Sandbox SD Models

Catalyzing the Widespread Understanding of Dynamics

Ninad Jagdish[1*] & Andreas Größler[1]

[1]Radboud University Nijmegen
P.O. box 9108, 6500 HK Nijmegen, The Netherlands

*corresponding author: ninad.jag@gmail.com, + 31644315682

Abstract

If the dynamically complex systems we live in today are to be managed successfully, widespread understanding of their dynamics seems essential. In this paper, we present a framework of desired characteristics for any medium targeting the creation of such understanding. The framework is used to structure the concept of "Sandbox SD Models" as a medium for catalyzing the creation of widespread understanding of dynamics. Sandbox SD models are stand-alone system dynamics models wrapped in intuitive interfaces without compromising on the critical elements of SD (such as, model endogeneity, stock and flow representations and the indication of causal linkages). They are designed with the aim of reducing the effort required to understand system dynamics and increasing the intuitive interest of users towards doing so. Sandbox Models are positioned as a stepping stone towards the more extensive use of conventional stock and flow models. A prototype sandbox based on the Urban Dynamics model has been developed as an app for touch-screen devices and its key features are described.

Keywords: microworlds, simulation games, sandbox models, visualization, widespread understanding of dynamics, intuitive interest

1. Introduction

In today's globally interconnected world, complex large scale systems are commonplace. Misperceptions of the dynamics within such systems are considered as a reason why people fail to manage them well. For successful management of complex systems, widespread understanding of their dynamics is desirable and needed. The field of system dynamics (SD) currently provides tools, methods and the conceptual language that help tackle such dynamically complex problems.

This paper presents a set of desired characteristics of a medium for communicating system dynamics models. The end goal of this medium is to help catalyze the widespread understanding of dynamics. The resulting framework of characteristics is used as the basis to structure the concept Sandbox SD Models.

Sandbox SD models are stand-alone system dynamics models wrapped in intuitive interfaces without compromising on the critical elements of SD (such as, model endogeneity, stock and flow representations and the indication of causal linkages). They are designed with the aim of reducing the effort required to understand system dynamics and increasing the level of intuitive interest of users towards doing so. The concept is positioned as a stepping stone towards the more extensive use and understanding of conventional stock and flow models.

A prototype of a sandbox SD model based on Urban Dynamics (Forrester, 1969) has been developed in the form of an application for touch screen computers. Key features of this prototype are described.

2. Review of Literature

Sandbox models are aimed at making system dynamics more accessible to people. Considerable work has been done towards this goal, especially through the use of microworlds. A good example is the C-ROADS (and C-Learn) initiative which makes climate models more user-friendly (Sterman et al., 2012). Literature on system dynamics microworlds include descriptions of specific microworlds, evaluations of the performance and learning effect of microworlds, and discussions on microworld design, usage and utility (Rouwette et al., 2004; Davidsen, 2000).

Morgan (2000) describes various cultural and ethnic factors that need to be taken into consideration in the design of microworlds. Such consideration of cultural differences in design is an important component of making microworlds more intuitive. Sandbox models are associated with an emphasis on improving interface design. Howie et al. (2000) demonstrate that changes in interface design can play a significant role in reducing the misperceptions of feedback in users. Jackson et al. (1994) describe the importance of learner centred design and the use of learning scaffolding to help the user progress through the learning curve.

The role of pictorial representation of system dynamics models in making them more accessible has been discussed by Camara et al. (1994). Though their discussion relates more to an agent-based representation of system dynamics models, the comments on the possible characteristics and behaviours of images are still relevant. Kim (1989) used images to represent the processes in a microworld on insurance claims processing. Claims were represented in the form of envelopes flowing in and out of an accumulation of outstanding claims. Sterman (2000) notes the importance of matching the nature of visuals used and the technical ability of the recipients of the model. A lack of such a match could result in the recipients perceiving the visuals to be either too complex or too simplistic. Lane (2008) describes the various diagramming conventions that have become common in the SD field and how they emerged. It is interesting to note that several of the diagramming conventions that stand as the status-quo today were not such obvious choices in the past. Black (2013) describes various aspects of system dynamics visuals that help them serve as boundary objects in participatory modelling workshops.

Maier & Größler (2000) create a categorization framework for SD based microworlds. Warren and Langley (1999) discuss three lines of development that are needed to exploit the potential of system dynamics in management, namely, linking system dynamics with established concepts in management, making system dynamics more accessible to managers, and helping managers through the learning curve by using simulation tools. Alessi (2000) discusses various characteristics of microworlds and goes on to describe a way to combine SD modelling software with authoring tools to create learning environments. Andersen et al. (1990) note the various issues that developers of microworlds (gaming interfaces) must contend with. These include the assumptions regarding the users’ psychology, defining the game’s purpose and decisions regarding gaming techniques. Kopainsky & Sawicka (2011) measured mental loads of participants using microworld supported descriptions of a reindeer pasture management task against those of a control group. The results indicate that microworld supported descriptions reduce cognitive load and improve performance of the participants.

Rouwette et al. (2003) reviewed over 200 papers on SD based microworlds and categorised studies on performance based on model characteristics, simulator characteristics and player characteristics. It is interesting to note that results on the relation between these characteristics of microworlds and their performance are often ambiguous. Certain studies indicate positive effects on performance for a characteristic while others show mixed or no effects. This may be because empirically evaluating the performance of microworlds relative to other means of communication is, methodologically, extremely hard (Größler, 2001; Davidsen, 2000; Warren & Langley, 1999). The existence of numerous control variables make it difficult to arrive at a generalised claim about the performance of microworlds (Größler, 2001).

