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The Choice of Actor Variables in Agent-Based Cellular Automata Modelling Using Survey Data

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Abstract: This paper considers whether existing approaches for quantifying variables in cellular automata (CA) modelling adequately incorporate all the relevant factors in typical actor decisions underpinning urban development. A survey of developers and planners is used to identify factors they incorporate to allow for or proceed with development, using South East Queensland as a reference region. Three types of decision factors are identified and ranked in order of importance: those that are already modelled in CA applications; those that are not modelled but are quantifiable; and those that are not (easily) quantifiable because they are subjective in nature. Factors identified in the second category include development height/scale, open space supply, and existing infrastructure capacity. Factors identified in the third category include political intent, community opposition, and lifestyle quality. Drawing on our analysis of these factors we suggest how and to what extent survey data might be used to address the challenges of incorporating actor variables into the CA modelling of urban change. The paper represents the first attempt to review what decision factors should be included in CA modelling, and how this might be enabled.

Keywords: agent based modelling; cellular automata; actor variable; urban simulation; survey data

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1. Introduction

The expansion of cellular automata (CA) modelling to incorporate actor variables—those variables that influence actors' spatial development decisions—is a critical move for such modelling to fully capture the processes of urban development and to forecast their trajectories. A recent review of contemporary issues in modelling urban change using cellular automata highlighted the important need to consider human decision factors in CA modelling [1]. The current paper addresses this need by considering whether existing approaches for quantifying variables used in CA modelling adequately incorporate all the relevant factors in typical actor decisions that underpin urban development. The paper represents the first attempt to review what decision factors should be included in CA modelling, and how this might be modelled. Using survey data, this paper identifies three such types of decision factors—those already modelled in CA applications, those that are not modelled but are quantifiable, and those that are not (easily) quantifiable, being based on subjective factors—and draws on the factors to suggest how and to what extent survey data might be used to address the challenges of incorporating actor variables into CA modelling of urban change.

A central issue in incorporating agent based modelling (ABM) into CA models revolves around the choice of actor variables, that is, what aspects of the decision processes of development actors have the most impact in shaping the cartography of development? The number of potential variables can be very large, given the possible sites and location variables involved in whether or not development will proceed in a particular cell when combined with individual actor decision rules concerning the development. Moreover, as

not all factors play equally important roles, the weighting to each decision variable needs to be considered if modelling is to reflect real world processes.

This paper addresses the challenge by using surveys of developers and planners to identify factors they incorporate in decisions to allow for or proceed with development in different areas, using South East Queensland (SEQ), Australia, as a reference region. While we acknowledge that other agents or stakeholders, such as communities and residents, can also play important roles in the process of urban development, as is evidenced by the legendary work of Jane Jacobs [2] and empirical studies in recent years [3,4], the scope of this paper focuses on developers and planners as the key actors in determining which areas will be developed or changed in density or land use, with planners setting the rules as to which areas are available for development, and developers making the decisions as to which specific sites are actually developed. The paper then separates these actor variables, relevant in development decisions, into those that are already included in standard CA modelling, those that are not (easily) quantifiable for CA modelling due to the subjective nature of the factors, and those that can be quantified and, thus, added to standard CA modelling. Thus, the paper contributes to enhancing our capacity in choosing actor variables for expanded CA modelling. It is essentially a pilot study, due to small sample sizes, but indicative of the scope for a similar survey based approach to optimise the selection of actor variables.

2. Agent Based CA Modelling of Urban Development

One challenge that remains in current CA modelling is the lack of factors representing individual human decision behaviours and their collective implications for urban change [1]. Different from natural or agricultural landscapes, urban systems are strongly influenced by various factors in both human and environmental dimensions. Factors relating to the areal features and the built environment are objective in nature and relatively easier to measure, and are commonly captured in CA models [5], while factors reflecting people's decision behaviours are subjective and significantly under explored [6]. The integration of CA and agent based modelling, or agent based CA modelling, allows the decision behaviours of various 'agents' or 'actors' to be incorporated and simulated in the cellular space, in order to understand urban change over time [7–10]. Agent based CA models are primarily used for the modelling of local area processes of land use and land cover change, where the CA model provides the 'ground' on which various urban agents act [11,12].

ABM usually describes the decision making of individuals within a group of the population, with the advantage of allowing their behaviour and decision making to interact with each other and with the environment they live in [13]. Thus, an agent based CA model is able to provide both aggregated spatial and socioeconomic outcomes as well as disaggregated outcomes at the individual level [14]. In this sense, the selection of agents plays an overriding role in the ABM process [15]. Agents commonly involved in the process of urban development include urban planners, property developers, municipal infrastructure and service providers, private landowners, peasants, policy makers and urban governors, and residents [16]. They are often modelled as software agents, representing groups of people rather than individual behaviour, in order to simplify the computational process. The negotiation and reconciliation among these agents ultimately result in the change in land use patterns, space suitability and zoning.

