all allocated plots?
- As optimal infrastructure and the overall degree of settlement contribute to the value of a plot, when is the best time to buy/sell?
- How do prices of real-estate increase over time?
- Does a land allocation system that offers a plot to each citizen actually contribute to a fair and equal wealth distribution? (Is it real-estate speculation disguised as social welfare?)
- What measures of urban management should be proposed to gear the land allocation process and settlement towards a more efficient and targeted land-use (taxes/incentives)?

Within a larger urban development area, several thousand plots are allocated by lottery in one go. Indicative studies in Muscat Capital Area and detailed studies in the neighborhood of Al Khoud revealed three major stages that are present throughout the progress of this settlement process, cf. (von Richthofen and Langer 2015), (Nebel and von Richthofen 2016a, b), and (von Richthofen 2014, 2015, 2016a, b, c, d, 2017):

Stage 1 The first stage is that of the pioneers. This stage is characterized by sporadic, distributed development of houses. The settlement process starts slowly. The pioneers settle out of necessity, not out of choice. Some are urgently in need of a new home such as young couples that want to move out from their parents' home and start a family, which requires a separate home in a traditional Islamic society like Oman. Slowly others follow. At this stage, construction is an adventure, as neither proper connecting roads are in place (dirt/mud roads dominate the scene), nor continuous water or sewage supply (this is guaranteed by calling respective tank cars), as well as electricity or landline connectivity. Building a home prior to the construction of the neighbors and further road and sewerage means to live in an area deprived of infrastructure and subject to future construction noise, dirt, and pollution. These factors significantly contribute to the lower desirability to settle on plots in this neighborhood in this phase. This stage can last many years.

Stage 2 The second stage is that of the convenience movers. Once a neighborhood has been built with a suitable amount of houses "per street", the municipality starts to develop the plot by paving broader connector streets and side roads, by installing electricity lines (incl. street lighting) and landlines. While this is not the official policy, the municipality has no other choice than to prioritize the road development. A survey for the new residential neighborhood of Al Khoud from 2011 to 2014 revealed this gradual development pattern of road infrastructure (von Richthofen 2016a, b, c, d). Typically at a much later stage, proper water and sewage systems get established. This stage is thus the time for the convenience movers. Building activities become comparably easy (opportunity costs are low) and it is also attractive to buy/sell properties due to the steadily increased quality of municipality services provided. Now people, e.g. unlucky in the lottery draw because their plot is located far away and in an undeveloped area, buy land and start to raise their homes together with those who just waited for the reduced efforts of construction. First shops, business buildings, and mosques are coming into place as a critical mass of customers is reached. Due to the mutual intensification of (governmental) infrastructure provision and (private) housing development, this stage is characterized by an acceleration and steep increase in prices. This stage lasts a few years only.

Stage 3 The third stage is that of the saturated speculation. The area is well developed in terms of municipality services yet a percentage of the plots is still empty. These are either plots of indecisive owners (they may have gotten a job in another city, went out of money or are planning on a more longer term), or used as trading objects because their price is coupled to infrastructure, availability, and accessibility of shops, restaurants and service providers as well as the overall structure of the neighborhood. Since males and females can apply for plots as of 2008 but generally only need one plot for their own family, a fair amount of plots have been allocated without a specific purpose. Here, the final price for an open plot (without constructions on it) as well as for already built houses is realized. This stage would come to an end with a full development of all plots.

In the following sections, we are giving a mathematical model for this settlement process: In Sect. 2 by means of cellular automata and most likely behaviors of the plot owners (including hypotheses for their tacit aims and preference structures). Here, the actual development in Al Khoud is used as an indicative reference for the settlement pattern in time. For the model set-up, special consideration is given to the development of plot prices by calibrating our assumptions to available sources. This includes a comparative estimation of real-estate prices and their development in Muscat Capital Area that has not been done till now. In Sect. 3 we give the results of several simulations to obtain a tangible view of the settlement process including the observation of certain patterns/structures that can be seen in the actual settlement as well. Moreover, we obtain a picture of how prices for plots evolve. These simulations clearly indicate that the combination of available and built land, as well as the degree of infrastructure provided by the government, is not, as might be assumed, arbitrary even if it does not follow the intended governmental logic of continuous and fair land allocation. The simulation also challenges the underlying assumption that a land allocation system contributes to a fair and efficient provision of housing as intended by the Omani welfare state. On the contrary, the simulation reveals that a subsidized land allocation without land taxation results in unhindered land speculation. Finally, we propose and discuss scenarios for efficient policies necessary in addition to the lottery in order to prevent undesired effects of land accumulation and social exclusion from house ownership. A résumé and outlook wraps-up our study.

2 Modeling the Settlement Process

2.1 Cellular Automata Simulation of Urban Development Processes

The conceptual framework for this simulation is Christopher Alexander's text "The City is not a Tree". This text acknowledges cities in general and urban development processes in particular as non-linear, multi-dimensional phenomena. (Alexander et al. 1977) This opens up two avenues for research: Cities as complex systems, see

(Portugali 2000), (Beirão et al. 2010), (Bielik et al. 2012), (Batty 2013), and (Bettencourt 2013), and Cellular Automata simulation of urban development processes, see (Coates et al. 2003), (Koenig and Bauriedel 2004), (Speller et al. 2007), and (Zünd 2016). This paper tackles only a particular aspect of the urban development of Muscat, namely the settlement and building process under the specific land allocation scheme. It also tackles just one scale, namely that of the governmental development areas of 2000–10,000 units. The simulation and derived scenarios shall nonetheless be understood as a layer in the complex and dynamic system of the Omani cities.

2.2 Simulation Setup

For our first generic set-up of the settlement process based on empiric observation, like in Al Khoud cf. Figure 1, and first numerical simulations let us use the 15 times 20 plot distribution shown in Fig. 2. This plot consists of main roads, connector roads and a combination of 18 plots for business houses (along two main roads) and a majority of 282 plots for family houses. As always houses are uniquely associated with streets, in our case if a house lies at the conjunction of two streets, then preference is given first to vertical main streets, then to horizontal main streets, then vertical connector streets and finally horizontal connector streets. Our rationale to perform this association of houses with streets is that, as indicated above, infrastructure is connected to streets and hence houses inherit the benefits provided by the degree of infrastructure from the streets in term of an object-oriented paradigm. As vertical streets and horizontal streets, respectively, are always separated by two plots there results in no ambiguity in this scheme. Moreover, ignoring the streets, each plot at a corner of the plot has three next neighbors, a plot at an edge has 5 next neighbors and a plot in the interior has 8 next neighbors (i.e. a Moore neighborhood). We consider plots for family houses that have a plot for a business house in their direct neighborhood as if these plots would lie at the boundary of the plot with the additional possibility of having 3, 5, 6, or 7 next neighbors depending on the relative location to the neighboring business house plots.

In the initializing stage of the simulations, we will separately populate the business house plots and the family house plots, randomly with different owner strategies (see next Sect. 2.3), and then update the strategic decisions of the owners in the next moves so that a cellular automaton comes into existence, which has an interconnectivity network that depends on what is happening at the streets (especially the connector streets), the population of next neighbor plots as well as the development of the complete plot (for businesses simply require a certain total amount of potential consumers to make sense). We assume that a family house is raised at one time stage and a business house is raised in two time stages. If owners decide to start a construction at a time stage, then all of them start simultaneously at the beginning of that stage.