Outside of efforts reported in academic literature, considerable progress has been made in making system dynamics more accessible. Documenting the numerous contributions in this regard is beyond the scope of this paper and thus only a few key examples are mentioned. The Creative Learning Exchange continues to produce accessible content and simulations to help students learn about system dynamics. Forio Corporation provides a platform to build system dynamics based microworlds, create intuitive visual interfaces around them and access them over the internet. Strategy Dynamics Ltd is also engaged in the creation of microworlds that help make understanding dynamics easier. The electronic book, *Beyond Connecting the Dots* creates a more visually intuitive and interactive format for teaching the concepts of system dynamics.

The documented insights and experiences from these efforts, performance evaluation studies and discussions provide a foundation for the development of sandbox SD models.

3. A Framework of Desired Characteristics

The framework of desired characteristics for the medium exists at the intersection between the factors that influence the understanding of dynamics, the factors that influence the scale of that understanding (i.e. how widespread it is) and design characteristics of a communication medium (refer Figure 3.1). The methodology used to derive it is best described as a process of causal factor identification. The method is similar in nature to abductive inference. In this process, one starts with the end goal and works backwards to identify the hierarchy of causal factors that influence this goal. We thus explored the influencing factors and filtered them based on whether they are likely to be addressable as design characteristics of the communication medium or not. The final list of factors that is thus obtained forms the framework for a medium that may help catalyze widespread understanding of dynamics.

Figure 3.1: Contextualizing the Framework of Desired Characteristics

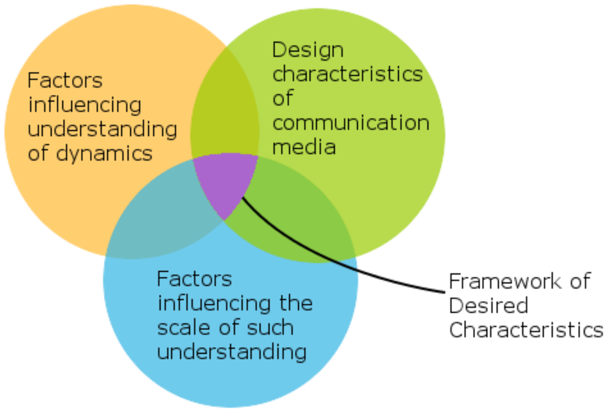
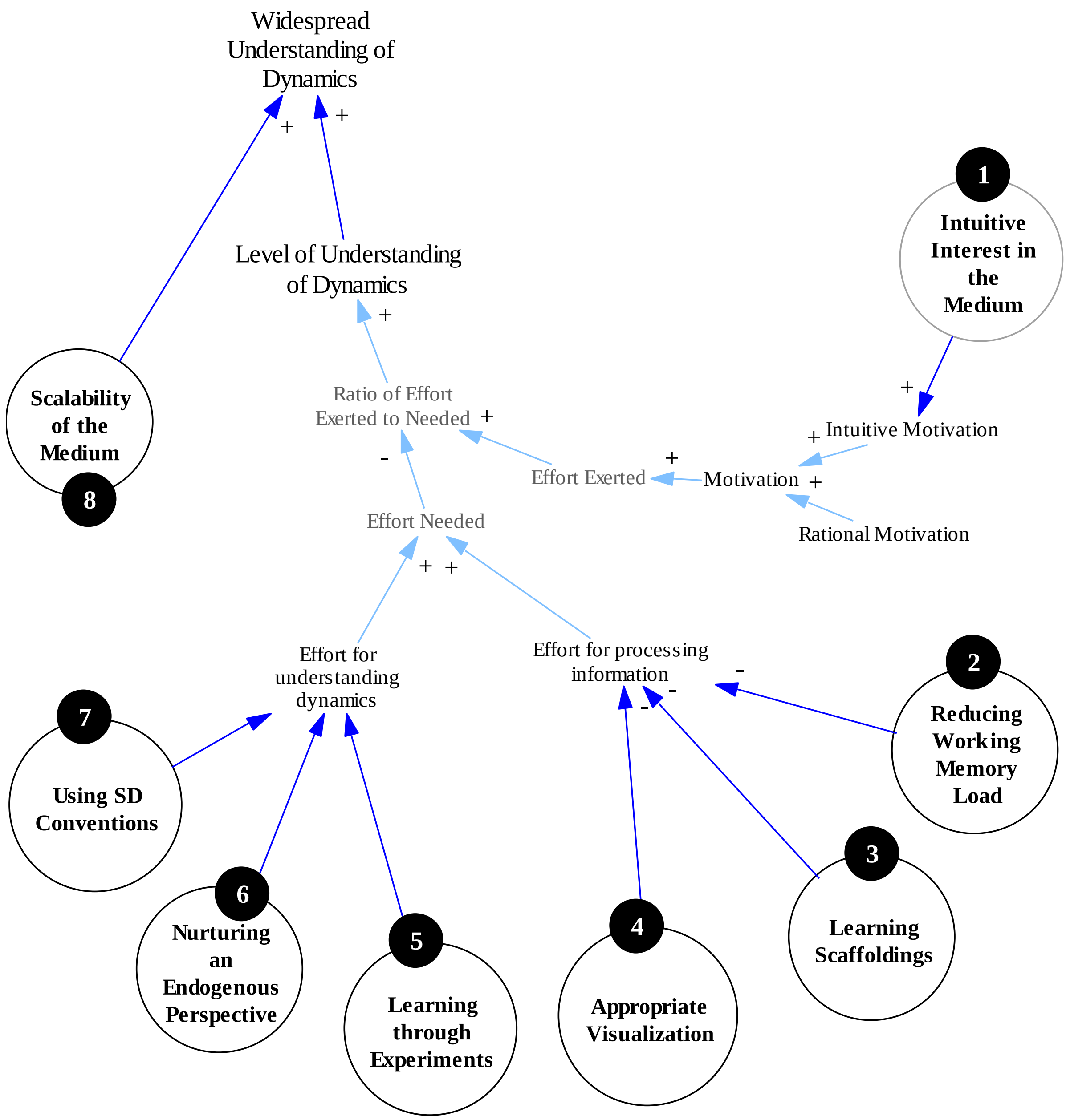