Two sets of attributes determining the decisions of agents have been most grounded in the existing literature: personal and attitudinal attributes [17]. Personal attributes relate to the personal characteristics of agents, such as socioeconomic and demographic characteristics including gender, age, education, income, marital status, family composition, or social network [18,19]; these characteristics are also known as 'static attributes' reflecting the latent effect of agents' residential choices that may further influence land use change and urban development. Attitudinal attributes relate to specific attitudes and decisions about urban development, such as the locational preference of residents and investors, investment decisions by property developers, spatial choices by urban planners and architects, and

housing policies implemented by urban governors [20]. Attitudinal attributes of agents, also known as 'dynamic attributes', evolve based on their interactions with other agents and/or within institutions and governance structures, resulting in certain criteria to trigger land use change over time [17,21].

Most commonly, agent based CA modelling relies on survey data as input, collected by questionnaires and interviews carried out among agents to characterise their roles, characteristics, attitudes, and the intrinsic relationships amongst different agents involved in the decision making process. Personal attributes are relatively straightforward, being assigned by agents' personal characteristics, while attitudinal attributes are hard to quantify and measure due to their subjective and dynamic nature. Attitudinal attributes are often represented by a series of decision rules, and parameterized using the Likert scale of agents' opinion [22] on a set of prescribed input conditions, known as factors or variables. Thus, the selection and identification of attitudinal variables for different agents play an important role in the ABM modelling process, which our study explores.

The application of ABM coupled with CA modelling in the domain of land use change and urban development has blossomed in the past few decades, and ABM based urban simulations have gained increasing attention from scholars in multidisciplinary contexts. We do not intend to set out a systematic review on ABM; rather, we provide a brief summary from highly cited papers and those published within the past five years in different national contexts, with the aim of identifying the current understanding of the roles that agents play in the spatial modelling of urban development and of variables used in quantifying agents' attitudes. Agents commonly discussed in the literature noted include experts, governments, peasants, residents, communities, retailers, industrialists, firms, developers, and urban planners (Table 1). The attitude of governments, which are often represented by experts, is more towards the 'top down' perspective, in terms of policy making, approval, implementation, supervision and administration; while firms, residents, and communities represent the receivers of policy and regulation implementation from the 'bottom up' perspective, or consumers/purchasers at the end of the property development chain.

Developers and urban planners serve as the primary facilitators of land use change and actioners of planning regulations in the urban development process, and are the target agents of our study. Table 1 indicates that other actors, such as residents, may also be central to agent based models. Thus, our analysis does not purport to be complete in terms of representing all the types of agents of urban development. However, the actions of planners and developers are always required to produce development, even when other actors play significant roles.

2.1. Urban Planners

In the planning process affecting urban development, urban planners play an important role by assigning regulatory control of the municipal government into operation. This regulatory control is policy based and provides a general framework under which the land use change process occurs [17]. Agent based CA models are designed to simulate the activities of the urban planners whose primary goal is to select and subdivide the cadastral parcels upon which future growth can happen. During the selection process, planners initiate subdivisions to split large pieces of land into roads, city blocks and cadastral parcels within the regulatory limits. The subdivision criteria and the choice of the planning zones in which growth occurs are influenced by specific policies, such as agricultural land preservation, urban regeneration and housing consolidation [10]. Besides, planners are also assumed to follow the principle of prioritising facility/utility accessibility and optimising usage in order to cater to the demand for newly developed areas. Thus, the attitudinal variables can be represented by how much planners evaluate the importance of transport accessibility, availability of facilities and utilities, land and environmental value, as well as the value of planning policies and regulations.

However, social and political factors are also influential in planning decisions about land use rezoning. For example, higher income communities often resist proposals to

increase urban densities in their neighbourhood, even though the location has the necessary infrastructure and accessibility [23]. The extent to which such factors influence planning decisions varies according to the extent to which the planning system takes into account community wishes and the extent to which it allows discretionary decision making [24,25]. More generally, whether urban development is allowed at a particular location can depend on the prevailing ideology at the municipal or provincial level, with more environmentally oriented administrations less inclined to zone natural habitats and the like for development [26]. Such factors mean that planning decisions may deviate from those that are based purely on the optimisation of locational attributes, and these factors are generally absent from current agent based modelling (Table 1).

2.2. Developers

It is widely acknowledged that developers are motivated by 'profit' and, therefore, search through actual or potential 'lots' identified by planners that they consider to be most profitable [27]. Thus, developers' attitudes about the allocation of land resources can be represented by how much they would maximise spatial efficiency, and optimise the location and quantity of land use to achieve the highest investment profit. Developers may be affected by their initial capital and lending capacity at an early stage of the land acquisition process [28]. Then, the level of desirability for land development can be evaluated by investment profit and reflected monetarily in terms of housing price, land price, and development cost, which are indirectly affected by variables related to locations, neighbourhoods, planning districts, and the proximity to transportation network, facilities and utilities (e.g., recreation parks, schools, hospitals, commercial centres).

