Regional Planning Model

ShapingSEQ Implementation Action – Small Area Growth Assumptions (SAGA)

Due diligence to identify modelling packages

Queensland Government

Declaration:

This regional planning model due diligence project was prepared by UACS Consulting Pty Ltd for Department of State Development, Infrastructure, Local Government and Planning (the department), with input from the department and in consultation with SEQ stakeholders. UACS Consulting Pty Ltd carries out projects for local councils and utility providers within SEQ. This has included projects using one of the preferred primary modelling packages (Forecaz Modeller). UACS Consulting Pty Ltd, continues to work with Council's and Utilities, including working with Sizztech (Forecaz Modeller software developer) to deliver projects that use the Forecaz Modeller. UACS Consulting Pty Ltd does not hold any proprietary interest or share in the Forecaz Modeller.

Executive Summary

The Small Area Growth Assumptions (SAGA) subprogram, an implementation action of *ShapingSEQ*, is designed to implement a regional planning model to produce a region-wide set of growth assumptions at a small area level of detail (e.g. property level). An integrated set of assumptions are required, in a modelling package, to meet the purposes of SAGA by: 1) exploring regional growth planning scenarios for future regional plan reviews; and 2) assist ongoing region-wide infrastructure decision making.

To produce and explore a region-wide set of SAGA scenarios, a regional planning model is required to bring together local government area related planning assumptions across South East Queensland (SEQ) into a region-wide model. A region-wide model would provide an SEQ-wide view of existing and planned growth, within and across local government boundaries.

The due diligence process was prepared to collaborate with regional planning stakeholders on the design requirements and identified modelling packages, for a regional planning model, before procurement. Progressing straight to procurement would not have benefitted from a collaboratively prepared set of design requirements for procurement assessment. To further inform procurement, the due diligence process also checked to see if there were any existing approaches that would meet the RPM requirements. It gave the opportunity to identify potential tenders for invitation but also provide the flexibility to have an open procurement process to consider any modelling packages that may not have been identified in the structured global search for modelling packages. The due diligence process in 2020 first identified potential urban modelling packages in step 2. It then assessed the packages against best practice approaches identified in step 1 (published in the 2019 LSDM report) and a list of design requirements developed in step 3. Preferred modelling packages are then detailed in step 4 to progress to procurement then the development, testing and implementation of the regional planning model.

A summary of the results included in the 2020 LSDM report is detailed below according to due diligence steps 2-4.

Step 2 – Identify potential modelling packages: One hundred and twelve (113) modelling packages were identified. Each was classified into categories, as follows:

- 23 x Shortlisted urban modelling packages that are available (Australia, New Zealand, USA, Indonesia, The Netherlands, Canada, China, Bulgaria and Belgium)
- 10 x Shortlisted urban modelling packages that are not available
- 20 x Economic forecast modelling packages
- 17 x Environmental / Climate modelling packages
- 12 x Modelling platforms
- 15 x Modelling method Inputs
- 12 x Transportation modelling packages
- 2 x Infrastructure Charges modelling packages
- 1 x Housing supply / demand modelling package;
- 1 x Social demographic modelling package
- 1 x Data management modelling package

The twenty-three (23) shortlisted modelling packages that are available progressed to step 3 and 4 to identify preferred modelling packages for the regional planning model.

Step 3 – Establish design requirements: Sixteen (16) design requirement categories were identified and defined from the step 1 literature review and stakeholder collaboration with the Growth Monitoring Program (GMP) Data Modelling Working Group (DMWG). They are, in no order of importance: Transparent, Dynamic, Structured and process driven, Bottom up, Current, Repeatable, Operator interchangeable, Micro, Ability to run scenarios, Ability to monitor growth, Resource efficient, Integrated, Accessible, Easily updated, Easily calibrated, and Adaptable. Design requirements for each category were also set out for the step 4 assessment of modelling packages against the step 3 design requirements.

Step 4 – Assessment to identify preferred modelling packages: Guided by the DMWG collaboration, three mandatory requirements were identified in step 4. They were identified by examining the design requirements and separating those aspects that were essential to meet the two SAGA purposes. The mandatory requirements were used to separate those modelling packages that did not meet the mandatory' requirements. Modelling packages that did not meet the mandatory requirements were removed from the preferred modelling packages list. The mandatory requirements were formed from findings of Step 1-3 and are: 1) GIS-Based; 2) Property-Based; and 3) Online Functionality.

The twenty-three (23) shortlisted modelling packages from step 2 were assessed against the step 3 design requirements and the mandatory requirements. Results of the due diligence process (steps 1-4) identified the following, in no order of preference, as the preferred four (4) modelling packages:

- UrbanSim
- Cube Land
- Forecaz Modeller
- What-If Online

Four other (sub) modelling packages were assessed as enhancing the preferred four (4) modelling packages for one or more of the regional planning scenario inputs. The four (4) preferred sub modelling packages are, in no order of preference: UrbanAPI, Metronamica, The WISE Model, and Envision. It was further found that, the four (4) preferred modelling packages could be supplemented with modelling method inputs that are not part of a modelling package (e.g. Classifier System, Artificial Neural Networks, Boolean Networks, Spatial Networks, Agent based models etc.). These would also further inform the development of scenarios and data inputs for the regional planning model.

The results of the due diligence process undertaken in 2019-2020 are proposed to be progressed to the regional planning model development (including procurement and availability), testing and implementation phases.

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1.0 Introduction

The Small Area Growth Assumptions (SAGA) are an implementation action of *ShapingSEQ*.

The SAGA subprogram is designed to implement a regional planning model to produce a region-wide set of growth assumptions at a small area level of detail (e.g. property level). An integrated set of assumptions are required, in a modelling package, to explore regional growth planning scenarios for future regional plan reviews and assist ongoing region-wide infrastructure decision making.

To produce and explore a region-wide set of SAGA scenarios, a regional planning model is required to bring together local government area related planning assumptions across South East Queensland (SEQ) into a region-wide model. A region-wide model would provide an SEQ-wide view of existing and planned growth, within and across local government boundaries.

Step 1 of a four-step due diligence process was completed in 2019 and included in the 2019 Land Supply and Development Monitoring (LSDM) report. Step 1 undertook a review of literature and identified and explored the different types of urban growth modelling and processing approaches. This report sets out the remaining steps 2-4 of the due diligence process. It is a technical report and assumes a level of background knowledge about urban growth modelling concepts, approaches and language.

1.1 Purpose

This report has been prepared to detail the final three stages of due diligence process to select an urban modelling package to be considered as the SEQ regional planning model.

<u>What is the regional planning model?</u> The regional planning model would integrate planning assumptions across SEQ to inform region-wide infrastructure needs and support future reviews of SEQ regional plans (e.g. scenario testing and communication). For clarity, the RPM requires an integration function and also the ability to model regional planning scenarios.

<u>What is an urban modelling package?</u> Adapted from Batty (2009) for the purposes of this subprogram, an urban modelling package is an integrated computer program used to explore existing and future urban spatial structure in terms of land use, population and employment.

1.2 Aim

The aim of the due diligence process is to identify preferred urban modelling packages that are best practice, can meet current and future needs for regional planning stakeholders in SEQ. Rather than progressing straight to any modelling package, the due diligence process in 2020 first identifies potential urban modelling packages. It then assesses the packages against best practice approaches identified in step 1 and a list of design requirements in step 3, prepared in consultation with SEQ planning stakeholders. Preferred modelling packages are then detailed in step 4 to progress towards the development, testing and implementation of the regional planning model. Opportunity may be provided for modelling packages that were not identified in this due diligence process to be considered via an open market procurement process.