Concerning the provision of municipal services, we assume that a street gets electricity and landline supply once 10% of its houses are there. The initial electricity is often illegally grabbed from neighboring plots or development areas. A connector road gets paved on average once 25% of its houses are there. In the observed

Fig. 1 Land settlement process as observed in Al Khoud 2008–2013, based on Nebel and von Richthofen (2016a, b)

case-study of Al Khoud 40% roads built prior to house construction. In the same case-study, 75% construction of roads was reached when 47% of the plots were built up. Continuous freshwater supply will be added to a street once 5% of its houses are in place (till then freshwater and sewage water still needs to be delivered and

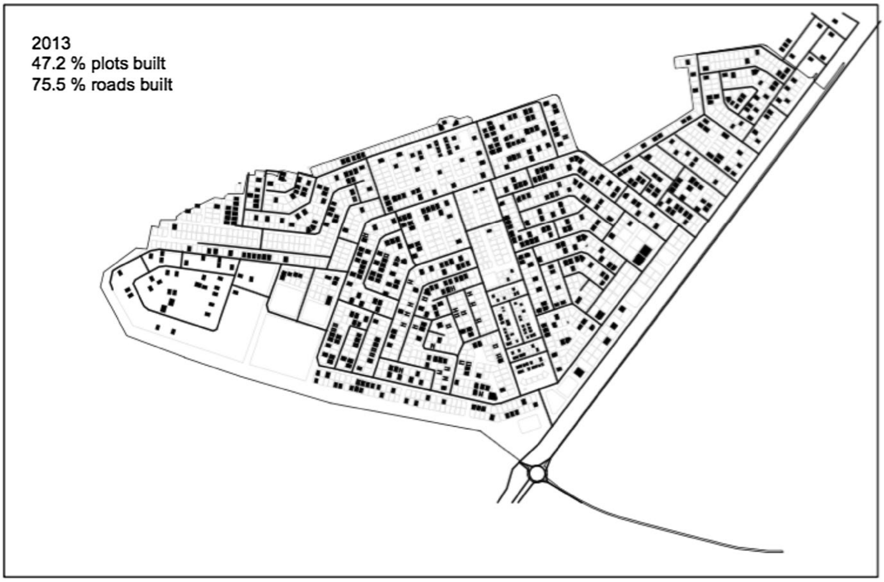

Fig. 1 (continued)

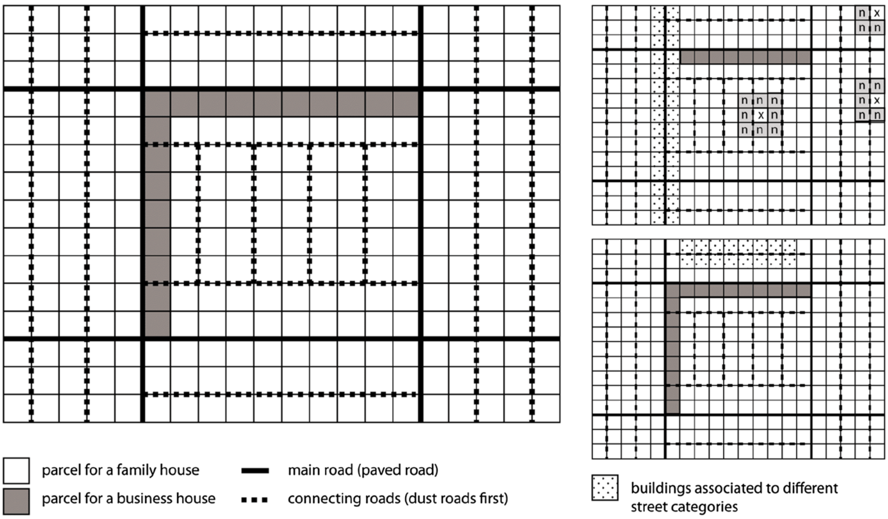

Fig. 2 Benchmark scenario for our settlement process showing the 15 times 20 plots of the plot, the streets and illustrating the association of houses to streets and the next neighboring plots (n) to a given plot (x)

collected by tank cars), and an underground sewage system will be established once more than 85% of houses are there.

Based on the study of the physical planning standard developed by (Weidleplan 1991) and the building code of the Muscat Municipality in 1992 together with empirical studies on the land allocation process in praxis we can conclude that:

- All Omani nationals have access to the plot market.
- There are no significant transaction costs attached to either obtaining or selling plots.
- There is no rush or pressures to sell plots since the interest rates are absorbed by the state banks and there are no taxes imposed.
- There is a constant demand for houses and there is a large number of buyers that outnumber the houses on the market since the allocation of plots is far behind the demographic development.[3]
- The real-estate market is protected from external, foreign investment since it is open to Omani and in special circumstances nationals of the Gulf Cooperation Council (GCC) only with exception of so-called Integrated Tourism Complexes (ITC) that are not considered here.
- All plots have the same standard size and shape of 20 m $\times$ 30 m = 600 m^2, e.g. the products are homogeneous.
- There is perfect mobility of the factors, e.g. buyers can easily switch from one seller to the other.

We can assume the plots to be perfect economic goods, the plot owners to be rational buyers and the setting to be the approximation of an ideal market. This equilibrium will be a Pareto optimum, meaning that nobody can be better off by exchange without making someone else worse off in the sense of (Debreu 1987).

Parallel to the development of connecting roads and neighborhoods the prices of the plots grow. In Sect. 3 we discuss this development based on close to real data and thus establish a calibrated model.

The Al Khoud development started in 2007 with a planned completion date of 2012, cf. (Muscat Municipality 2012). As a typical example of planned settlement in Muscat, it follows a scheme developed by the municipality to deliver 2000 plots of land. The municipality reports to the ministry of development that updates the national 5-years-plans. As observed by (Nebel and von Richthofen 2016a, b) the implementation of the urban development of Al Khoud did not happen as planned. The initial settlement process was slow, leaving most of the plots unbuilt by the end of the planned 5 years (2007–2012, see Fig. 1). The following 5 years saw faster development (2012–2013, see Fig. 1), yet the process was not completed by the time of writing this article. The same observation could be made in other newly planned neighborhoods of Oman. This gap between planned and observed settlement processes triggered the desire to explore the phenomenon with an agent-based model.

[3] In 2009, when females where allowed to enter the plot lottery, 300.000 new applications were recorded in the Ministry of Housing.

2.3 Models of Ownership (Housing Development) Strategies

As outlined in the introduction decisions, to build family houses may depend on a variety of reasons, including urged demand, low opportunity costs, or investment and land trading opportunities.

The agents can be classified according to 3 dimensions: their sales strategy ("keep" vs. "sell"), their development strategy ("build up" vs. "don't build up") and the urgency to implement them (sell/build: "now" vs. "later"). Accordingly, several classes of agents can be identified. Some act as sellers, some buyers, and some keepers. Since some agents act beyond satisfying their immediate need for a home or cash, hybrid forms emerge as well such as buyers turning into sellers, like amateur and advanced sellers, and business owners. Table 1 summarizes some classes of agents that seem to be most prominently involved in the settlement process, and neglect others, like a seller who doesn't build and has no urgency either but will just occupy a plot and wait more or less forever without a dedicated impulse to contribute to the land settlement.

Based on this classification, we give a non-exhaustive list of possible strategies based on which an owner of a plot may act:

Fast sellers (F) Owners that sell the plot immediately, because they are in need of cash (e.g. to buy a car or pay off debts) and never intended to build a house. These owners sell their land independently of the location and the development of prices over longer terms.

Pioneer movers (P) Owners who immediately start to build a family house after they have been allocated a plot. These owners develop their land independently of the location and the development of prices over longer terms. They represent the ideal actors in the sense of the government welfare provision as it was originally conceived.

Neighborhood-driven movers of type n (Nn) Owners who desire a home for their family but have more time as pioneer movers. i.e. they can wait until a certain level of ease of construction is reached which is, as we discussed, in a way related to the number of already established neighboring houses. They start building a family house if at least *n* of their next neighbors have built their houses. e.g. an "N3 owner" starts to build his/her house if three of his/her next neighbors have finalized the construction of their houses. First movers would be of type N0. Of course, the owner of a plot at a corner (or edge) of the plot can only be an N1, N2, N3 (or N1, N2,…, N5), whereas the owner of an interior plot can have any type ranging from N1 to N8. To simplify the initialization, we will at first not distinguish between interior plots and those at the boundary for the random distribution of the types, and, before the start of the simulation, adjust (i.e. downgrade) the types if necessary, i.e. an N8 at a corner becomes an N3.