However, factors other than locational attributes can be important in determining decisions as to whether to develop a particular parcel of land. Initially, the parcels that are most ideal for development might not be available, because the owner does not want to sell, for example. Developers with larger land banks may be more willing to reserve some well located parcels from development in the hope of long term speculative land value gains [29,30]. The timing of development is also influenced by housing cycles. In addition to lower production in the down phases of housing cycles, developers may maximise their production when prices are rising (rather than basing production on peak housing values) because this increases demand for housing as an asset [31]. Moreover, agent to agent behaviours can be significant. Where developers can obtain concessions from planning regulations that increase their profit, which is possible in planning systems with more planning discretion, a parcel may be developed faster and/or at a more intensive level than the official planning regulations might allow [32]. Therefore, a simple reading of developer decisions based on maximising profits according to the values of locational attributes can omit the negotiation, ownership and timing factors that play a key role in whether a land parcel will be developed or not in a certain period. Again, such factors are essentially absent from current agent based CA modelling (Table 1).

2.3. Quantifying Decision Variables

While most potential decision factors are nonquantitative, methods exist for transforming qualitative variables into indices or other forms of measures that can be incorporated into agent based models. The subjective average weighting, given to the importance of various factors, can be calculated from individuals' attitudinal hierarchies that rank the importance of each pair of factors [33]. Where pairwise comparison of attributes in a cell/location is not possible, a weighted summation method can be used to compute a suitability score, as shown in Wu [34]. A variant of this involves the use of fuzzy logic, in which weights of relevant criteria are assigned on the basis of preference factors and then aggregated with criterion values (potentially including qualitative criteria) to produce a single value for each cell [35].

Potential methods for incorporating qualitative decision criteria are, thus, available. Nevertheless, qualitative variables still need specification via categorisation or dummy

variable designation, for example. Where agents can be categorised into groups with similar behaviour, then field work, interviews and census data can be used to derive behavioural characteristics and choices [36], including choices based on qualitative variables. This approach has been applied by Wahyudi et al. [27,28], to distinguish different developer behaviours in urban development modelling. Thus, ABM approaches require a sufficient number of nonunique behaviours to allow criterion weights to be estimated and applied to CA models. In the next section, we present a case study to scope the extent to which planners and developers' decision criteria for urban development are nonunique, as well as the extent to which such criteria can be quantified and categorised.

Table 1. A summary of agents and their attitudinal variables used in selected papers (ordered by publication year).

Paper	Modelling Purpose	Agents	Attitudinal/Decision Making Variables
Waddell, 2002 [37]	Modelling urban development for land use, transportation, and environmental planning in Eugene-Springfield, Oregon, USA	Residents; developers	Travel model, specified events, mobility, locational choices, land price, real estate development.
Waddell et al. 2003 [38]	Designing UrbanSim as a model system to address emerging needs to better coordinate transportation and land use planning	Developers	Existing development characteristics, land use plan, environmental constraints, proximity to highway and arterials, proximity to existing development, neighbourhood land use mix and property values, recent development in neighbourhood, access to population and employment, travel time to CBD and airports, and vacancy rates.
Huigen, 2004 [39]	Understanding the settlement process and spatial effects of population growth for future land use and land cover change in Isabela, Philippines	Residents	Needs, desires, experience of residence: whether residents' potential option fits the development's requirements, whether they pay the initialisation costs on land use change, whether they execute and evaluate land use change.
Kii and Doi, 2005 [40]	Modelling land use and transport for the policy evaluation of a compact city of Takamatsu, Japan	Residents; firms	Residents: household types, place of residence, shopping places, utility level of household, level of consumption of goods, level of consumption of land, neighbourhood environment, the numbe of available services or goods per trip, the number of shopping trips, commuting cost, rental cost; Firms: set of commercial firm locations, their income level, price of goods from firm.
Salvini and Miller, 2005 [41]	Simulating the evolution of an integrated urban system in Greater Toronto Area, Canada	Developers; residents; firms; property owners	Transportation network, travel times, vehicles, buildings and dwelling units, locations, neighbourhoods, planning districts, monetary values of houses, schedule of transport.
Brown and Robinson, 2006 [42]	Modelling the patterns of development based on initial movement into exurban areas	Residents	Social comfort, openness/naturalness, residential aesthetics, schools and work, housing cost and good value, convenient to shopping and schools, community size.
Jepsen et al. 2006 [43]	Modelling the shifting pattern of cultivation field in Vietnam	Residents	The number of people in the household and the number of people in one household holding the plot requirement.
Wagner and Wegener, 2007 [44]	Implementing a fully microscopic model of urban land use, transport, and environment in metropolitan area of Dortmund, Germany	Residents; firms; developers	Land use, activities, travel demand, networks, link loads, air quality.
Fontaine and Rounsevell, 2009 [12]	Modelling future residential pressure on a regional landscape in East Anglia, UK	Residents	Their evaluation of the relative contribution of environmental amenities: roads, key service areas, market town, cities, coastline.