1.3 Due Diligence Overview

Figure 1 provides an overview of the due diligence process, divided into four steps. Step 1 was completed in 2019 and was included in the best practice research section of the 2019 LSDM online report. Steps 2 – 4 are included as sections 2 – 4 of this report, each presenting the methods undertaken and results respectively. An overview of the due diligence steps is included as Figure 2.

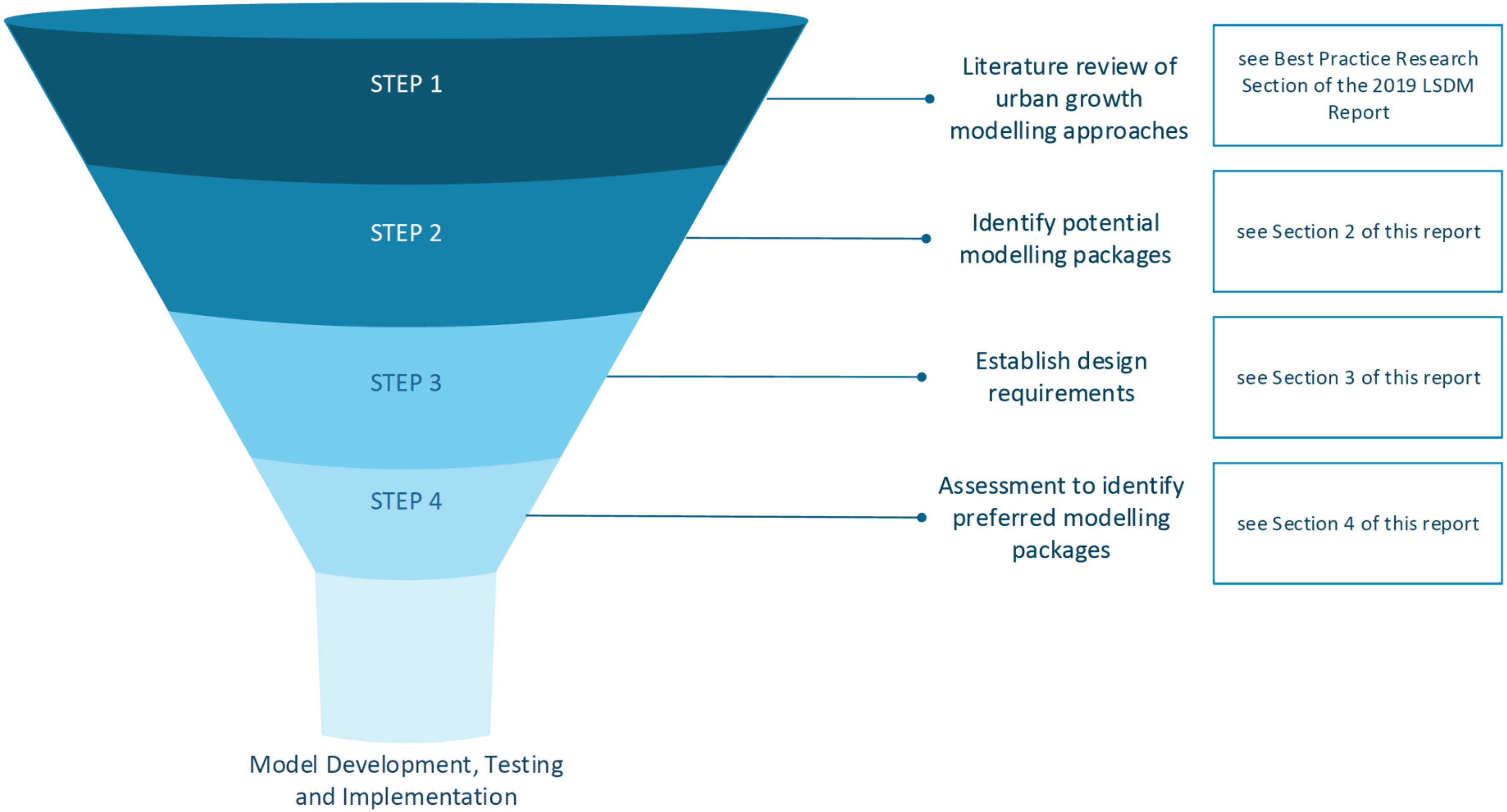

Figure 1: Due Diligence Overview

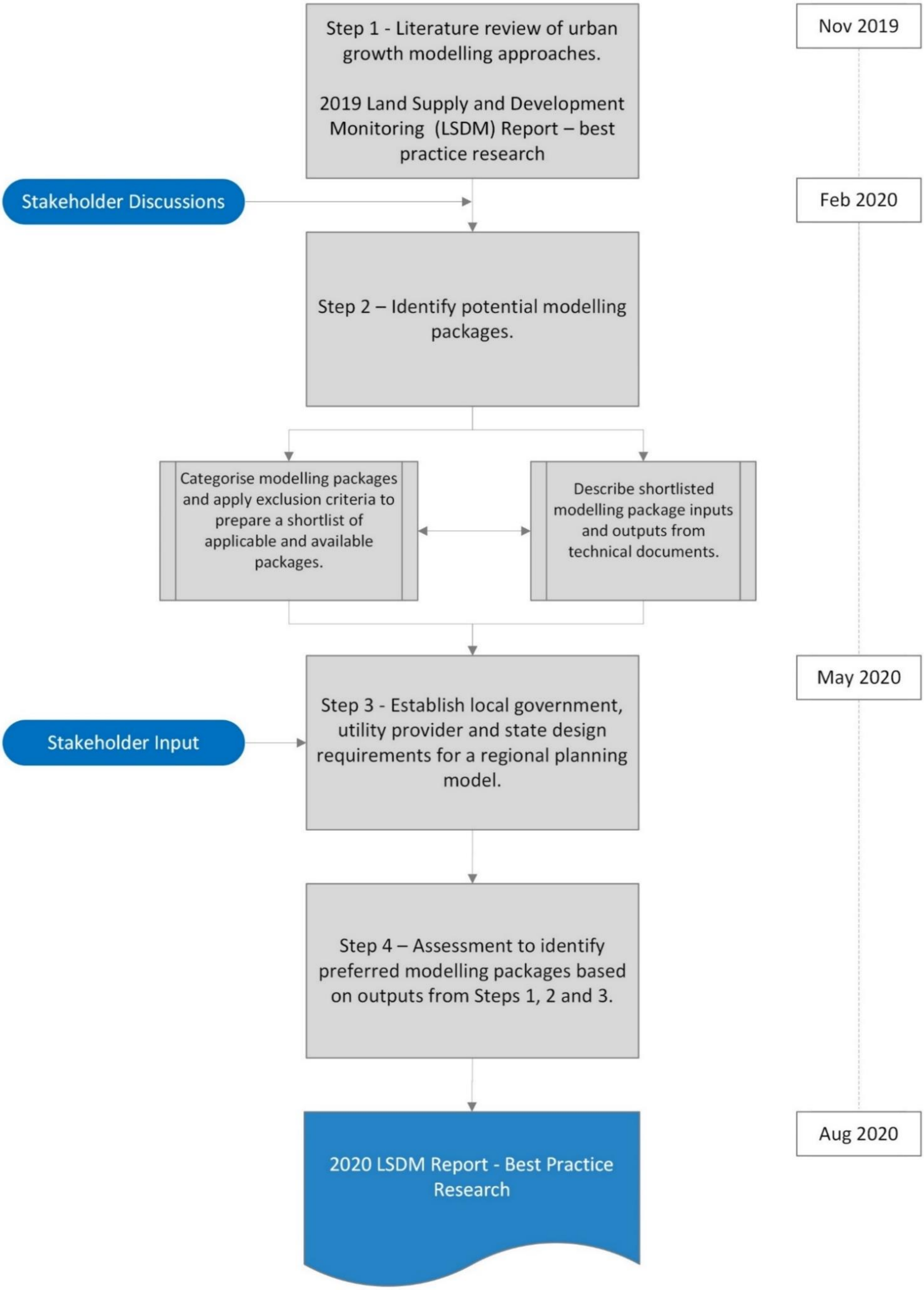

Figure 2: Due Diligence Detailed Overview with Timeline

A context piece is set out to gain an appreciation of the subprogram in relation to the existing SEQ context. Importantly, the existing SEQ context has guided the need and approach to this subprogram. Next, a breakdown of the subprogram timeline from 2020 to 2022-2024 is set out. To conclude the introductory section of the report, regional planning model interrelations and interfaces with other stakeholders and their models are briefly set out.

1.4 Subprogram Context

Urban modelling in SEQ is undertaken by many stakeholders. Typically, an urban model is produced by each local government. Given there are 12 local government areas in SEQ, the SEQ region has a minimum of 12 growth models, each forecasting their own population and employment growth (i.e. planning assumptions). Adding to this, are other major growth areas, such as Priority Development Areas (PDA), that have growth managed and forecast separately across many of the SEQ local governments. Other stakeholders at a state government level, such as Queensland Department of Transport and Main Roads (TMR) and other relevant sections of Department of State Development, Infrastructure, Local Government and Planning (the department), utilise the local government and PDA growth forecasts for their planning and projections.

Information is often exchanged among stakeholders to carry out their statutory responsibilities. Information is requested, input, analysed, and used to output data which is then used by others to input, calibrate, analyse and so on. This data exchange is circular and largely interrelated – it informs each other. However, typically, this flow of information occurs local government by local government at a time in a rather manual and iterative process.

The aim to produce and use a regional planning model recognises a need to improve current approaches to modelling existing development and future growth forecasts in regional planning. The SAGA subprogram is designed to capture all this information and integrate it in a modelling package to explore and better understand projected growth, as a whole, across local government boundaries and across PDAs and show all the region's growth assumptions at a small area level of detail (e.g. lot level).

To produce a region-wide set of SAGA, an urban modelling package is required to prepare the 'regional planning model' by bringing together the various planning assumptions across SEQ in an integrated region-wide model. A regional planning model can provide an SEQ-wide view of existing and planned growth, within and across local government boundaries.

Without a 'regional planning model', *ShapingSEQ* and future regional planning reviews may not be able to sufficiently explore and communicate the potential impacts of potential alternative land use patterns or potential dwelling supply benchmarks. To assist, the SAGA subprogram aims to develop a regional planning model to better inform:

- Regional plan decision-making and future regional plan reviews; and
- Regional plan scenarios and their impacts on existing and planned infrastructure networks, guiding the best use of existing infrastructure and aligning future infrastructure delivery and regional plans.