Infrastructure-driven movers of type n% (In) Owners who follow, in a way, the same strategy of building a home as neighborhood-driven movers but who really want to exploit the benefits of infrastructural well-equipped neighborhoods. They base their construction decision on the level of the development of the street. With respect to the mentioned percentages at the beginning of Sect. 2.2, we use the types I10, I25, I45, and I75 for plots associated with connector roads and I10, I45 and I75 for main streets, cf. Table 2. In the absence of reliable decision profiles, these types and their correspondence to an amount of provided infrastructure are best assumptions aligned with the Al Khoud example. To simplify the initialization, we will at first not distinguish

Table 1 Overview of the motivations/desires of owners, their sales and construction strategies as well as their urgency to carry out their strategies

Agent motivation/desire	Agent type	Sales strategy	Construction strategy	Urgency
Fast sellers (F): in need of instant cash (e.g. to buy a car)	a	Sell	Don't build	Now
Pioneer movers (P) in need of immediate home (e.g. family founder)	b	Keep	Build	Now
Neighborhood-driven for own use (Nn)	c	Keep	Build	Later
Infrastructure-driven for own use (In)	d	Keep	Build	Later
Aggregate speculation for rent/sale (An)	e	Keep/sell	Build/don't build	Later
Accumulate speculation for rent/sale (Cn)	f	Keep/sell	Build/don't build	Later
Hybrid agent types				
Amateur seller (Sn)	a, b, c, d	Keep/sell	Build/don't build	Now
Advanced amateur seller (e.g. professional) (Tn)	e, f	Keep/sell	Build/don't build	Later
Business (Bn)	c, d, e, f	Keep/sell	Build/don't build	Later

Table 2 Connection between the observed infrastructure improvements and the types of the infrastructure driven movers

	Fresh water supply	Electricity and land-lines	Inter-mediate step	Paved connector roads (approx 75%)	Stage before all the infrastructure is in place
Amount of houses	5%	10%		47%	
Infrastructure driven mover type	(Still some kind of pioneer setting)	I10	I25	I45	I75

For means of an equidistant spacing between the types we use I45 instead of the more accurate I47 type

between connector roads and main streets and, before the start of the simulation, adjust (i.e. downgrade) the I25 types at a main street to type I10 if necessary.

Type n aggregators (An) Owners who are driven by the desire to own n plots (with or without houses). i.e. they aim to possess a certain number of plots that allows a certain steady income for them and their families in the future. Once they possess them they start building houses on all of them, once some suitable comfort for the construction is guaranteed. i.e. after they have obtained n plots (or if there are no more seller available) they become type I45. These people do not need the houses for themselves; they are going to let them.

Type n accumulators (Cn) Owners who want n (empty) plots in a vertical or horizontal next neighborhood in order to build a connected residential block of flats, hotels or malls. This strategy aims at covering a complete street front. Like the aggregators, they become type I45 after they have achieved their goal.

Amateur sellers of type n% (Sn) Owners who sell their plot either immediately (S0), or based on the level of the development of the street (analogous to infrastructure-driven movers) in order to achieve higher prices. With respect to the mentioned percentages, we have the types I10, I25, I45 and I75 for plots associated with connector roads and I10, I45 and I75 for main streets. To simplify the initialization, we will at first not distinguish between connector roads and main streets and, before the start of the simulation, adjust (i.e. downgrade) the S25 types at a main street to type S10, if necessary.

Advanced amateur sellers of type n% (Tn) Owners who first build a house on their plot once the street is paved and then sell it based on the level of the development of the street (analogous to infrastructure-driven movers). Again, the development of the neighborhood is, as we discussed, a proxy for the degree of infrastructure provided and consequently the prices for the house. With respect to the mentioned percentages, we have the types T45 and T75:

In order to not complicate the discussion at this stage, we exclude further trading or exchanging of plots. If for instance, aggregators and/or accumulators are not able to reach their goal then the plots remain empty. For owners of plots for business houses we assume just one strategy set:

Type %n Business Owners (Bn) Owners of plots for business houses who base their construction decision on the number of houses built in the complete plot, like B50 who wait until 50% of the plots for family homes are occupied by houses (i.e. until 141 houses are built).

In this set-up, the strategy of the business owners is simply to wait until a certain degree of development is reached. This means that businesses are a function of the degree of development and can, in a way, be neglected in simulations that deal merely with the possibilities of decreasing the number of unused plots of land in order to achieve a full settlement. Moreover, we exclude further positive feedback from having nearby shopping possibilities available that would make the neighborhood more attractive once the businesses are run. Indeed, although being quite reasonable to argue that good shopping opportunities enhance both the value of the surrounding plots as well as the tendency to build houses in such neighborhoods, we lack enough data to back-up these effects. We assume such effects to be less than in European cities anyway as Oman is a car-country and driving some distance to have a stroll through a mall, go shopping, and even consult a medical doctor is common. On the other hand, proximity to mosques seems to have an added value (which is hard to quantify and may depend on age as well).

2.4 Simulation Set-up without Trade

Figure 2 shows the results of a simulation on our introduced 15 times 20 plots grid, over which the following initial population of agent types is randomly distributed:

- family house owners: 1/19 F, 2/19 N1, 2/19 N2, 2/19 N3, 2/19 N4, 2/19 N5, 2/19 I10, 2/19 I25, 2/19 I45, and 2/19 I75
- business house owner: 100% B50

To reduce complexity at this stage, trading is excluded by this choice of agents. The simulation follows a straightforward process:

Initialization First, an input file is read that contains the geometry of the plot, the numbers of plots, the street locations and the initial population. Then, streets are generated, if necessary, or read from the input file if the automated street assignment is off. Next, the initial owner proportions are extrapolated from the input file to the actual plot size, and the owner types with their adequate amounts are then randomly distributed over the complete plot. Moreover, this will become more important later on in the large scale simulations, at the initialization part it is also determined if and in which direction the cumulative buyers can reach their goal, i.e. are there enough sellers available next to them vertically or horizontally, and how far in each direction. In particular, it may already be decided that cumulative buyers stop their engagement if not enough suitable sellers are available.

During the actual building phases, the following steps are repeated until a stationary equilibrium is reached (i.e. when nobody is willing to build or sell, or when the plot is completely occupied):

1. for each empty plot check, if the conditions for building of the specific owner are fulfilled, if yes, set a ‘build flag’ (don’t build immediately, so that there is no influence on the others owners in the same phase)
2. build the houses with the ‘build flag’

3. upgrade the street infrastructure if necessary
4. update the number of neighbors

For graphical coding of the development status of streets in Fig. 2, we used a black color for asphalted streets and a gray color for non-asphalted streets. Complete lines represent streets with full infrastructure, dashed ones those with continuous freshwater supply, dashed-dotted lines stand for streets that are just equipped with electricity, and dotted lines indicate a dirt road. Finally, rectangles with dark filling represent houses just built in the corresponding phase.

One of the major challenges is to actually get a good approximation of the (generic) price of a plot. The next section hence aims to distill the characteristics of price formation that later will be incorporated into the simulation.

3 The Effects of Trades and the Growth of Plot Prices

In order to determine the effects of trades and the growth of plot prices, we first need to compile historical data for real-estate prices in Muscat (see Sect. 3.1) and then correlate these to a "currency" that we can easily utilize as a proxy for value increase. This currency will be called "monetary unit" (MU). Starting from 1 MUs for an empty plot, a plot with a house in a completely developed neighborhood has a value of 10 MUs. The observed timeframe for development from the end of stage 1 (pioneers), through stage 2 (convenience), to the beginning of stage 3 (saturation) is at least 5 years. As shown in Sect. 3.1 the annual real-estate price increase is 125%. The price bracket for plots in 2016 is 5000–20,000 OMR. These figures serve to align the simulation in Sect. 3.2.