Table 1. *Cont.*

Paper	Modelling Purpose	Agents	Attitudinal/Decision Making Variables
Robinson and Brown, 2009 [45]	Evaluating effects of land use development policies on exurban forest cover in South eastern Michigan, USA	Land developers; residents	Land developers: structuring the supply of residential landscapes to residential land buyers, land development density Residents: residential location relative to roads and aesthetic features, and their effects on the amount of tree cover on the landscape, aesthetic value to residents and ecological services.
Haase et al. 2010 [46]	Modelling residential mobility in a shrinking city in Leipzig, Germany	Residents (households)	Attractiveness of place, migration/persistence choice; population components: net migration, fertility, mortality.
Valbuena et al. 2010 [11]	Exploring the effects of farmers' decision on landscape structure in rural regions of Netherlands	Farmers	Whether farming represents their main income, age of the farm head, agribusiness type, farm size, the likelihood of the existence of a successor and the location of the agent and the farm; whether the diversification of farm practices was seen as an economic alternative; whether farmers would expand their holdings; and whether they would participate in programmes for nature and landscape conservation practices.
Zhang et al. 2010 [47]	Modelling of urban expansion in Changsha, China	Government; peasants; residents	Governments: how much they would follow a certain spatial and temporary principle, how to maximise spatial efficiency and optimise land use amount and land use location Residents: how to maximize the utility function, how much they evaluate the importance of transport accessibility, land value, and environmental value; Peasants: how to evaluate the importance of distance to the centre of city or town, distance to urban arterial road, neighbourhood density of protected agricultural land, construction land, increases in sealed surfaces, urban sprawl, traffic congestion and residential segregation.
Jjumba and Dragicevic, 2011 [10]	Simulating the process of urban land use change at a cadastral scale and incorporating the interactions of the key stakeholders in City of Chilliwack, Canada	Planners; developers; households; retailers and industrialists	Policy scenarios: preference weights of the land use types that fall within its neighbourhood Planners: agricultural land preservation, urban containment Developers: proximity score for the highest profit lot, weights representing desirability for different types of land use, the count number of different types of land use in the neighbourhood Households: income, value of residential unit occupied by an agent, average household income in the agent's neighbourhood, average property value in the agents' neighbourhood, list of suitable vacant residential units Retailers and industrialists: location of their businesses and activities, specialisation of their operations, economic worth of their business.
Wu and Birkin, 2012 [48]	Modelling spatial microsimulation of demographic change in Leeds, UK	Residents (households)	Characteristics of surrounding individuals, households, the area that they live in such as marriage, the areas that they used to/are going to live in, local housing and the local population, migration and mortality.
Arsanjani et al. 2013 [49]	Simulating urban growth patterns in Tehran Iran	Residents; government; developers	Residents: infrastructure accessibility and high density residential areas Developer: investment profit, housing price, land price, development cost Government represented by experts: river streams risk zone, roads network buffer, highways buffer, airports risk buffer, military facilities risk zone, power facilities risk zone, parks buffer, and non-suitable slope.

Table 1. *Cont.*

Paper	Modelling Purpose	Agents	Attitudinal/Decision Making Variables
Celio et al., 2014 [50]	Modelling land use decisions in a pre-Alpine area in Switzerland	Experts	Agricultural network, parttime business, education, accordance to federal ecological programs and aims.
Wahyudi et al. 2019 [27]	Modelling the impact of capital possession by land developers on the location selection and their effects on urban development	Developers	Developers: the maximum profit in land development; initial capital through lending
Wahyudi et al. 2021 [28]	Simulating the impact of different sizes of developers on urban development in Jakarta, Indonesia	Three types of developers (large, medium and small)	Large developers: investing a minimum land size of 100 hectares into urban area, approximately US $500 million or over Medium developers: investing from US $140 to 500 million Small developers: investing from US $70 to 140 million

3. Identification of Agent Based Decision Variables: A Case Study

To identify what factors are considered by planners and developers in deciding on locations for development, three surveys were carried out of actors involved in decisions about the selection of areas to develop or redevelop (densify) for urban residential use in South East Queensland, Australia. Three sets of decisions exist that determine whether a site is to be developed or densified for residential use. These decision sets range hierarchically from the determination of areas that are appropriate for medium to long term urban growth at the regional planning level, to the planning for development over the short to medium term of areas within the urban boundary, and then to the prioritisation of development within those areas identified in medium term plans. The first set of decisions involves those by the state planning authority (in this case, the state government) that prepares planning legislation and develops plans that show the staged release of land for development in the region and the associated infrastructure to support new development. The second set involves decisions by planners in local government and private planning consultants in determining which areas should have plans made that allow urban development, and which specific controls over the type of development permitted. The third set of decisions involves those made by developers as to which areas permitted in development plans should have priority for short term development. Accordingly, we developed and deployed three separate questionnaires that identified the decision factors by each type of agent—state planners, local government planners and planning consultants, and developers.

3.1. The Questionnaires

Appendices 1–3 in the Supplementary Materials show the questions used in each questionnaire. The State Planner Questionnaire (Appendix 1 in the Supplementary Materials) includes open ended questions on how areas for greenfield and higher density residential development were chosen, and factors involved in considering whether to expand major transport infrastructure or where to build new transport infrastructure. The transport questions were included as the major transport capacity is the central infrastructure factor in decisions at the regional level on where expanded or higher density development should be located.