Figure 3.2 presents this framework of desired characteristics in the form of a causal-factor map (with the desired characteristics encircled). Existing knowledge from various fields (such as cognitive science and psychology) were used to identify the desired characteristics. For example, the need for reducing cognitive load draws upon the distinction between short term memory (STM) and long term memory (LTM) (Hebb, 1949) and the concept of working memory capacity (Baddeley, 1992; Baddeley, 2003). Another example is how the idea that learning involves the transfer of information from the STM to LTM through the development of schemas was included in the framework.

A schema is a way of categorizing and grouping information so as to make it relevant in the context of existing knowledge (Swezller, 1994). In other words, the working memory capacity is employed for utilizing such information and skills when they are first learned. Through repetition, a schema develops and the process becomes more automated to the point where the content (or skill) is considered to have been learned (Swezller, 1994). Thus the provision of learning scaffolding to aid the development of schemas and make the content easier to understand is recognized as being essential.

Figure 3.2: The Framework of Desirable Characteristics of the Medium



4. The Concept of Sandbox SD Models

Concisely defined, a sandbox SD model is a system dynamics based microworld that exhibits all the desired characteristics in the framework (refer Figure 3.2). In order to better describe the concept, for each of the desired characteristics in the framework, corresponding supportive design elements were identified. These design elements and the associated desired characteristics they support are listed in Table 4.1.

Assigning a name to this collection of desired characteristics and design elements makes it easier to perceive and use them as a concept. The name 'Sandbox SD Models' has been chosen to reflect the various characteristics exhibited by this medium. Sandboxes are enclosures filled with sand in which children can play. Found in multiple cultures across the world, they provide a safe and non-intimidating environment in which children can to learn about their physical environment by experimentation. The term "sandbox" in the name symbolizes, simplicity, intuitiveness, learning through experimentation, and ease of use. The use of the term "model" is used to indicate that the medium is a computer model. And finally, "SD" points to the fact that the essential philosophy and visual language used in system dynamics are retained so as to serve as a stepping stone to conventional stock and flow models.

Table 4.1: Design Elements of Sandbox Models

	Desired Characteristic	**Supporting Sandbox Model Design Element**
1	Intuitively interesting design	1) Use of contemporary interface designs 2) Built for computer form factors that are considered intuitively interesting
2	A focus on reducing working memory load	3) Chunking of information 4) Provides relevant information only when needed and on demand
3	Provide learning scaffoldings	5) Use of spiral learning approaches where existing understanding is used to contextualise and assimilate new content

	Desired Characteristic	Supporting Sandbox Model Design Element
4	Appropriate visualization information	6) Balance between the amount of visualization with the need for reducing cognitive load 7) Use of visuals that are relevant and engaging for the target user groups
5	Allow learning by experimentation	8) Use of quantitative SD models allowing for appropriate changes to its structure and parameters
6	Nurture an endogenous perspective	9) User inputs at the macro level (as opposed to specific decisions for each time period) 10) Provision of a visual overview of the system and its interconnections at an appropriate level of aggregation 11) Focus on capturing feedback complexity (as opposed to categorical complexity)
7	Use established SD conventions	12) Retains the visual essence of stock and flow diagrams used in system dynamics
8	Scalability	13) Built for platforms that support scaling and wide distribution

5. A Prototype of a Sandbox SD Model

In order to demonstrate the concept of sandbox SD models, a couple of prototypes based on existing system dynamics models were developed in line with aspects listed in the preceding table. A prototype based on the Urban Dynamics model (Forrester, 1969) is described here. Urban Dynamics was selected as it is a large, well-known model about a topic of universal relevance – the growth and evolution of cities. Figure 5.1 depicts the main stocks and flows in the urban dynamics model. A brief overview of the