A regional planning model would allow exploration of, among other things: the impact of identified region-shaping infrastructure, the effect of nominated region-wide consolidation and expansion dwelling supply benchmarks and the impact of any future proposed state planning policies.

1.5 Subprogram Timeline

The due diligence process identifies preferred modelling packages and is part of the broader SAGA subprogram to deliver a regional planning model to inform future regional plan reviews. Figure 2 sets out the due diligence work undertaken in 2020 and the subsequent regional planning model's development, testing and implementation.

Another key aim of the regional planning model is to inform the planning of region-wide infrastructure. In this regard, the regional planning model is to align with the development of the Department of Transport and Main

Roads (DTMR) and University of Queensland (UQ) iMOVE Cooperative Research Centre (CRC) project. The iMOVE CRC is currently investigating developing the capability within DTMR to implement an integrated land use transport model, with the ability to test different land use scenarios in response to key infrastructure projects. Information from the regional planning model will need to be consistent and compatible with the iMOVE CRC project. Aligning identified design requirements and development timeframes will assist with this.

Bi-lateral integrated modelling between iMOVE and the RPM is necessary for compatibility and integration between land use and transport planning. Noting transport is one of many types of trunk infrastructure to have a nexus between land use and infrastructure planning. The RPM could provide an integration of current LGIP assumptions across SEQ. iMOVE could then:

- utilise these integrated assumptions to run transport modelling scenarios, in consultation with local governments,
- inform any regional planning RPM scenarios; and
- inform transport planning (using regional planning RPM scenarios) - for a dynamic integration between land use and infrastructure planning.

More information is provided in the sections below, detailing the regional planning model interrelations and interfaces with other stakeholder information and modelling platforms (see section 0).

Figure 3: Timeline of the regional planning model – model due diligence to new regional plan

1.6 Regional Planning Model Interrelations and Interfaces

Understanding the context of the regional planning model among other plans and modelling approaches in SEQ is fundamental to the regional planning model's development. Many modelling approaches are prepared by local government, utility providers and state government departments. All have different purposes and reporting requirements and cover different geographic areas and are at varying spatial scales (i.e. levels of detail). Further exploration of these differences and compatibility challenges was undertaken as Step 3. However, the key observation to be made is the interrelatedness of these various approaches in projecting and planning for population and employment growth. Data and information are transferred in and out of the many approaches detailed in Figure 4. The regional planning model spans, and to some extent, integrates many of the approaches identified in Figure 4. Principally, by bringing together the Local Government Infrastructure Plan (LGIP) planning assumptions for all 12 local government areas into the one regional planning modelling package. To clarify, the regional planning model takes the LGIP planning assumption outputs for each SEQ local government and brings them together to show a regional view. It does not change the outputs nor replace the functions or use of each local government's LGIP planning assumptions.