The Local Government Planner and Planning Consultant Questionnaire (Appendix 2 in the Supplementary Materials) includes questions asking the planners to list and rank the most important factors to consider when planning new areas for greenfield urban development and for higher density urban development. It also includes questions asking the planners to list and rank the most important factors to reach a decision in favour of development proposals for greenfield urban development or for higher density urban development in areas outside current planning controls. This is a typical urban development

situation, especially for higher density development. Then, planners were asked to rank the factors that caused most public concerns in greenfield and higher density development. The concerns of the public are a major consideration in whether planners approve urban development plans and proposals. Supplementing this, the planners were asked to report the extent to which public concerns were actually incorporated in planning decisions; they were also asked to rank the most important factors involved in deciding whether to build new transport infrastructure since, as with the State Planner Questionnaire, this is the most critical infrastructure constraint in determining the feasibility of development.

The Developer Questionnaire (Appendix 3 in the Supplementary Materials) starts by asking what type of development the developer is most likely or intended to carry out in the next five to ten years in the region. This is to allow a comparison of development factors between different types of intended development. Then, the questionnaire asked developers to rank the most important factors considered in starting a project, from a list provided in the questionnaire. This list contains a mix of demand and supply factors, both positive and negative to urban development, including factors relating to market demand, various funding and cost factors, environmental constraints, access factors, major infrastructure availability, lifestyle, and community resistance to development. We included specific factors in the developer questionnaire so that the interviewees could be reminded of the spatially specific factors that might be involved, these being more easily incorporated into expanded ABM models than nonspatial factors. We considered that this was not necessary for the planner questionnaire, as our understanding of planning decision making sees it as considering spatially specific factors being central. Developers were then asked the likelihood of investing in various areas within the region in the next 5–10 years. As part of the wider project on climate change in coastal development, the questionnaire also asks developers to rank the importance for development in the next 5–10 years of factors in a list that included specific factors potentially affected by climate change, such as sea level rise, as well as demand factors that might be impacted by climate change. Finally, developers were asked about the number and type of development they had carried out over the last five years, to ascertain any differences in questionnaire responses between different types of developers.

3.2. Survey Method and Responses

Potential respondents in each questionnaire were identified from the authors' local professional networks, which include membership of industry associations including planning. Upon ethics approval from the Human Ethics Unit of The University of Queensland (approval number 2018000655), the relevant survey questionnaires were either distributed in person or by email to potential respondents' office or email addresses. A participant consent statement was supplied in each case. The surveys were conducted over an eight-week period between May and July 2018, with a total of 8 state planners, 40 local government and private sector planners and 48 real estate development companies being contacted. After a couple of follow up email reminders (one in week four and one in week six) we received responses from one state planner, 14 local government and private sector planners, and 7 developers, resulting in a response rate of 12.5%, 35% and 14.5% for the three sets of surveys, respectively. The local and private sector planners comprised five local government managers and senior planners and five senior consultants, and four in undisclosed status. The developer companies included one in residential land development and one in residential, retail and other commercial development; and three in undisclosed status. The single state planner response was excluded from further analysis considering that one sample data was inadequate to yield reliable conclusions, and the fact that the role of state government planners is focused on planning legislation and strategic planning to determine whether or not an area is broadly suitable for development. Thus, the paper's identification of planning actor factors affecting urban development does not include state level strategic parameters for the application of detailed local planning controls. Response levels for the other two questionnaires were considered adequate to provide preliminary

findings on specific actor variables that might be considered for inclusion in agent based CA modelling.

3.3. Survey Findings: Planners

The survey results by planners are summarized in Tables 2–6. Tables 2 and 3 summarize the importance of individual factors in planning and allowing new greenspace areas to be developed. In both tables, environmental factors are seen as the most important for new development. Infrastructure factors, particularly access to public transport and other infrastructure, are generally considered as the next most important. Social infrastructure access, for health, education and so forth, is often considered important. The alignment of a new development area with existing plans and planning goals is also important, especially where development is proposed outside strict application of existing plans (Table 3). For plan making for new development (Table 2), the incorporation of adequate open or other public space is an important consideration in formulating the structure of the plan. For development proposals outside current planning controls (Table 3), the contribution of the proposal to regional supply compared to market demand/need can be an important consideration.

Table 2. Planners' assessment of importance of individual factors in planning new greenspace areas for urban development (N = 14).

Factor	No. of Times Ranked 1st	No. of Times Ranked 2nd	No. of Times Ranked 3rd	Mean *
Environmental protection/constraints/access	4	5	3	2.71
Public transport access	0	5	1	1.14
Open/public space	3	0	0	1.07
Infrastructure access/cost	2	1	1	1.00
Access to health, education, community facilities	1	0	3	0.57
Alignment with planning scheme	1	0	1	0.43
Market acceptance	1	0	0	0.36
Political intent	1	0	0	0.36
Placement of land uses	1	0	0	0.36
Other	0	3	5	1.00

Note: * A score of 5, 3 and 1 are assigned to those that are ranked 1st, 2nd, and 3rd in the survey data, respectively, to represent the importance of each factor in planning. The mean score for each factor is the weighted arithmetic mean of all scores by all respondents.