3.1 Determining Real-Estate Prices for Residential Plots and Houses in Muscat 2011–2016

Determining residential plot and house prices in Muscat is essential to calibrate the simulation. The chosen time period of 5 years corresponds to the (theoretic) time frame officially allocated for urban development of typical residential neighborhood in Muscat (Nebel and von Richthofen 2016a, b) and coincides with the availability of historical data only recently published in the various sources used below. Since the official data sources do not publish this detailed information estimated real-estate prices for Muscat from 2011 to 2015 can be inferred from proxy values such as affordable housing programs, online real-estate brokers and the development of rental markets in Muscat (Figs. 3, 4).

3.1.1 Official Data Sources

The National Centre for Statistics and Information (NCSI) published data on real-estate in three different publications. The annual (National Accounts 2015) lists *Real-Estate and Business Activities* alongside other economic activities. The

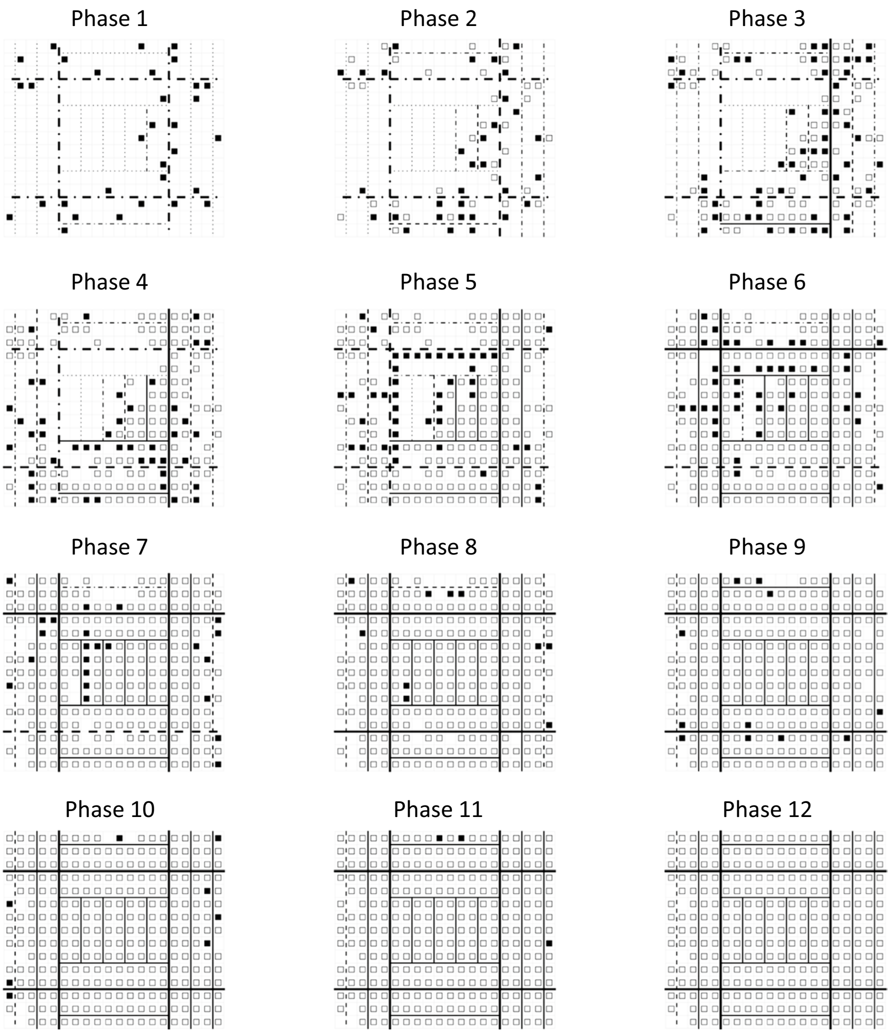

Fig. 3 Results of a smaller scale simulation based on the setting introduced in Fig. 2 to illustrate the possible outcomes of our simulation code

(Monthly Statistical Bulletin 2016) lists the *Traded Value of the Property in the Sultanate* consistently since 2011 alongside the number of properties issued, sales contracts, legal fees collected and mortgage values. The annual (Housing and Construction Statistical Bulletin 2015) lists in detail the *Value of sales, Number of Land plots registered, granted per Year by Governorates and Willayat* consistently since 2012, but has not been published for 2015 and 2016 at time of writing this article. Although some data gaps exist and the administrative boundaries of the Governorate of Muscat and Batinah had just changed in 2011 these publications form a valid base for the last 5 years.

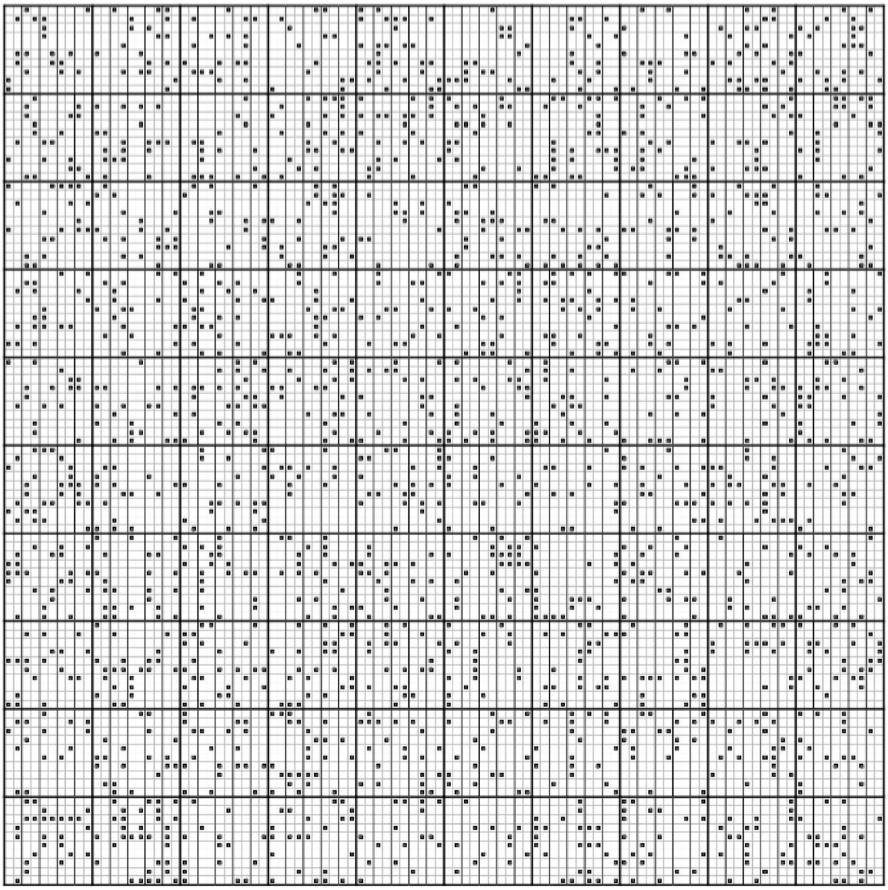

Fig. 4 Simulation of the settlement process: early phases showing established and new settlers (agents)

Real-estate statistics in Oman The trade of residential plot and houses forms the majority of the Omani real-estate market by numbers in Oman. According to NCSI "the traded value of property in Oman amounted to 7.67 bn OMR during the first ten months of 2016" and is corresponding to a 5.4% contribution to the GDP of Oman. In contrast to the volatile oil and gas sector, this figure remained constant and rose relatively from 4.5% in 2015, see (National Accounts 2015). The legal fees collected correspond to less than 1% of the traded value consistently since 2011. The properties issued nationally by the government range close to 200,000 units per year for 2016 and 2015 representing a three-fold rise from merely 70,000 units per year in 2011. Since 2011 the average price of *Real-Estate Land* increased by 570% in five years, see (Monthly Statistical Bulletin 2016). The steepest increase of 228% occurred from 2015 to 2016 which can be seen as a reaction to the general economic downturn after the oil-price drop in 2015 and inherent investment strategies of Omanis.