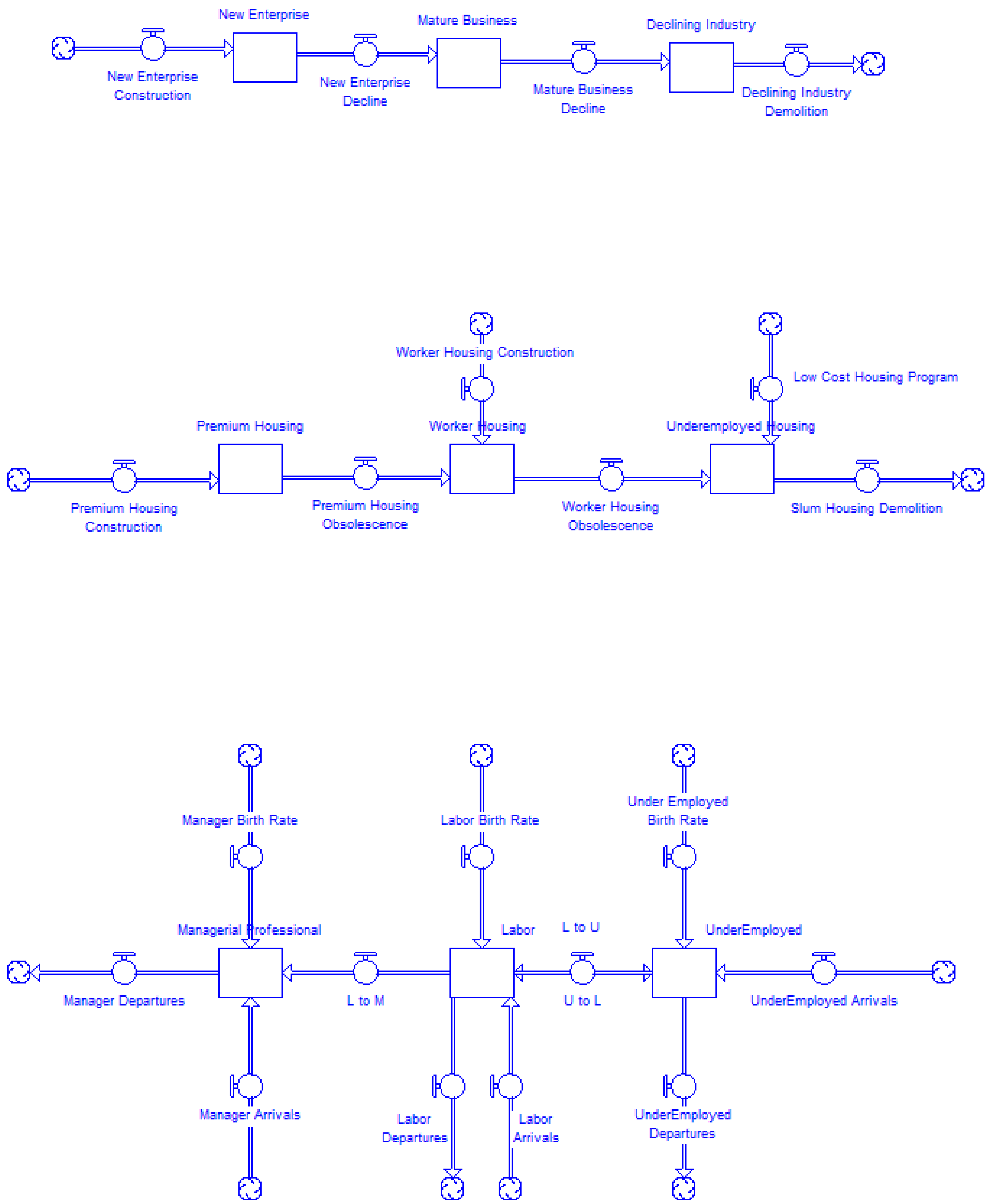
Urban Dynamics model is provided here to provide context for the reader. For a more detailed explanation of the model, the reader is directed to Forrester (1969).

The urban dynamics model divides the city system into three ‘sectors’ – the enterprise sector, the population (or workforce) sector and the housing sector. The enterprise sector comprises three kinds of enterprises – new enterprises, mature business and declining industry. The workforce sector consists of three kinds of workers – managerial professionals, labor and underemployed workers. The housing sector has three kinds of houses corresponding to the three worker categories – premium housing (for managers), worker housing (for labor), and low cost housing (for the underemployed).

New enterprises are constructed and they decline with time (influenced by the state of the city) to become mature businesses (refer Figure 5.1). Mature businesses age to become declining industry and the latter are eventually demolished. Similarly, premium housing declines to become worker housing, which declines into low-cost housing which is eventually demolished. Premium housing and worker housing is actively constructed. However, the model assumes that low-cost housing is only constructed when a low cost housing program is active.

Each of the flows in the model is influenced by multipliers that are estimated based on variables from various sectors of the model. A key multiplier in the enterprise sector is called the ‘enterprise multiplier’. In the workforce sector, ‘arrival multipliers’ and ‘mobility multipliers’ influence the flows of the different workers in and out of the city and between the three stocks. Housing multipliers influence the construction and obsolescence of the three types of housing. These multipliers are defined through the extensive use of table functions and in many instances chains of multipliers are built into the structure (i.e. a multiplier, which has another multiplier as input, which in turn has a third multiplier as input). A discussion of these multipliers is out of scope and the reader is directed to the original book for more details.

Figure 5.1: Main Stocks and Flows of the Urban Dynamics Model



The Urban Dynamics Sandbox is developed as an application that runs on touch-screen tablets and phones. Simple visuals are used in it to depict stocks and flows. At the core of the sandbox is the fully replicated code of the original Urban Dynamics model. In order to achieve this, the Dynamo equations from the Urban Dynamics book were translated and transferred into a computer language that could be compiled into an app for touch screen computers.

Figure 5.2 shows how the main stocks, flows and multipliers are visually represented in the sandbox. A graph panel maps out key stocks and certain variables of the system so that users have a handle on how the system evolves over time.

A key feature that contributes towards reducing working memory load is the use of zoom to control the amount of structure visible to the user. The benefit of choosing to design the sandbox model for touch screen devices is that zooming in and out of content can be done with an action that is very intuitive – the screen pinch. This ability to easily control the zoom level has been leveraged to give users a convenient way to take control of the amount of information they want to see.

When the user is at a low zoom level (i.e. zoomed out) they see a simplified overview of the system (refer Figure 5.3). As they zoom into the model, more structure and details emerge. Additional variables and linkages appear and causal links morph to reveal a more refined structure.

Another feature of the sandbox is the built-in on tap information system. This feature helps provide users information when relevant and on-demand. The on-tap information system is activated when a user taps on any of the images that represent a system element (stock, flow, or variable). Upon being tapped, an information panel appears at the bottom of the screen covering the graph panel. Figure 5.4 shows two instances of the on-tap information panel.