Table 3. Planners' assessment of importance of individual factors in deciding development proposals for new greenspace urban development outside current controls. (N = 14).

Factor	No. of Times Ranked 1st	No. of Times Ranked 2nd	No. of Times Ranked 3rd	Mean *
Environmental constraints/gains	2	3	2	1.50
Infrastructure cost/timing/availability	2	1	3	1.14
Need/demand for development	3	0	0	1.07
Alignment with plan objectives/strategy	2	1	2	1.07
How public transport addressed/accessed	1	3	0	1.00
Contribution to land supply within urban footprint	2	0	0	0.71
Community concerns	1	0	1	0.43
Access to health, education, community facilities	1	0	0	0.36
Not applicable	0	1	1	0.29
Road network access	0	1	0	0.21
Other	0	4	5	1.21

Note: * As in Table 2.

The planners' survey responses in the case of higher density residential development in existing urban zones raise many similar issues (Tables 4 and 5), although the factors

driving planning for higher density development inevitably show some differences to those for greenfield planning. Public transport access emerges as a key planning consideration in both making plans for new high density precincts (Table 4) and in whether to allow high density development in locations that are not currently permitted (Table 5). Infrastructure availability more generally is also important in both cases, while social infrastructure, such as health and education facilities, is often a factor in making new high density plans. The availability of open space is an important factor in planning new high density development, and more general urban design factors are an important consideration in deciding on high density development proposals outside current controls. The most important factor in deciding on proposals outside existing controls is the extent to which the community supports the proposal. Here, it may be possible to use census data to identify the types and locational context of populations more, or less, likely to oppose development. Decisions about development outside existing controls can also take into account existing supply of high density zones and market demand for new zones, along with broad regional planning goals.

Table 4. Planners' assessment of importance of individual factors in planning new areas for higher density urban development (N = 14).

Factor	No. of Times Ranked 1st	No. of Times Ranked 2nd	No. of Times Ranked 3rd	Mean *
Public transport access	4	3	0	2.07
Open/public space	1	3	3	1.21
Access to education, community facilities, shops	0	3	2	0.79
Market acceptance	2	0	0	0.71
Alignment with planning scheme	1	1	1	0.64
Infrastructure capacity/cost	0	2	1	0.50
Environmental constraints	1	0	0	0.36
Protection of heritage character	1	0	0	0.36
Height/scale	0	1	1	0.29
Other	4	1	6	2.07

Note: * As in Table 2.

Table 5. Planners' assessment of importance of individual factors in deciding development proposals for new high density development outside current controls. (N = 14).

Factor	No. of Times Ranked 1st	No. of Times Ranked 2nd	No. of Times Ranked 3rd	MEAN *
Community acceptance/impact	4	2	1	1.93
Public transport access	2	4	1	1.64
Infrastructure charges/offsets/availability	2	1	1	1.00
Not applicable	1	2	3	1.00
Urban design components/context	0	3	2	0.79
Existing supply of high density areas	2	0	0	0.71
Infrastructure capacity/cost	0	2	1	0.50
Alignment with plan objectives/strategy	0	2	1	0.50
Market demand	1	0	1	0.43
Environmental constraints	1	0	0	0.36
Public/open space	0	0	2	0.14
Other	1	0	2	0.50

Note: * As in Table 2.

Tables 2–5 also confirm the importance of building new transport infrastructure in determining the acceptability of an area for greenfield or higher density development. Table 6 shows the most highly ranked factors for new infrastructure planning relate to the demand for new transport infrastructure in relation to existing capacity/availability and, as a subset of this, the demand for new public transport in relation to existing capacity/availability. A further subset identified was existing road capacity. General planning strategy and objectives, and the related issue of the need to change transport mode share, were also ranked

highly by a number of planners. In terms of CA modelling, these factors are generally quantifiable, although in most cases this would involve major data collection exercises.

Table 6. Planners' assessment of importance of individual factors in deciding to build new transport infrastructure.

Factor	No. of Times Ranked 1st	No. of Times Ranked 2nd	No. of Times Ranked 3rd	Mean *
New residential demand/population density	2	3	2	1.50
Availability/capacity of/demand for public transport	3	0	1	1.14
Alignment with plan objectives/strategy	2	0	0	0.71
Need to change mode share	0	3	0	0.64
Not applicable	1	1	1	0.64
Cost	0	2	1	0.50
Existing road capacity	0	2	1	0.50
Funding source available	1	0	0	0.36
Community impact/concerns	0	1	2	0.36
Environmental factors	0	0	2	0.14
Other	5	2	4	2.50

Note: * the same as Table 2.

3.4. Survey Findings: Developers

The survey asked developers to rank factors used in deciding whether to start a new development in the next 5–10 years (Figure 1). Financial factors emerged as the most important ones—funding, profit margin, market demand in next 5–10 years, land price, development costs, and major infrastructure. Except for land price, data on these items is difficult to obtain, even for public companies. Thus, the main financial drivers of development are likely to remain beyond the scope of CA modelling, although it might be possible to develop proxy variables to represent development costs using physical site variables, inter alia. Interviews could be used to classify developers into behavioural types that allow some prediction of decisions relating to financial variables, as performed by Wahyudi et al. [27,28].