Real-estate statistics for the Province of Muscat The (Housing and Construction Statistical Bulletin 2015) lists the value of sales for the province of Muscat (including the 5 Willayats Muscat, Bowsher, Seeb, Al Amrat and Quryat) to be 536.6 Mio OMR for 2014. The number of land plots registered for the first time amount to 4264 and the number of land plots granted to 1297, totaling to 5561 land plots. This number decreased from 2013 and will decrease in the future as land reserves are getting scarce throughout Muscat Capital Area whereas other provinces in the interior of Oman expand gradually (von Richthofen and Langer 2015). The NCSI data allow us to infer that average prices of *Real-Estate Land* in Oman increased by 126% annually from 2011 to 2015 (excluding the exceptional increase of 228% in 2016). We can further conclude that the government is constantly releasing land plots to meet the demographic growth of Oman. Since only 3% of the total territory of Oman is currently urbanized there is theoretically no shortage of land in the near future across the whole country. The detailed data across provinces of Oman also shows that the real-estate development is highly heterogeneous and that land plots in Muscat are in high demand and at the same time scarce. Looking further into the Willayats of Muscat the NCSI data reveals that land plots in neighborhoods developed earlier and that are serviced by infrastructure reach substantially higher prices than those in remote neighborhoods developed later.

Determining residential plot and house prices in Muscat: The previous data refers to aggregated units of *real-estate land* or *land plots*. Accordingly, the average price for a land plot in Muscat in 2014 was 96 500 OMR a price too high for the regular 20 m × 30 m residential land plot in Oman or Muscat. If residential plot prices and the value of houses do not appear in official statistics, how can we then determine the price?

3.1.2 Affordable Housing Programs

The (Housing and Construction Statistical Bulletin 2015) lists loans granted to households not exceeding 20.000 OMR "so that these households can build suitable houses at their localities and place of economic activity against paying reasonable monthly installments not exceeding 25% of borrower's income". The Sultanate granted more than 80 Mio OMR for this scheme to date across Oman. These loans are granted by the government, the Housing Bank, the Ministry of Defense and the Petroleum Development Oman (PDO). While only 1400 new families benefited from this housing grant in 2014, the affordable housing program and the resulting value of a built house of 20,000 OMR plus can be seen as the lowest price for new properties in Oman in 2016.

3.1.3 Online Real-Estate Broker

A first approach can be to search for properties for sale in Muscat online. Real-estate brokers list plot prices varying from 7000 to 30,000 OMR and villa prices for 80,000–140,000 OMR depending on the size and location in Muscat in 2016. ("Muscat Real-Estate for Sale," n.d.) These figures are negotiable asking prices that contain the necessary bargaining margin to reach the minimum selling prices that can be 1/4 to 1/3 lower. Since 2015 the Ministry of Housing applies a transfer tax of 5%, but statistics have not been released yet and it is assumed that taxable contract prices are not the full prices paid. The newly founded Oman Real-Estate Association is supposed "to track value movements and be alerted to any fraudulent reporting of sale values". The (Property Briefing–Sultanate Oman: Residential Commercial 2014) prices 3 bedroom apartments in Muscat between 35.000 and 90.000 OMR. For 2011 the (Oxford Business Group 2016) prices land in Muscat from 45 to 140 OMR/m^2 in Seeb and Mawaleh, while the prestigious neighborhoods of Shati Qurm 280–500 OMR/m^2. The posted online real-estate prices minus a 30% discount effectively given as a bargain reflect the 2016 market upper price range. The online real-estate information can be used to infer a territorial price range of 5000–20,000 OMR for empty land plots of 600 m^2 and 25,000–110,000 OMR for villas in 2016. According to the Muscat Municipality (1992) building regulations, these villas can have up to 320 m^2 floor space. The data compiled by real-estate agents suggests a price range of 45–500 OMR/m^2, corresponding to 14,400–160,000 OMR per house.

3.1.4 Development of rental markets in Muscat

Another proxy for the development of real-estate prices is the rental market in Muscat. The rental market directly follows the land development costs consisting of land plot price and construction costs. The latter has remained constant due to uniform construction methods, low technical standards and the use of low-skilled underpaid labor, see (Georgetown University School of Foreign Service in Qatar 2011). According to (The Sultanate of Oman—Real-Estate Market Observations 2014, 3) the rental market remained stable throughout Muscat with the exception of up-market tourism and residential complexes that increased in value since 2011. The (Property Briefing–Sultanate Oman: Residential Commercial 2014) compares residential "average rent for quality property" since 2011 with a 121% increase and a 135% increase for "integrated tourism complex properties" towards 2014, yet without disclosing the sources or methods of data acquisition. The (Oxford Business Group 2016, 207) writes that the government of Oman implemented a 3 year annual 7% rent inflation cap (this cap was revoked shortly after). The same group reported in 2012 that rents dropped in Muscat by 1/5 (apartments) to 1/3 (villas) due to the economic downturn. The 2014 report states a rebound of 15% for rental property in Muscat. The rental market development shows parallels to the development of sale prices for land plots as compiled by the NCSI and can thus be used to further underpin an annual growth rate of 120% over the last 5 years.

Drawing from the above (Sects. 3.1.1., 3.1.2., 3.1.3., 3.1.4.) we can estimate the real-estate prices for Muscat from 2011 to 2015 in the following table:

As a first, simplified assumption for our future simulations, we can thus, based on Table 3, that an empty plot of land is worth 10 K OMR. Let us use this value as an equivalent of 1 monetary unit (MU). A reasonable conservative estimate of a price for a house (including the plot of land) is 100 K OMR. Although this may still underestimate the real situation, it gives, as we will see, a profound estimation of the

Table 3 Estimation of the real-estate prices for Muscat from 2011 to 2015 Sources: (National Accounts 2015), (Monthly Statistical Bulletin 2016), (Housing and Construction Statistical Bulletin 2015), (The Sultanate of Oman—Real Estate Market Observations 2014), (Property Briefing—Sultanate Oman: Residential Commercial 2014), and (Oxford Business Group 2016)

	NCSI	Affordable housing	Online broker	Rental market	Estimated real-estate prices
Price of 600 m^2 land plot OMR	–	–	5–20 K	–	5–20 K
Price of 600 m^2 land plot with 320 m^2 villa OMR	–	20 K	14–160 K	–	14–160 K
Annual growth rate (2011–2015)	126.00%	–	–	120.00%	125.00%
Price of house OMR/m^2	–	62.5 K	45–500 K	–	45–500 K

immense shadow economy that comes with land speculation. Hence, we assume that a house, including the plot of land, in a fully developed neighborhood is worth about 10 MUs.

3.2 Simulation with Trade

Based on this information, let us assume, as stated above, that after the lottery each plot costs 1 money unit (MU). Then, we assume that certain factors add value to this price in the following ways[4]:

- *Infrastructure* + 2 MUs for paved streets. This indicator represents the ease of reaching a plot of land and starting the construction of a house.
- *Neighborhood growth (i.e. houses on direct neighboring built)* + 1 MU for 1–2 neighboring houses, another + 1 M for 3–4 neighboring houses, further + 1 MU for 5–6 neighboring houses, and finally, + 1 MU additionally for 7–8 neighboring houses. This indicator is related to the development level of the streets (water, eccentricity, etc.) as well as the "desirability" level of the specific area.
- *Complete plot settlement* + 1 MU for reaching a complete settlement degree of 25–50%, another + 1 MU for reaching a complete settlement degree of 50–75%, and finally a last + 1 MU once a complete settlement degree of 75–100% is reached. This indicator takes the overall quality of living in the respective plot into account. The more people live there, the more shops, schools, mosques or entertainment facilities are established.