Regional Planning Model Interrelations

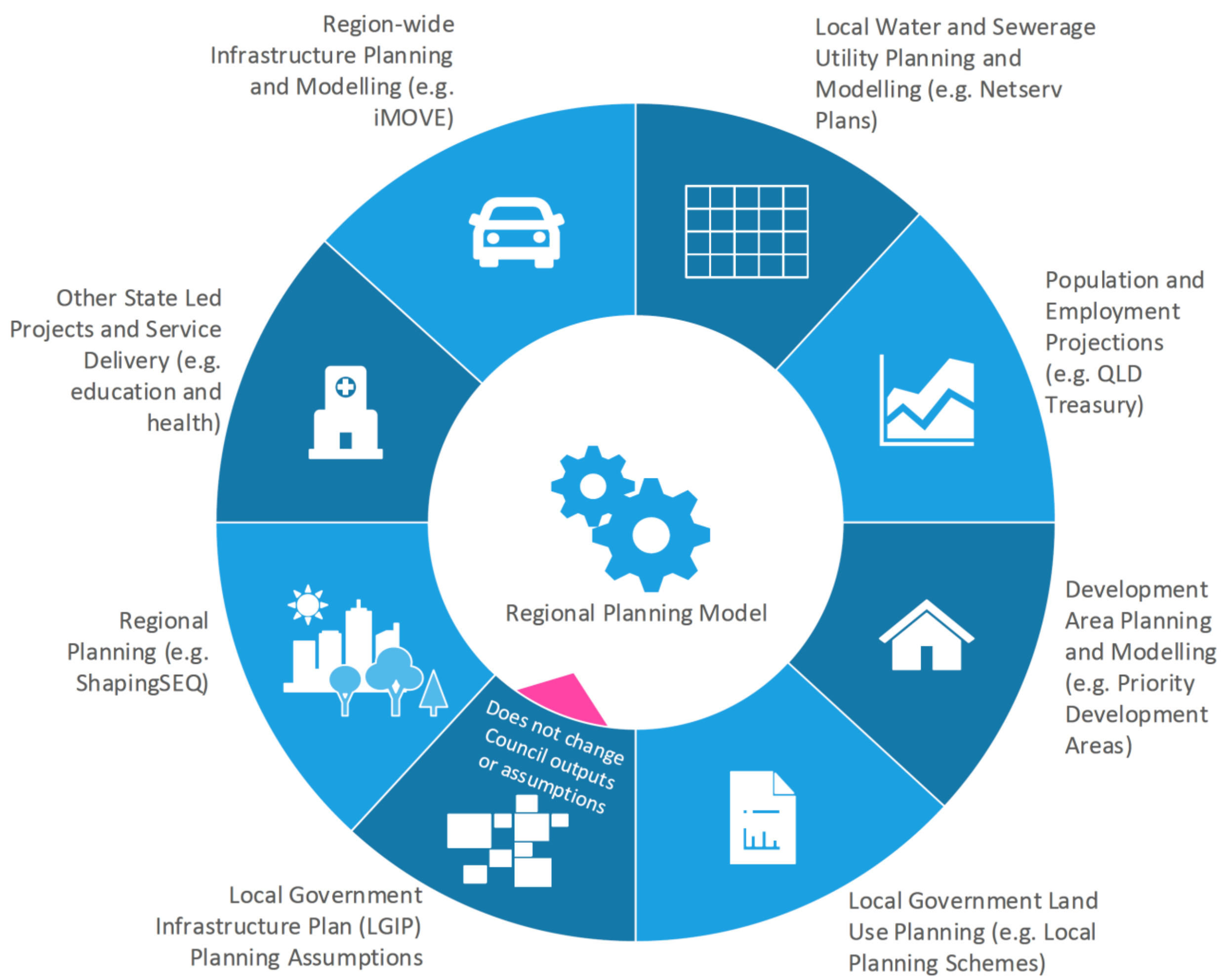

Figure 4: Regional Planning Model Interrelations

Key interfaces between the regional planning model and other stakeholder models have been identified to assist with stakeholder engagement and the regional planning model's design. Four key interfaces have been identified and are detailed in Figure 5, including regional planning model interfaces with: 1) LGIP assumptions; 2) priority development area assumptions; 3) DTMR and UQ iMOVE CRC; and 4) population and employment projections. Each interface is explored in Step 3, supported by stakeholder input, to establish the regional planning model design requirements. Design requirements is a term used to describe what the model needs to do and for whom. For example, a design requirement is for the regional planning model to bring together the 12 SEQ local government LGIP planning assumption outputs and explore alternate patterns of growth for a future regional plan. Identifying and exploring these design requirements facilitates the compatibility of data flowing in and out of the regional planning model with the other stakeholder models. It also facilitates the usefulness of the regional planning model for other stakeholders' purposes and, overall, helps meet the SAGA subprogram aims.

Data Flow and Compatiblity Interfaces

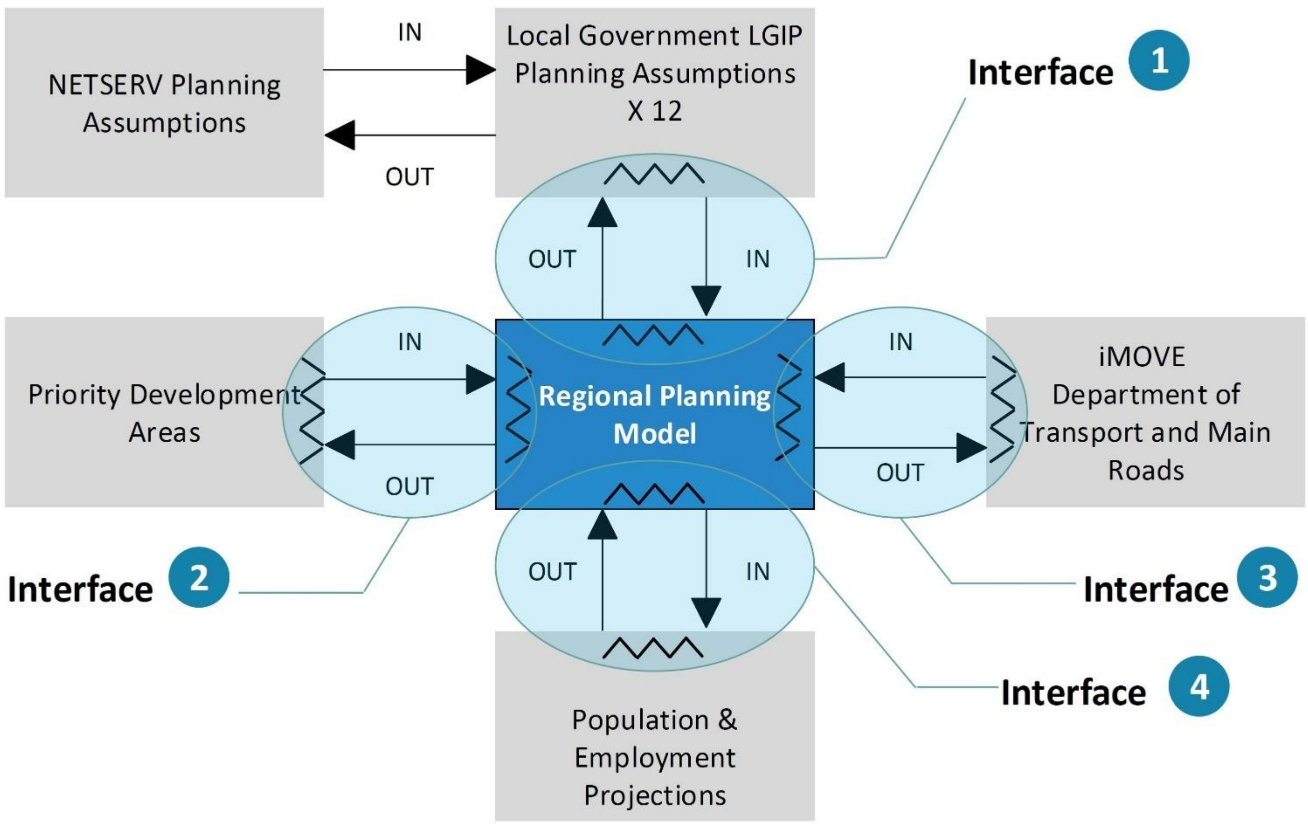

Figure 5: Data flow and compatibility interfaces

Note: This figure provides an overview of the data flow and compatibility interfaces. Many other components and interrelations occur that are not captured in this diagram, however, these four are the key interfaces identified for the regional planning model.