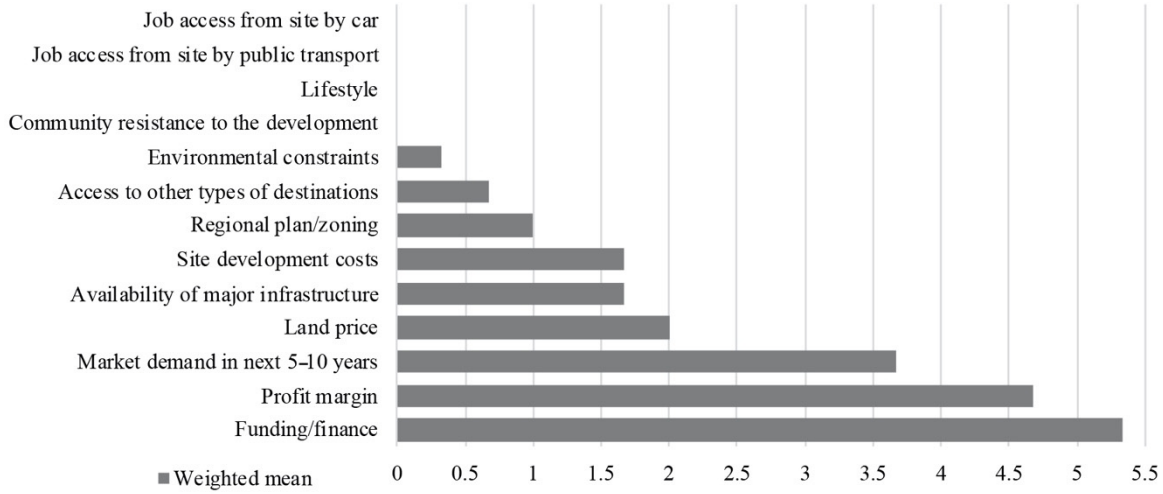

Figure 1. The importance of individual factors in deciding whether to start a new project in the next 5–10 years by developers. The weighted mean score is calculated as the sum of the number of the raw score divided by the total number of respondents. A raw score of 5 is assigned to those ranked first, 3 assigned to those ranked second, and 1 to those ranked third.

Finally, developers were asked to assess the importance of individual factors in deciding to develop land within 1 km of the SEQ coast (Figure 2). The leading importance of

market demand in such decision making underscores the importance of financial factors in the decision to develop. The general significance of developing for a coastal lifestyle market reinforces this importance. Nevertheless, the environmental factors listed in the questionnaire had variously important roles in decisions to develop in coastal areas. In terms of CA modelling, such factors are capable of quantification and, thus, of being modelled.

The survey results for developers aggregate the view of different types of developers. The limited number of respondents did not allow survey results (Figures 1 and 2) to be meaningfully disaggregated by the type of the developers. Thus, the results are broadly indicative only, with the understanding that the overall findings could vary with a different sample mix of developer types.

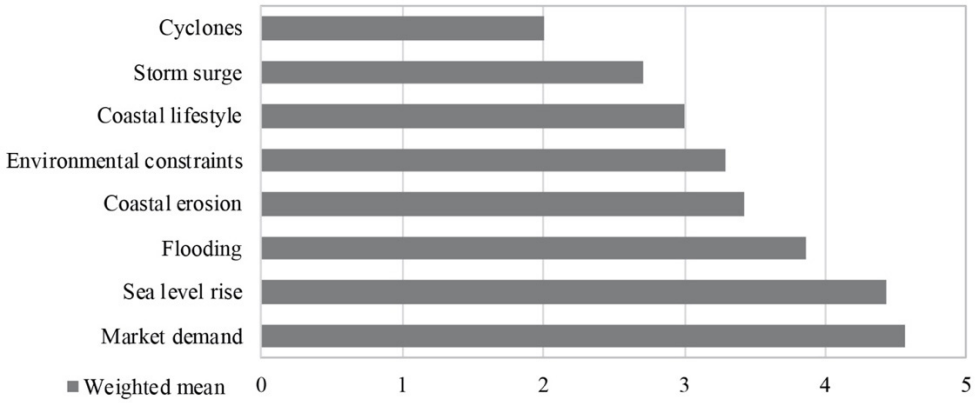

Figure 2. The importance of individual factors in deciding whether to develop land within 1 km of SEQ coast by developers (n = 7). The weighted mean score is calculated as the sum of the raw score for each factor divided by the total number of respondents, with 'not at all important' = 1, 'slightly important' = 2, 'moderately important' = 3, 'important' = 4, and 'very important' = 5.

4. Discussion

The value of this study lies in the identification of a number of potential development decision variables that have not been used in current scholarship yet and that would require considerable data collection efforts to enable them to be quantified, or at least categorised, for inclusion in CA models that incorporate actor variables. For extending agent based CA modelling, the most problematic factors identified are, firstly, those that might be able to be categorised but are near unique and, secondly, those that are difficult to categorise.