Figure 5.2: Overview of the Sandbox Model Interface

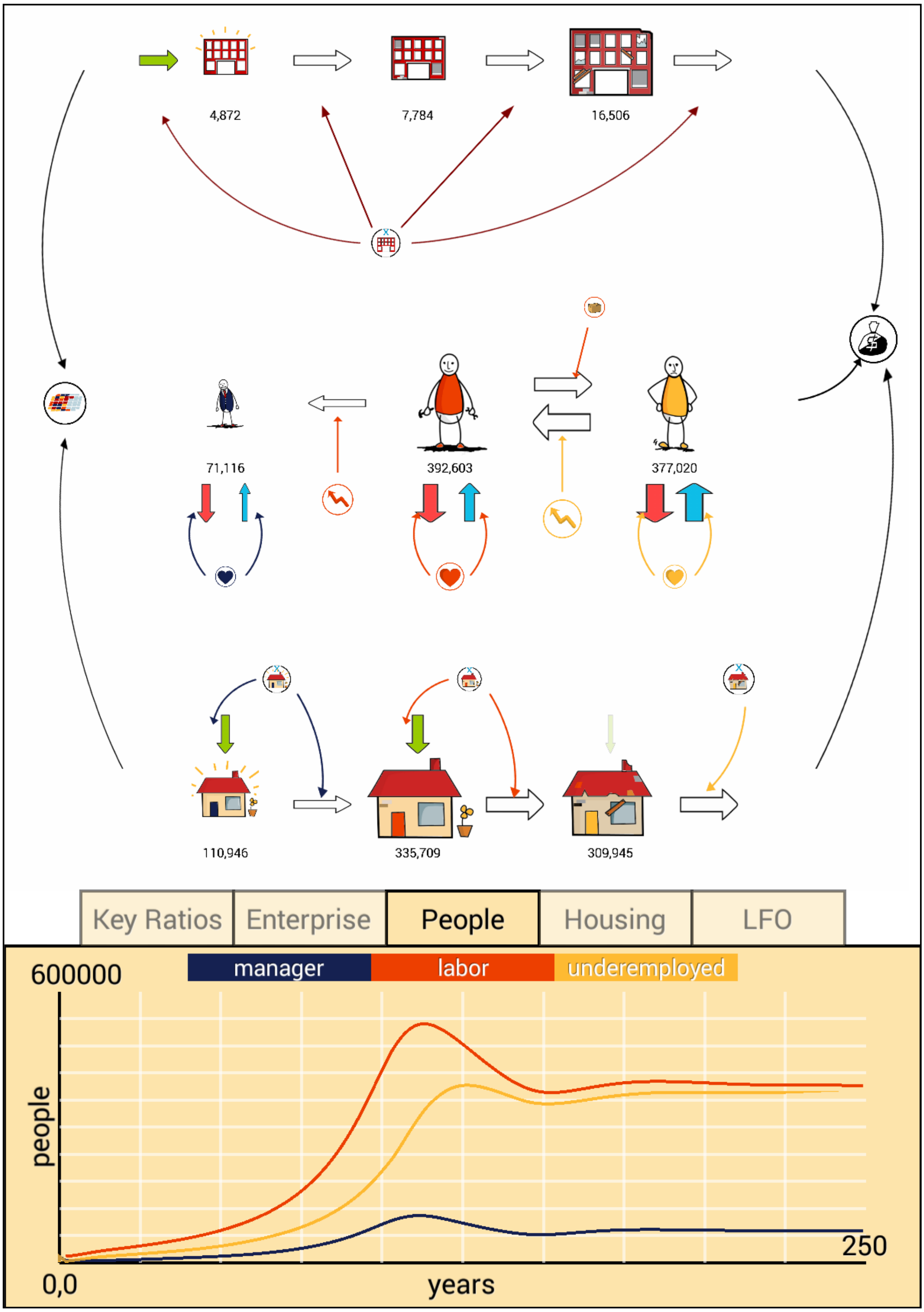


Figure 5.3: Zoom Level