The large-scale simulation has a grid size of 100 × 100 cells. The simulation is initialized with a distribution of agents (P, Nn, In, Sn, Tn, Cn) described in Sect. 2.1

[4] All additional factors for the price are thus normalized with respect to the value of an empty plot after the lottery, i.e. the pure value of land.

Table 4 Initial agent distribution for the scenarios 1–4

Agent types	P (%)	N1 (%)	N2 (%)	I45 (%)	S1 (%)	S5 (%)	S7 (%)	S9 (%)	T7 (%)	C2 (%)
Scenario 1 and 2	20	5	5	15	12.5	5	15	5	12.5	5
Scenario 3 and 4	35	–	–	10	12.5	5	15	5	12.5	5

Note that scenario 1 and 2 and scenario 3 and 4 have the same initialization set

as shown in Table 4. Business houses are excluded from the simulation as they depend on a certain population level of the plot with family houses and then come quickly into existence, thus they are not relevant for the occupation dynamics.

The simulation is aligned with the previous data to the best of our knowledge: As discussed the development of the MUs is aligned with the 5-years real-estate price index for the Muscat capital area. The settlement structure and geometry follow the physical planning guidelines and empirical data from Al Khoud/Muscat capital area. It has to be noted, that the very nature of the settlement process and the rather thin quantitative data background allow us only to discuss matters in a qualitative way. Settlement research in Oman is still in the early phases and interesting information on how positive or negative incentives impact the settlement process are given implicitly only. We strongly believe that our simulations really can help at this stage to have a compass for decision making under the given uncertainties.

Additionally to the above-described Initialization and Building Phases, the simulation is equipped with Trading Phases. For every seller, we checked if his/her selling conditions are fulfilled. Then the list of cumulative buyers is processed for a potential buyer, and if somebody is found the plot gets sold. For cumulative buyers, their possible ways to buy in a row is adjusted (e.g. if he/she buys a house vertically there is no possibility anymore to buy horizontally). If there are no cumulative buyers, the plot is sold to an Infrastructure-driven owner (I) from outside.

After 1000 iterations the simulation scenario 1 results in a partial settlement of the area covering 80% of the plots. To simulate the influences of land-management measurements in the form of incentives, the simulation is run in 4 scenarios:

- Scenario 1 reflects the status quo and has no positive incentive (financial benefit) nor negative incentive (taxation) imposed on the settlers. Note that this Scenario 1 is the same as the result of the simulation as discussed earlier.
- Scenario 2 introduces negative incentives in the form of land-speculation taxes.
- Scenario 3 introduces positive incentives in the form of benefits given to settlers that develop their land.
- Scenario 4 introduces a combination of negative & positive incentives.

The simulation allows discussion of the completion rate per phase in Fig. 5a. It also indicates the average value of plots per phase in Fig. 5b. Figure 5c shows the number of sales per phase. Figure 5d sums up the total value of sales per phase. It further indicates the infrastructure investment by the government in reaction to

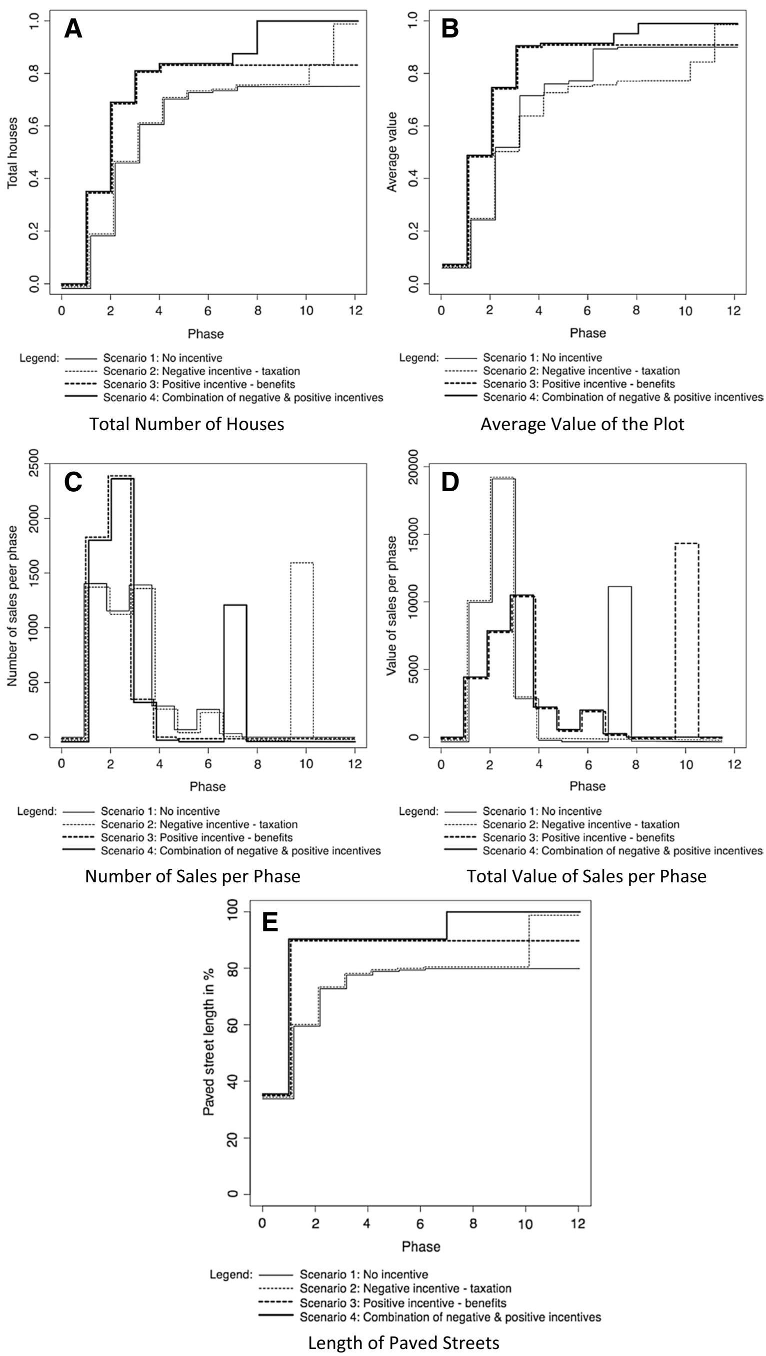

Fig. 5 Results of the simulation of the settlement process with respect to the four discussed scenarios

private development stages in Fig. 5e. All figures superimpose the graphs for scenarios 1–4 and allow a detailed discussion of alternatives.

The large-scale simulation is thus already Scenario 1: No taxation and no positive incentives. Figure 5a indicates that an equilibrium of developed and non-developed plots is quickly reached after an initial trade and development phase where owners of undeveloped land keep on speculating for a rise in real-estate prices. In consequence, the average plot value plateaus early as seen in Fig. 5b. The number of sales per phase declines as well as the total value of sales per phase, see Fig. 5c, d. In response to this the total paved road is never completed either, see Fig. 5e. This 'grid-lock' situation cannot be resolved by market forces alone and the empty plots will not be developed.

An interesting and important question is the sensitivity of our simulations with respect to changes in the initial distributions of the agent types. The first glimpse on this is given in the scenarios 3 and 4, cf. Table 4. Additional four scenarios are discussed in the appendix to not disturb the flow of the presentation.