In terms of factors that might be categorised/quantified, CA models most commonly involve factors representing urban design components or environmental context, including the height/scale of buildings, water body, distances to public transit and other public facilities, elevation, and slope [51]. Based on such contextual factors, agent based CA models further incorporate socioeconomic and demographic characteristics of agents [18,19] as well as their attitudinal attributes usually collected by survey or quantified by available secondary data. For example, land use amount and location, land value, housing prices, infrastructure (e.g., access to transport), and buildings and dwelling units are commonly used to define the conditions/criteria that trigger the decision making of urban planners, developers and governments, who play the dominant role in urban growth. The survey results in this study point to several further categorical/quantifiable decision factors that would act effectively as random elements in a CA model. Specifically, the infrastructure cost or timing factors identified by a number of planners (e.g., demand or need for development, infrastructure cost and availability) help to quantify how to incorporate consideration of the provision of new infrastructure. New infrastructure supply is dependent on a range of planning factors, including the remaining capacity of existing infrastructure in relation to potential increases in demand, and the 'lumpiness' of new infrastructure and whether existing infrastructure can be incrementally expanded to meet increased demand. The importance of such variables for any particular type of infrastructure is highly contextual,

requiring unique data that is often not in the public domain. On the other hand, several decision variables identified in Tables 4 and 5 (e.g., height/scale and open space) are amenable to quantification and, hence, potential incorporation in CA models. Urban design factors are not easily incorporated, however, as some of the relevant factors are inherently subjective. However, some subjective factors, such as streetscape quality, may be quantifiable via public evaluation/scoring. Other more quantifiable elements, such as height in relation to street width, are the subject of professional debate [52].

In terms of difficult to categorise/quantify factors, this study identifies several social and political factors that are influential in planning decisions about land use rezoning decisions but difficult to categorise. Such factors include political intent, placement of land uses, and alignment with planning objectives/strategies. Including these will require the quantification of key strategic planning elements and key elements (e.g., size and location) of newly zoned urban areas, with enough examples in a region to provide a data base for the analysis of decision variables. The further problem here is that there are unlikely to be enough examples in a region to allow parameter calculation over the life of a particular regional plan. Calculation of relevant variables across several regions is unlikely to produce useful results because each region has a unique decision making environment, in addition to unique location imperatives. In addition, this study pointed to several subjective factors, including market acceptance, the degree of community support or opposition, and lifestyle, which are difficult to integrate in agent based CA models. The extent to which such factors influence planning decisions varies according to the extent to which the planning system takes account of community wishes and the extent to which it allows discretionary decision making [24,25]. They are essentially difficult to use in predictive modelling because of their inherently subjective and contextual nature (although, as suggested, census data might assist in this). Such subjective factors, deeply rooted in the complexity of urban system, may deviate from ones that are based purely on the optimisation of locational attributes, and, thus, are generally absent from current agent based modelling.

A further issue concerning the assessment of proposals outside existing planning controls is the essential unpredictability of the location of such proposals. The key problematic factors involved are the ownership of a potentially developable site by a developer, and the financial situation of the developer, such as ability to borrow funds (although sites receiving zoning approval are often on sold before any development takes place). Even with knowledge of ownership of sites (where this can be discerned with no opaqueness arising from the existence of 'shelf' companies whose ultimate beneficiaries are unknown), a database would need to be constructed of site owner variables that could be used to predict the intention to develop along with variables such as business cycle stage. Many of the relevant owner variables are probably too subjective to know with any accuracy, although this problem will be reduced to the extent that much greenfield development is carried out by public companies, for which relevant data is more readily available.

5. Conclusions

The limited types of actors considered in this study and the small sample sizes mean that the findings are intended to be indicative, raising implications for further research into agent based CA urban modelling. The results revealed by the survey data are largely qualitative and call for future work for quantification and modelling application along the following directions. First, to differentiate the impact of different factors on urban development, it is possible to quantify the degree of the importance of different factors using parameters or weights, which can be obtained using survey data. Second, the design of future questionnaires or interviews should be guided by the nature of the underlying factors impacting urban development, with the aim of identifying those factors that are difficult to quantify in agent based CA modelling. For example, to measure the impact of community support, it is possible to design questionnaires that break down the measure of community support into different perspectives and set up a Likert scale to evaluate each perspective. This process needs to consider the contextual background (e.g., urban

and rural space) [53]. Third, a systematic analytical framework would be useful to guide the quantification of such factors obtained from survey data. For instance, the analytic hierarchy process (AHP) as a structured technique can be employed for organizing and analysing complex decisions, relating variables to overall goals, and evaluating alternative solutions [54]. With the approach thus proposed for identifying appropriate actor variables to incorporate into agent based CA models, we suggest further variables beyond those included in existing agent based CA modelling be considered in order to fully replicate real world decision making about spatial choices for development.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/geographies2010010/s1. Supplementary Material 1: Appendix 1 Questionnaire for state planners; Supplementary Material 2: Appendix 2 Questionnaire for local government planners and private sector planners; Supplementary Material 3: Appendix 3 Questionnaire for developers.

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