Controlling Visible Information

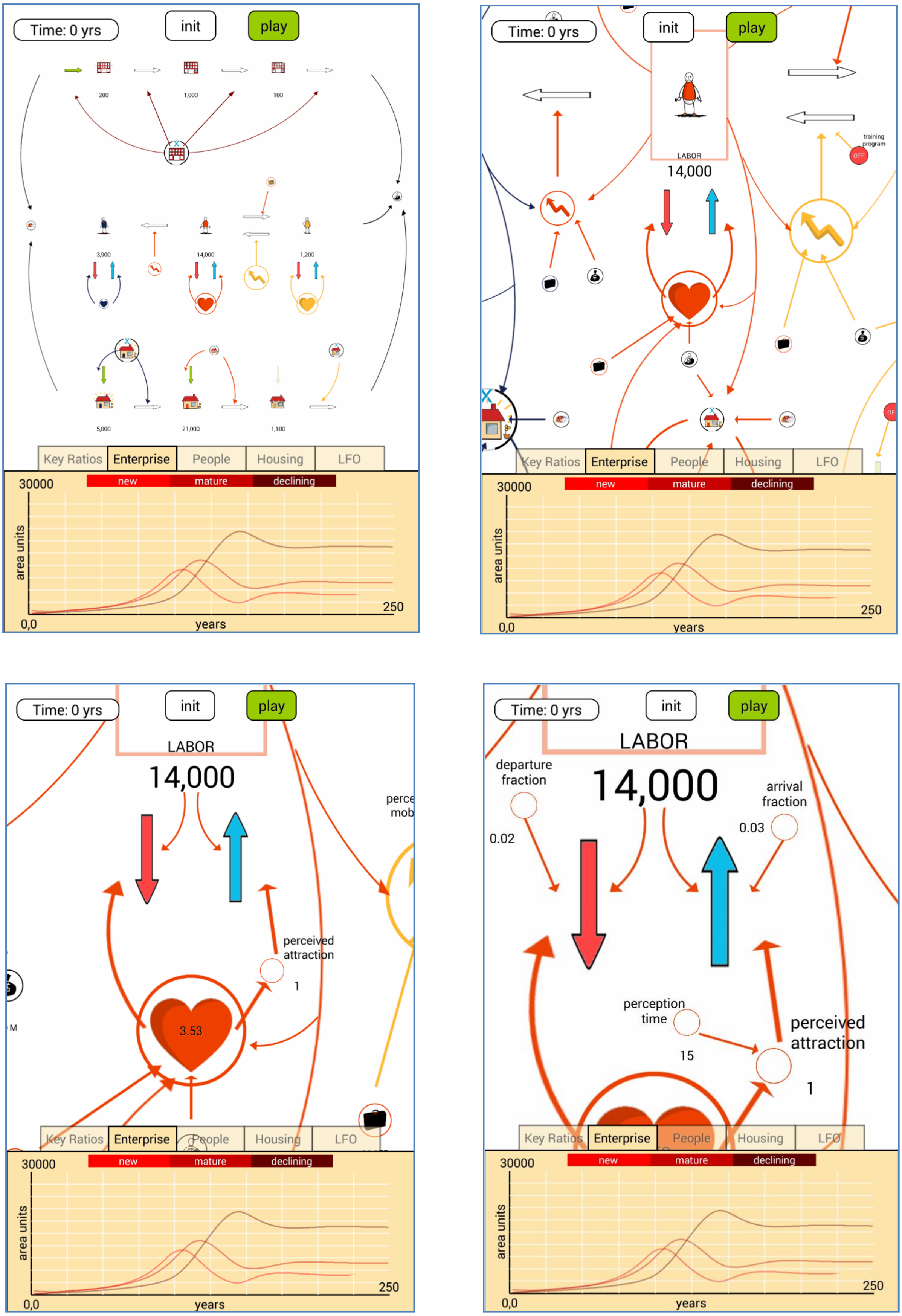
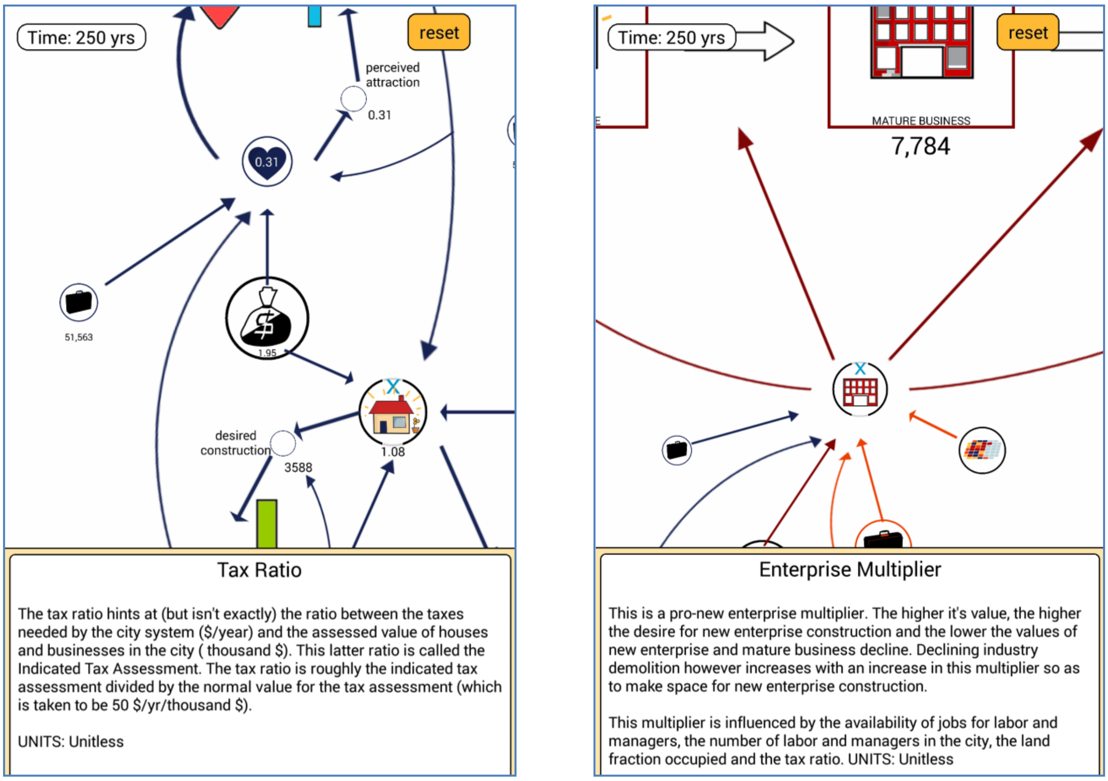