Let us now consider the impact of positive or negative incentives. From point of view of decision making it is necessary to name these incentives, let it be taxes or additional monetary benefits for building houses fast. From the point of view of our simulations, these incentives are rather proxies for changing the changing the time-frame at which people are willing to build their houses. For instance, under the financial pressure of taxation, an N5 neighborhood driven agent may be tempted to build his house already if there are just four neighbors around or even less. i.e. the very nature of these incentives is that agents re-evaluate their building decisions at each step of the simulation based on the imminent threat of losing money (either in the sense of being no longer able to gain a bonus payment or to be forced to pay taxes).

Scenario 2 explores a set of taxes: Land transaction fees based on actual land prices, land-speculation taxes for empty plots, community charges reflecting the governmental infrastructure provision, and the return of undeveloped land to the government. Let us assume that these governmental measures directly influence the preference structure of the agents. Once these negative incentives are in place, the agents will consider their building decisions and will gradually lower their expectations regarding a favorable environment to start construction so as to minimize financial losses. These reconsiderations of building decisions are reflected in the simulation in terms of an additional downgrade phase after the trading phase. Downgrades of owner types simulate taxes on empty plots. After the equilibrium is reached, the owners of empty plots are "downgraded" as follows:

- Cx -> S7 Cumulative Mover to Seller with value 7
- Tx-> Sx Advanced Seller to Seller
- Nx -> N (x − 1) Neighborhood driven to driven with one less neighbor
- Sx -> S (x − 1) Seller to seller with one less value
- N1 -> P Neighborhood 1 Driven Mover to Pioneer Mover
- I -> P Infrastructure Driven Mover to Pioneer Mover

Every owner type hence ends either as P or S1, so every plot will be built eventually. Our simulations show that this leads to an increase in efficiency so that very soon after a stationary equilibrium is reached the remaining empty plots are occupied.

Taxation forces the undecided land-owners to eventually sell their land as the costs of keeping it gets higher. Figure 5a indicates a return of undeveloped plots to the market after a certain time lapse (as defined by the height of the taxes). While the average plot value develops slightly slower than in Scenario 1 it eventually topples it, see Fig. 5b. The number of sales per phase and the average value of sales per phase is identical to Scenario 1 until the said taxation mechanism kicks in and releases the undeveloped plots back to the market as seen in Fig. 5c, dD. This process resolves the 'grid-lock' effect of Scenario 1 and contributes to higher development rates until the area is fully build up. This, in turn, forces the government to complete the road infrastructure as well, see Fig. 5e.

As explained, the municipal provision of paved roads lags behind the plot settlement, yet the budget for the complete roads have to be set aside. In particular, the change in paved street length demand for further urban development is interesting. Without taxation about a fifth of the budget is not used for infrastructure provision until a very late stage, but once an equilibrium is reached this amount is more or less immediately required to service the plots. However, there still remains some period of time after the initialization where continuous investment in streets is required.

Scenario 3 explores a set of incentives: Additional loans for pioneer settlers, reduced community charges for pioneer house construction, preferred selection of plots, payments for longer stays, etc. Again, we assume a direct influence on the preference structure of the agents. Whoever takes part in a lottery under the thus changed frame conditions will have an intrinsic motivation to start building a house as soon as possible. Hence, compared with scenario 1 the number of "early builders" is considerably increased, which is reflected in the changed initial conditions in Table 4. The positive incentive mechanisms in form of financial benefits change the initial behavior of the settlers. This is modeled in a different initialization distribution. In short, more incentives will 'convince' more settlers to build. Therefore scenario 3 results in a faster development rate and higher completion level as seen in Fig. 5a. Yet this process cannot convince land speculators to develop their land, as the average value levels out at the same level as in Scenario 1 and even earlier, see Fig. 5b. The number and value of sales per phase increase much faster, see Fig. 5c, d. That results in a faster road development, as seen in Fig. 5e. This scenario will eventually create a similar 'grid-lock' situation as in Scenario 1 with 15% of empty plots.

Scenario 4 explores the impact of both taxes and incentives geared towards an efficient and complete land development benefiting those addressed by the welfare system and burdening the speculators. The effects of Scenarios 2 and 3 are combined in this simulation, resulting both in a faster and higher initial completion rate and faster return of undeveloped plots to the market, as seen in Fig. 5a. The average plot value increases faster, as seen in Fig. 5b. The number of sales per phase and the average value of sales per phase is identical to Scenario 3 until the taxation mechanisms kick in and release the undeveloped plots back to the market similar to the effect of taxation on Scenario 2, as seen in Fig. 5c, d. To enable further flexibility, we extended the simulation phases to allow Infrastructure Upgrades. If a specified phase is reached (i.e. a specific number of successive building phases), or if an equilibrium is reached prior, all streets are getting paved.

Both positive and negative incentives show that the government could create a steering mechanism for better control of land allocation and infrastructure provision. By means of taxes and benefits, the government could both phase and quantify its spending instead of raising expectations of 'instant fulfillment' that are neither achievable nor beneficial to the settlement process. In practical terms, by means of this simulation, the government could know when to spend the first 50%, then the next 25%, and so on.

This large-scale simulation shows that the present land allocation system in combination with subsidized private house construction as describe in scenario 1 does not reach the desired outcome of an optimal and efficient settlement process. The trade of the plots as perfect economic goods as well as the understanding of plot owners as rational buyers under an approximated ideal market alone will not result in full and fast housing development. As shown in Fig. 5a–d in Scenario 1 a speculative real-estate boom started for the sole profit of private investors. Those agents who can afford not to build and who are not in immediate need of cash, e.g. those least in need of a welfare system as originally intended by the land allocation system, will generate profits for themselves. Figure 5b, average value per plots, shows that the process of land allocation becomes even more difficult to access for those who are in need once the real-estate boom has been started. Taxation will not only curb the real-estate boom, it will also return undeveloped plots to the market. This offers a second chance to all buyers. As shown in Fig. 5c the volatility of plot trade is highest in the beginning. Again, the taxation mechanism is a means to control this. In direct contrast, positive incentives will revive the market, leading to faster and higher development rates. The government itself, which allocated land plots, is left out of the wealth accumulation process while still burdened with continuous infrastructure provision. In a state with limited resources, such a process is neither economically nor socially sustainable. For these reasons land-management measures as mentioned in the beginning of this article and modeled here in the form of negative and positive incentives need to be introduced.

4 Résumé and Outlook

Social simulations are unlike simulations in physics where clear laws govern the complete set without a doubt, one has to work with suitable assumptions and base them on observations. Here, we outlined the observable governing dynamics of settlement (governmental infrastructure decisions, different agent types, plot occupation) as well as the implicit dynamics of plot price growth. We used these to derive a tangible foundation for our simulations. In particular, we here present the first approach to discuss and study the housing price dynamics and the immense value generation that emerges from a state donation.

In view of the problems of land settlement in Oman as outlined in the introduction, we can clearly state that the described simulations are suitable to visualize the settlement process and shed light on otherwise tacit parameters, like the investment times in streets and the actual development of housing prices. Although based on qualitative findings, our simulations clearly indicate that the lottery system is not efficient in the sense that a considerable number of plots will not be used for building houses. We showed that easy-to-implement positive and negative incentive mechanisms are suited to resolve this issue and to increase the efficiency of the land settlement system.

Although the lottery system is intended to be socially fair our simulation indicates that average values of plots rise significantly and hence socially disfavored families soon face the problem that available plots will be too expensive for them and lock the market, while undeveloped plots are still available. In that respect, another adjustment may be required, e.g. that families with an income below a certain threshold may be eligible to receive more lots in the lottery or that a dedicated percentage of the plots is reserved for low-income persons. Even though taxation on land and property is currently underdeveloped in Middle East societies like Oman, such mechanisms need to be introduced in order to balance market forces and social welfare systems. As Scenario 1 showed the 'business as usual' model will lead to an ever-increasing demand for land-plots while not achieving full completion rates and distorting the market. Administrative adjustments in the form of taxation, as developed in scenario 2, will be difficult to realize in Oman, when decision makers are at the same time powerful stakeholders in the local real-estate game. This paper thus wants to alert those who believe in, and those intended to benefit from the social welfare aspect of the land allocation system. Instead of abolishing it, we discussed how to even enhance it by offering additional benefits, see scenario 3. Yet, only the interplay of taxation and benefits can if closely monitored by the government, in the future lead to an efficient and fair land development process.