2.0 Step 2 - Identify Potential Modelling Packages

2.1 Overview

Building on the literature review included in the 2019 LSDM (Step 1), this section details Step 2 of the due diligence process which identifies potential urban modelling packages. The key aim of Step 2 was to produce a shortlist of modelling packages that have the potential to meet any design requirements of the SEQ regional planning model. The shortlisted modelling packages identified in Step 2 were progressed to Steps 3 and 4 for assessment against design requirements – producing a list of preferred modelling packages (see section 4.3).

Results of this step (2) are organised into the following:

- Shortlisted modelling packages that are available (see section 2.3.1)
- Data inputs and outputs of shortlisted and available modelling packages (see section 2.3.2)
- Shortlisted modelling packages that are unavailable (see section 2.3.3)
- Other modelling packages categorised (see section 2.3.4)

A description of each table is included at the relevant results section of the report. Before the results of Step 2 are presented, the next sections detail the method undertaken to identify potential modelling packages.

2.2 Method

2.2.1 Overview

Step 2 uses publicly available information about urban modelling packages to list and examine each modelling package and its suitability for the regional planning model. Step 2 reviewed academic and non-academic literature. The academic material encompassed published books, peer-reviewed articles and academic conference transcripts. Literature was examined for urban modelling packages and examples of their use through case studies or other mention in theory or methodological development. The non-academic literature review generally consisted of government planning documents or databases and private consultancies technical user manuals. The literature review was a structured review that followed a set of tasks for database selection, search strategies, material extraction, categorisation and exclusion.

The literature review and analysis of the findings comprised three tasks:

- Task 1: database selection;
- Task 2: search strategy and material extraction; and
- Task 3: categorisation and exclusion.

Each of the three main tasks has been further divided into subtasks respectively as described in the following sections.

2.2.2 Task 1: Database Selection

Literature databases were selected across two broad categories - academic literature and non-academic material.

2.2.2.1 Academic database

Google Scholar was the database search engine used for the academic literature search. Google Scholar was selected as it spans an extensive range of databases – providing a wider search than searching one database. Google Scholar databases include key academic databases, such as, Science Direct, Web of Science, ProQuest, Sage Journals, Scopus Springer, Taylor and Francis and Wiley Online. Contributing to its selection, is Google Scholar's ability to source academic material not indexed with any other academic database (e.g. conference articles). The literature review targeted published books, peer-reviewed articles and academic conference articles.

2.2.2.2 Non-Academic database

Non-academic material was sourced via the standard Google search engine. Google's standard search engine provided links to non-academic material such as governmental bodies or private institutions. Internal website search functions, research portals or databases were also used to locate material when direct internet links were not appearing in the Google search results.

Government bodies included local regional councils, metropolitan city councils, state government planning departments and government-sponsored research departments. Internet links were noted to ascertain a level of confidence that they were the official sources. For example, noting the modelling package origin country and the search results URL extension, such as .gov, .au and .uk. Private sources include consultants, private research groups, university-sponsored research groups and non-government organisations. Any reference of private sources in academic material was noted to gain some confidence of the source material. This involved locating the website through reference lists; observing known branding/promotion material in web domains; and, noting key individuals with ties to the private institutions and mentions in academic material.

2.2.3 Task 2: Search strategy and material extraction

The search strategy and material extraction were performed according to five strategies. The aim of this task was to compile a list of modelling packages. Task 3 would then further categorise and exclude modelling packages to arrive at a shortlist of modelling packages. The first strategy targeted modelling packages identified in the 2019 LSDM report (step 1). The second strategy was performed to locate additional modelling packages to those located in step 1. Strategy 3 targeted publicly available urban modelling information used in the metropolitan regions of Perth, Sydney, Melbourne and Adelaide. Strategy 4 targeted urban modelling consultant packages and local government models in Queensland. Strategy 5 was performed included modelling software packages that were identified through stakeholder input.

2.2.3.1 Strategy 1 – search literature review modelling packages

The first strategy extracted modelling packages listed in the best practice research literature review (Step 1), included in the 2019 LSDM report. The names of the modelling packages from Step 1 were entered in the Google Scholar search engine. The search was refined to the modelling name being included in the literature's titles rather than the body paragraphs. The selected literature was perused for references to the term 'Model', and all discovered instances of additional modelling packages were added to a draft shortlist for further investigation. Once all model information was extracted, reference lists were searched for the oldest reference of each modelling packages. This was done to establish a model's origins and original authors for reference and further searches. The oldest referenced literature relevant to the model was searched in Google Scholar, and the above process was restarted until there was evidence to suggest the original reference of the model package was found.

The original referenced paper was used to extract various background information on the model. The categories of information extracted are as follows:

- The Modelling Package's Name
- The Developer's Name

- Year of Publication
- Country of Origin
- Examples of Use and Calibration
- Modelling Packages Acquisition Web Address
- Reference to The Original Paper
- The Available Model Support Services
- Licensing Rules and Pricing where record whenever available

When the original founding paper did not provide all the above background information, the standard Google search engine was used with the following search terms '*insert model name* publisher', *'insert foundation paper* author'.

Once all required background information was documented on the draft shortlist, the initial models were then searched again through Google Scholar with additional search criteria. The search was restricted to the model's name in the literature title and also the published year was restricted to post-2010. The available literature was searched for the following terms 'application of *insert model name*', 'Case study' and 'Calibration of *insert model name'.*

A list of reference documents was compiled for each model and each document was perused for any listing of other modelling packages. All shortlisted alternatives to the initial models underwent the same process of locating the original founding paper, documenting background information, sourcing reference documents and perusing for new urban modelling packages. This process continued until all found models were listed, and all search leads where exhausted.

2.2.3.2 Strategy 2 – search for additional modelling packages

Search strategy 2 aimed to locate additional modelling packages. It utilised the search strategy 1 process but started with defined search terms for academic and non-academic databases, rather than the model package names identified from the 2019 LSDM report. The search terms used are as follows:

Academic Search Terms for Google Scholar

- 'Regional planning model'
- 'Urban Growth Models'
- 'Employment Land-Use Modelling'
- 'Population Land-Use Modelling'
- 'Modelling Approaches and Application'

Non-Academic Search Terms for standard Google

- '*Insert country/region name* planning department'
- '*Insert country/region name* modelling package'
- '*Insert institution name* modelling package'
- '*insert country/region name* Land-Use modelling'.

The word 'modelling' was also interchanged with its American - English spelling (e.g. modelling).

Titles were observed for the following terms;

- 'Application of *insert model name*'
- 'Case study'
- *'*A comparative review of modelling software'

- *'Insert model name* Review'

The literature was then perused for new modelling package names and added to the list of modelling packages compiled in search strategy 1.

2.2.3.3 Strategy 3 – search for modelling packages used by government in selected Australian metropolitan areas

Search strategy 3 aimed to capture any publicly available information about modelling packages used in larger Australian metropolitan areas. Metropolitan areas of Perth, Sydney, Melbourne and Adelaide were targeted as these were considered representative of larger and higher growth areas – comparative to SEQ.