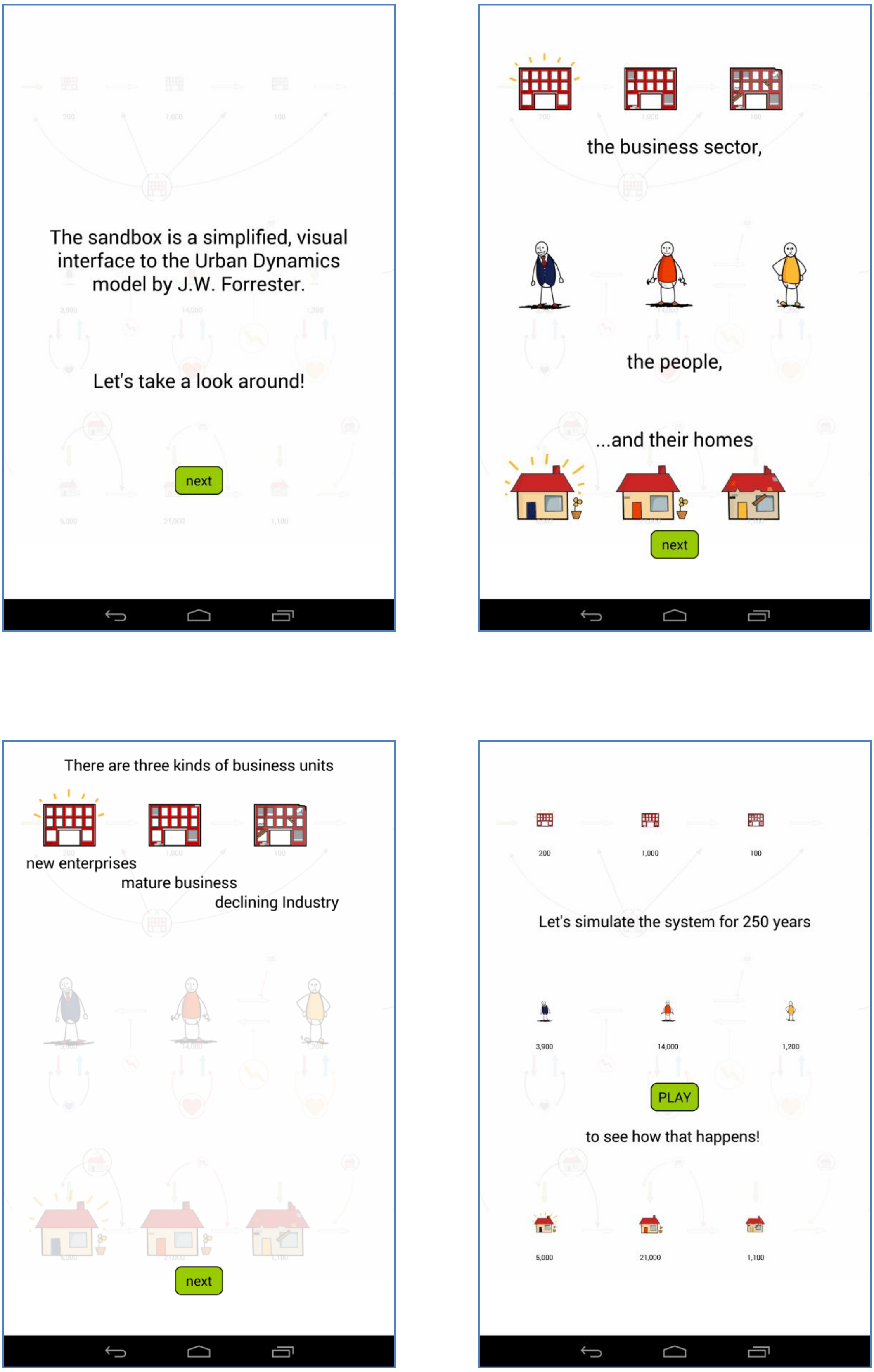
Figure 5.4: On-tap Information System



A core part of providing learning scaffolding is the use of spiral approaches to learning. This involves the introduction of new information in context to the information a user already has so that it can be more easily assimilated. When a user accesses the sandbox on their device for the first time, they are guided through an introductory tutorial. This tutorial serves as the main learning scaffolding in the sandbox. The tutorial is designed to give the user an essential overview of the model structure, its behavior and interface features. The entire sandbox is not described in complete detail, but rather the user is provided foundational information based on which they can explore the remainder of the sandbox and its features. The tutorial is designed to be interactive in nature with the user having to simulate the system multiple times during its course.

While describing the entire tutorial is out of scope, Figure 5.5. shows four screenshots from the tutorial as an illustration of the tutorial content.