Instead of an abstract simulation on a square grid, a future implementation of the simulation could match the actual urban geometry of planned settlements such as Al Khoud. This would reveal irregularities in the urban geometry and illustrate possible spatial distortions and boundary effects.

Further extensions of our simulation will address the mixing of tribal groups across households, their plot development and trade behavior to discuss the possibilities of clans to obtain connected areas within a neighborhood and thus reproduce tribal links and social division originally intended to be overcome by the lottery land allocation system.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Appendix: Impact of Different Initial Population Distributions

The lack of reliable data on the actual initial distributions of the agent types is in some way a drawback of our simulations. So far best guesses were used to initialize the scenarios 1–4. In this appendix, we provide further simulations based on these scenarios where in particular the numbers of Pioneer Mover (P) and Neighborhood Driven Movers (N1, N2), as well as Infrastructure Driven Movers (I45) are altered, cf. Table 5. In Fig. 6, the results of the corresponding simulations are displayed with

Table 5 Initial agent distribution for the scenarios 1–4 discussed in the main part of this text and the additional scenarios 5–8

Agent types	P (%)	N1 (%)	N2 (%)	I45 (%)	S1 (%)	S5 (%)	S7 (%)	S9 (%)	T7 (%)	C2 (%)
Scenario 5	10	10	10	15	12.5	5	15	5	12.5	5
Scenario 3 and 4	35	–	–	10	12.5	5	15	5	12.5	5
Scenario 6	30	5	–	10	12.5	5	15	5	12.5	5
Scenario 7	25	5	5	10	12.5	5	15	5	12.5	5
Scenario 8	20	10	5	10	12.5	5	15	5	12.5	5
Scenario 1 and 2	20	5	5	15	12.5	5	15	5	12.5	5

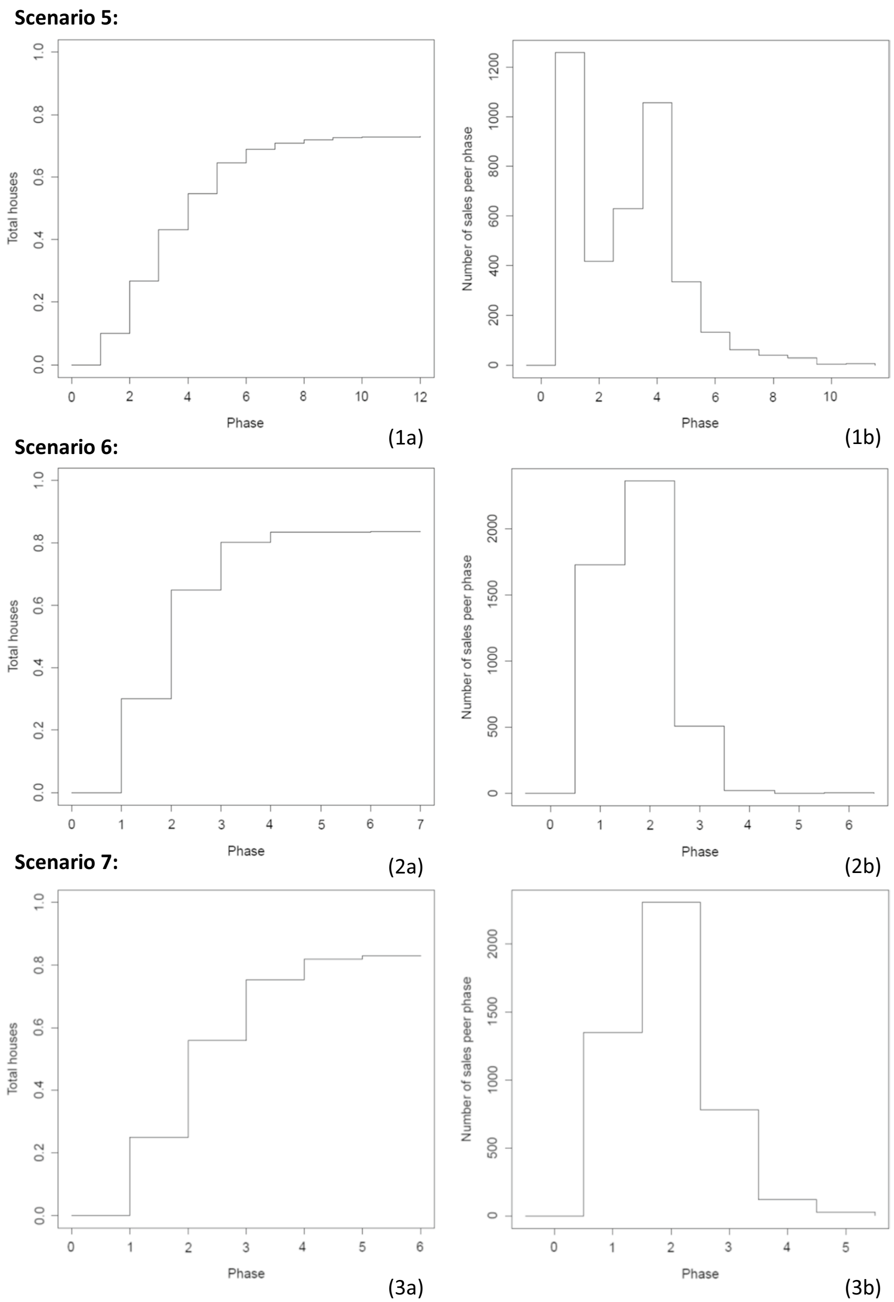

Fig. 6 Comparison of simulation results with different initial conditions as described in Table 5

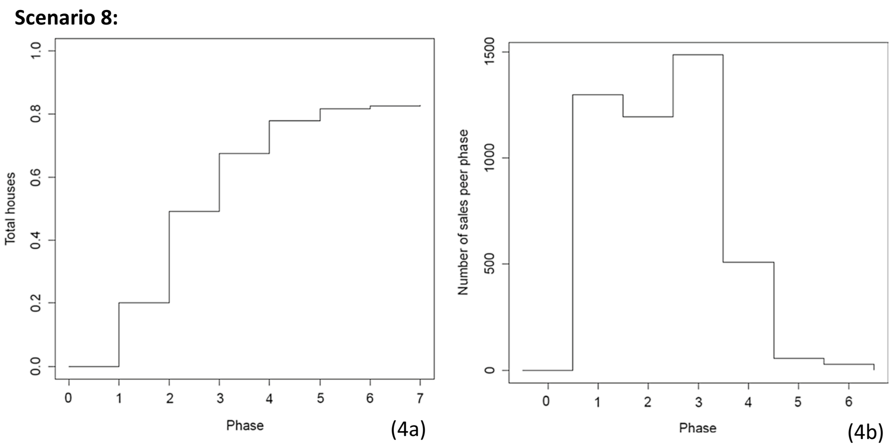

Fig. 6 (continued)

respect to the development of the total number of houses (left column) and the number of sales per phase (right column).

With respect to the degree of development of the area, scenario 5 behaves worst, and we observe that higher numbers of P agents lead to (slightly) higher development levels and to achieving the equilibrium faster. In particular, the majority of sales takes place at earlier phases. This is in alignment with our main insights that the more comfort the agents desire for building houses the more difficult it will get to populate the complete parcel of land (and therefore certain incentives for building houses sooner are recommended).

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