Google searches were undertaken to identify the local government and state planning departments applicable to each metropolitan area. Local government or state planning department search engines, applicable to the metropolitan areas, were searched with the following terms:

- 'Regional planning model'
- 'Urban Growth Models'
- 'Employment Land-Use Modelling'
- 'Population Land-Use Modelling'
- 'Modelling Approaches and Application'

Using the above approach, no information regarding urban modelling packages was sourced for the Perth, Sydney, Melbourne and Adelaide metropolitan areas. Therefore, this search strategy has no impact on the following sections.

2.2.3.4 Strategy 4 - search for other modelling packages used in Australia

Search strategy 4 searched other local government or state planning department databases (within their websites), reports and planning assumption documentation to identify any additional urban modelling packages used in Australia. The search terms used were:

- ‘Regional planning model’
- ‘Urban growth model’
- ‘Land-use model’
- ‘Modelling consultant’
- ‘*Insert regions name* modelling’

Search engines within each of the following departments were searched:

- New South Wales - Department of Planning and Environment
- Queensland – Department of State Development, Manufacturing, Infrastructure and Planning
- Northern Territory - Department of Lands, Planning and the Environment
- South-Australia - Department of Transport, Planning and Infrastructure
- Victoria - Department of Transport, Planning and Local Infrastructure
- Western Australia - Planning Western Australia
- Tasmanian - Tasmanian Planning Commission

State or territory planning departments and local governments were searched with the search terms.

Any information retrieved about modelling approaches was perused for the following terms;

- 'Regional modelling process'
- 'Urban consultancy'
- 'Land-use modelling'
- 'Population model'
- 'Employment model'

Where available, information was collected across the following categories;

- Councils name
- Year of use
- Data required
- Technical documents
- Examples of use

2.2.3.5 Strategy 5 – stakeholder identified modelling packages

Search strategy 5 provided additional modelling packages from stakeholder consultation in step 3 that were not captured from the structured literature review, here in step 2.

The additional modelling software packages were identified from stakeholder input, as follows:

- Regional planning model online survey results
- Draft literature review report for the iMOVE CRC project provided by DTMR
- Regional planning stakeholder comments on version 1 of the draft 2020 LSDM report – best practice research section

The additional model names were searched through google scholar to document the following;

- Country of origin
- Developer
- Application
- Case studies
- Acquisition requirements
- Additional literature material available in English

The consolidated information per model was then applied to categorise or exclude the modelling software packages. A further twenty-two modelling packages were added and underwent categorisation and exclusion.

2.2.4 Task 3: Categorisation and Exclusion

The list of modelling packages from Task 2 underwent a categorisation and exclusion process to arrive at a shortlist of modelling packages. The results are presented across four tables:

1) Shortlisted modelling packages that are available;
2) Data inputs and outputs of shortlisted & available modelling packages;
3) Shortlisted modelling packages that are unavailable; and

4) Other modelling packages categorised.

2.2.4.1 Unavailable modelling packages

The minimum information requirements to be classified as available for use included: developer contact details, current examples of use and support service offerings. Where this information was not available, modelling packages were considered inactive or no arrangements in place for distribution, sharing or licencing and therefore not included for further consideration.

2.2.4.2 Categorisation of other modelling packages

To arrive at a shortlist of modelling packages, the list of modelling packages found from task 2 were categorised into the different types of modelling packages available to separate those not applicable to the regional planning model. This was done as it became apparent in task 2 that many of the modelling approaches retrieved were not strictly population and employment urban modelling packages. Being an urban modelling package, as defined in the introduction section, was established early in the project as a key requirement of the regional planning model. As a result, the list of modelling packages was categorised according to Table 1 below to identify those packages that are not strictly population and employment urban modelling packages. Literature was examined to identify terms listed in Table 1, indicating the retrieved modelling approach was not a population and employment modelling package.

Table 1: Literature review categorisation and exclusion

Example Terms	Category
‘Economic forecast’ ‘CGE modelling’	**Economic Forecast Modelling**
‘Environmental adaption modelling’ ‘Climate change modelling’	**Environmental/ Climate Modelling**
‘Modelling platform builder’ ‘Modelling resource library’	**Modelling Platforms**
‘Modelling data systems’ ‘Modelling theoretical approach logics’	**Modelling Approaches and Data Inputs**
‘Transportation distance modelling’ ‘Transportation infrastructure land-use’	**Transportation Modelling**
‘Infrastructure modelling’ ‘Infrastructure charges modelling’ ‘Infrastructure asset management’	**Infrastructure / Infrastructure Charges Modelling**
‘Housing supply/demand’	**Housing Supply/Demand Modelling**
‘Asset modelling’ ‘Data management modelling’	**Data Management Modelling**
‘Social modelling’	**Social Demographic Modelling**

2.2.4.3 Data Inputs and Outputs of Shortlisted and Available Packages

The retrieved documentation for each of the shortlisted urban modelling packages were examined for details about the types of inputs required for the model to run and also the type of outputs from the model. Information from any technical manuals supporting the modelling package were prioritised. Other retrieved documentation was used where a technical manual was not publicly available.

2.3 Results

2.3.1 Shortlisted Urban Modelling Packages

The results identified twenty-three (23) shortlisted urban modelling packages that are available. Results are summarised in Table 2, detailing modelling packages originating from nine different countries (Australia, New Zealand, Indonesia, United Stated of America, The Netherlands, Canada, China, Bulgaria and Belgium). Developers of the modelling packages vary and include universities, consultancies, institutes and government. Some have been developed collaboratively between these organisations.

Table 2: Shortlisted urban modelling packages that are available

Shortlisted urban modelling packages that are available	Developer	Origin Country
What-If Online	Chris Pettit & Australian Urban Infrastructure Research Information Network	Australia
Vision Illawarra	University of Wollongong Australia – Smart Infrastructure Facility	Australia
Forecaz Modeller	Sizztech	Australia
The WISE Model	Waikato Regional Council	New Zealand
Cube Land	Citilab and Bentley Systems	United States of America
The Clarke Urban Growth Model/ SLEUTH	Keith C Clarke	United States of America
What-If 2.0	Richard Kolsterman	United States of America
Dynamic Urban Evolution Model (DUEM)	Xie Yichun	United States of America
CommunityViz	City Explained Inc	United States of America
SPARC & INDEX	CRITERION PLANNERS	United States of America

Uplan4	Information Center for the Environment	United States of America
UrbanSim	Paul Waddell	United States of America
Land Transformation Model	Purdue University	United States of America
Envision	Oregon State University	United States of America
LanduseSIM	Sepuluh Nopember Institute of Technology	Indonesia
Xplorah Model	Research Institute for Knowledge Systems	The Netherlands
METRONAMICA	Research Institute for Knowledge Systems	The Netherlands
Moland Model	Research Institute for Knowledge Systems	The Netherlands
CLUE	Tom Veldkamp & Louise Fresco	The Netherlands
iCity	Daniel Stevens	Canada
Future Land-Use Simulation Model (FLUS)	Guangdong Key Laboratory for Urbanisation and Geo-Simulation	China
Urban Development Simulator & UrbanAPI toolkit	UrbanAPI Consultancy	Bulgaria
RuimteModel/ Space Model	The Government of Flanders	Belgium

2.3.1.1 Inputs and Outputs

The inputs and outputs of each model included in Table 2 were described to understand the type of information used to 'run' the modelling package and the type of outputs produced. This information informed the assessment of each model against the design requirements identified in Step 3.