Figure 5.5: Select Screenshots of the Tutorial



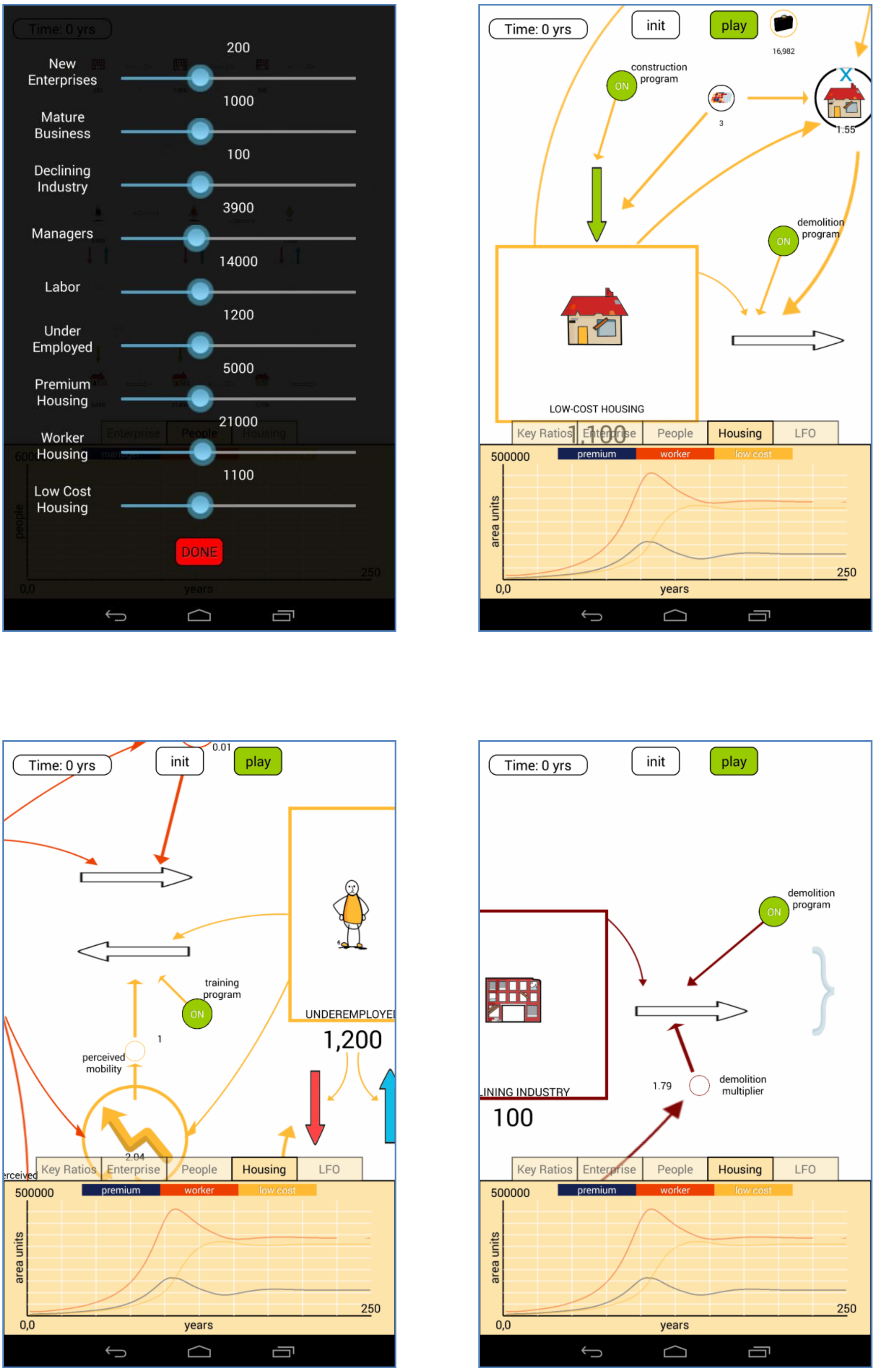
An important aspect of sandbox models – the one that distinguishes them from animations or still images – is the ability for users to change things in the system and observe how the simulation is affected. In the Urban Dynamics Sandbox, users are given access to change the initial values of all the physical stocks in the system. Four influential policy structures are also built in to the model. These are (a) low cost housing construction (b) low cost housing demolition (c) an underemployed training program and (d) declining industry demolition.

These policies are visually integrated into the model structure in the form of on screen switches that can be toggled even while the system is being simulated (refer figure 5.6). As the user simulates the system and applies various policy combinations, the graph panel captures the new behaviour of the system while still displaying the baseline plots. This allows for a convenient visual reference to how the changes in the system are influencing its behaviour.

The images used in the sandbox are constructed so as to retain the visual conventions that are commonly employed in the field of system dynamics. For example, the images for stocks are contained within rectangular boxes. The flows are represented by thick arrows while the causal links are represented by distinctly thin arrows. The images for auxiliary variables are contained within circular outlines.

In order to make it easier for a user to perceive the changes in the system, the size of the images is linked to their magnitude. When the system is simulated, as the magnitude of any element (flow, stock, variable) changes, the size of the corresponding image adjusts accordingly. This allows a user to visually trace the changes as they ripple through the system, observe how the flows influence the stocks and also make direct visual comparisons of relative magnitude.

Figure 5.6: User Input –Sliders and Policy Toggle Switches



6. Conclusion

In this paper we presented the concept of Sandbox SD Models—a medium that may aid the catalyzation of widespread understanding of dynamics. Sandbox models are designed so as to exhibit characteristics that help overcome known barriers to the understanding of dynamics. They are conceived and presented as a stepping stone towards the more extensive use of conventional system dynamics models.

Future work on sandbox models in the short term would focus on extensive prototype development and usability testing. The real test of the implicit hypothesis—that sandbox models help understanding of dynamics—will only be obtained by observing how such models are perceived in multiple cultural and professional contexts.

Apart from sandbox models, one can also identify other "offspring" of the framework of desired characteristics (Figure 3.2). These offspring result when some of the characteristics in the framework are selectively not considered. For example, if "facilitating learning by experimentation" and "providing learning scaffoldings" are not considered, we arrive at the concept of intuitive visualizations for system dynamics models. Such visualizations would use similar design elements as described in the prototype but they would be static images and not interactive software. Visualizations of this kind may add value in introducing dynamic models in books and posters. If one only excludes the characteristics of "facilitating learning by experimentation" we arrive at the offspring of interactive SD visualizations. Interactive SD visualizations would be similar to the described prototype in all respects except that it will not be a model that can be simulated. It would thus not allow for parameter changes and policy testing. The user would be able to unfold the model visually and gradually build up an understanding of the interconnections and feedback complexity of the system. Such visualizations would be especially relevant in the communication of large qualitative SD models.

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