2.3.2 Unavailable Shortlisted Urban Modelling Packages

Table 3 is a list of shortlisted urban modelling packages that are unavailable for use, due to various reasons. For example, they are not or no longer shared; developers do not provide support services; not available commercially; or haven't been updated to be compatible with current computer operating systems or programming. The modelling packages included in Table 3 met the definition of an urban modelling package in the structured review but are unavailable. For this reason, they are separated from the modelling packages in Table 4 that do not meet the definition of an urban modelling package.

Table 3: Shortlisted urban modelling packages that are unavailable

Shortlisted urban modelling packages that are unavailable	Developer	Origin Country
California Urban Future Model (CUF)	Landis J D	United States of America
Disaggregated Residential Allocation Model (DRAM)	Stephen H Putman	United States of America
Employment Allocation Model (EMPAL)	Stephen H Putman	United States of America
Growth Simulation Model	Maryland Department of Planning	United States of America
VecGCA	Geocomputing Laboratory, University of Calgary	Canada
MUGICA Model	Alcalá University	Spain
SimLand	Fulong WU	China
S-CMM-CA	Weilin Wang & University of Wuhan	China
DLPS-VCA	Guangdong Key Laboratory for Urbanization and Geo-Simulation	China
BUDEM	Beijing City Labs	China

2.3.3 Other Modelling Packages Categorised

Table 4 is a list of other modelling packages which were not shortlisted as they did not meet the definition of an urban modelling package. The urban modelling packages in Table 4 are principally for purposes 'other' than land use, population and employment growth modelling. Modelling packages in this table include approaches that are generally inputs to the urban modelling package or use the outputs of the urban modelling package, but, by themselves, are not a 'standalone' and 'integrated' urban modelling package.

Table 4: Other modelling packages categorised

Modelling Software Package	Category
HOPSIM	**Economic Forecast Modelling**
CATLAS	
NBER	
OUTVYE	

Project Link	
RISE Model	
CGE Models	
DAE-RGEM	
Lowry Model	
ENPIRIC Model	
Herbert-Stevens Model	
Forrester Dynamic Model	
BDO EconSearch Modelling	
NIEIR Internal Modelling Packages	
Mills Linear Programming Model	
Koopmans-Beckmann Quadratic Model	
Wharton Annual and Long-Term Econometric Model	
Multi-Agent Based Environmental Landscapes (MABEL)	
The Urban Institute Model for Housing Market Analysis	
Wilson's Statistical Gravity Model and Random Utility Theory	
MIMES	**Environmental/ Climate Modelling**
MANNCA	
TerrSet	
LUMASS	
Natura2000	
Urban Expansion Dynamic (UED) Model	
Urban Expansion Scenario Model	
Land Change Modeler	
Dinamica EGO Modelling	
Urban Land-Use Model (SULM)	

Nature Outlook 2030 NARA-S-2009	
The Auckland Regional Model (ARM)	
Landcom Sustainability Tool (PRECINX)	
Forest Investment Framework (FIF model)	
Waterworld – Land Use Change Model	
Land Utilisation and Capability Indicator (LUCI)	
Integrated Valuation of Ecosystem Service and Trade Offs (InVEST)	
MASGISmo	**Modelling Platforms**
GeoAutomata	
Repast	
SWARM	
Mason	
StarLogo	
Nova	
Echo	
Boids	
CORMAS	
NetLogo	
GEOFLEX	
Logistic Regression (LR)	**Modelling Method Inputs**
Regression Tree (RT)	
Machine learning and Artificial Intelligence (i.e. Artificial Neural Networks (ANN))	
Markov Chains (MC)	
Bayesian Belief Network	
Swarm Intelligence	

Stochastic Perturbation	
Boolean Networks	
OptimizationTool	
NACE Classification System	
Shannon Entropy Classifier System	
Equilibrium Problems	
Radial Basis Function Neural (RBFN) Network Model	
Spatial Networks	
Randomised algorithms (e.g. Monte-Carlo)	
BITZIOS	**Transportation Modelling**
START	
ZENITH	
VKT Regression Model	
METROPILUS	
MUSSA	
MEPLAN	
The TIGRIS XL	
Sustainable Pathways 2	
SWIM2	
TRANUS	
DELTA	
Pie Solution's NOVOPLAN	**Infrastructure / Infrastructure Charges Modelling**
INTEGRAN Internal Modelling Packages	
AHURI modelling	**Housing Supply / Demand Modelling**
ASSURE	**Social Demographic Modelling**
KINESIS	**Data Management Modelling**

3.0 Step 3 – Establish design requirements

3.1 Overview

Step 2 provided a shortlist of twenty-two (22) urban modelling packages to further examine their suitability for the regional planning model. Step 3 develops design requirements to facilitate the selection of preferred modelling packages based on the Regional Planning Model's need to explore region-wide growth scenarios for regional plan reviews and support region-wide infrastructure planning. The design requirements will also assist with the development, testing and implementation of the regional planning model.

3.2 Context

Throughout the due diligence process, it became evident that the shortlisted urban modelling packages were either 1) simplistic GIS rule -based allocation models; 2) more sophisticated GIS rule-based allocation models supplemented by other modelling methods; or 3) other hybrid microsimulation models underpinned by different theories (e.g. random utility theory, complexity theory, economic equilibrium theory etc.) and supplemented by other modelling methods (e.g. artificial neural networks, Bayesian networks, agent-based models, randomised algorithms such as Monte-Carlo).

The shortlisted modelling packages are also made up of different processing modules, and some more than others, with varying levels of sophistication to model existing development and forecast. For example, some modelling packages have modules that deal with transport, land use and market factors. Throughout the review of the modelling packages, and the preparation of design requirements, it became apparent that some modelling packages were better suited to parts of the modelling process but were able to draw on other modelling packages to input other modelling outputs. For example, some more sophisticated GIS rule-based allocation modelling packages used 'modelling method inputs' (refer to table 4), such as Bayesian network and artificial neural network outputs to calculate development propensity. Others use agent-based models to examine market behaviour patterns to inform housing type demand and had more modules than others. Further, some urban modelling packages contain modules that input external data, such as employment projections, and some are able to perform these functions 'in-model'.

3.2.1 A Regional Planning Model Schematic

As hybrid approaches are advocated in the literature, especially when modelling in practice, it was considered appropriate to explore the use of more than one modelling package for use as the regional planning model. One to perform some functions and, if required, other modelling packages to provide different inputs to the regional planning scenarios. For example, provide more sophisticated input to housing type demand or employment demand. Figure 6 provides for a 'Primary' modelling package and the opportunity for a 'Sub' modelling package or other modelling method inputs, if required. Figure 6 details the flow of input data in one direction – from left to right into the regional planning model. In responding to regional planning stakeholder feedback, importantly, the regional planning model incorporates and integrates the input data from the various sources 'as is'. A draft data structure is set out to signify the importance of a data structure that can be integrated across all sources. This is likely to be further refined throughout the ongoing SAGA subprogram.

Assisting with the integration is the existing Ministers' Guidelines and Rules (MGR) which specify minimum requirements for a LGIP. The MGR sets out the minimum reporting categories for planning assumptions (e.g. detached, attached etc.). These will largely be common across all LGAs. There however, will be differences in land use classifications, therefore translation to common land uses would be required. All current and available LGIP existing and ultimate development will be used.

From the centre of Figure 6 to the right shows the data flow, back and forth, as scenarios are developed and refined from input sources in and out of the regional planning model primary and sub modelling packages and methods.

Example types of input data that may inform the preparation of scenarios provided through a regional planning model, for regional planning purposes, are as follows:

- Projections
- Propensity
- Developable areas
- Housing demand
- Settlement patterns
- Infrastructure realistic availability
- Planning Scheme Zones
- Employment demand

These scenario inputs are not reliant on local government data provision as the regional planning model will utilise region-wide input data that is regionally consistent for regional planning purposes. This is considered best practice when modelling scenarios over large metropolitan areas or regions. Hybrid approaches are often formed in practice to supplement microsimulation approaches with data-driven approaches when data is not regionally consistent or available at a small area level of detail.

3.3 Planning theory

Some modelling packages include processes that are underpinned by theory. In response to stakeholder feedback, consideration was given to include 'theory' as a design requirement. Being explicitly based on theory for some model processing is considered desirable and is included as a design requirement as part of the assessment in step 4.

Although being based on theory is included in the design requirements, no particular theory was specified and theory was not included as a mandatory design requirement. This is because various modelling approaches apply different theoretical foundations. Some shortlisted and available modelling packages do not follow theory in their modelling - but have the ability to incorporate theory in their inputs. Further, a modelling package may explicitly and implicitly apply multiple theories in its approach. For example, it could explicitly incorporate random utility theory for one part of the modelling process but also implicitly follow complexity theory in its overall approach. For example, exploring the interrelations of the component parts at a micro level and accounting for complexity characteristics such as hierarchical structures, non-linearity, self-organisation, emergence etc.

Further supporting theory not being included as a mandatory requirement is the literature advocating urban planning does not have its own set of theories (E. R. Alexander, 2016; Allmendinger, 2017). Instead, it draws upon a wide range of theories and practices from different disciplines – all of which are not specifically directed to implementation in an urban modelling package. For example, Allmendinger (2017) identified four broad categories of theory that planning theory draws upon: exogenous theory, framing theory, social theory and social scientific philosophical understandings.

Worth noting is that urban planning seeks to establish more theory in the urban planning discipline as an understanding of cities is evolving. Complexity theory is more so prevalent and agreed upon as a guiding theory and used in urban growth modelling than traditional planning theories such as central place theory. Providing further context, is that much of the theory being explicitly utilised in the modelling packages is regarding the econometric components of the model such as random utility theory and bid rent theory. Models that fit within these theoretical frameworks have a legacy in urban modelling evolution from the 1960s (e.g. Cube Land and UrbanSim). Others such as Whatif and Forecaz have emerged more recently and do not strictly follow a theory, having been established from GIS and being largely rule based planning tools.

Given the points set out in this section, theory was not included as a mandatory requirement but rather assisting with the determination of more preferred modelling packages. For instance, having theory as a design requirement gives preference to models that follow theory as theory-based models are considered in this report to be more readily equipped to explore the econometric modelling scenarios (e.g. housing type) than the rule-based models.

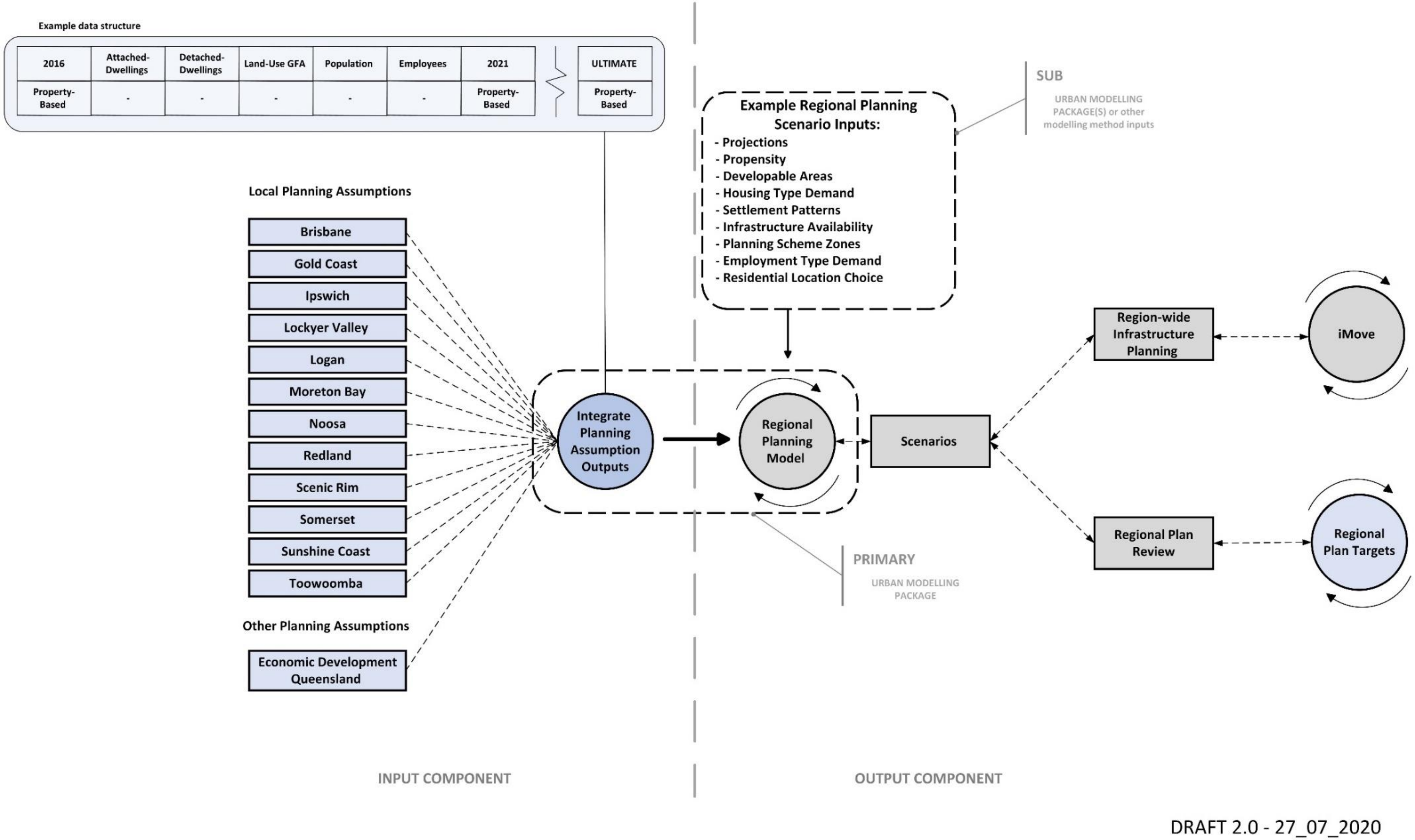

Figure 6: The Regional Planning Model Schematic

3.4 Method

Step 3 further explored and detailed specific design requirements for consideration in the SEQ regional planning model. The Step 3 method comprised of four key tasks as detailed below:

3.4.1 Task 1: Development of design requirement categories and definitions

Design requirement categories and definitions were first developed to prompt more detailed design requirements; organise design requirements; and more succinctly communicate the design requirements to SEQ regional planning stakeholders. The design requirement categories were developed from the:

- Step 1 literature review results;
- Step 2 results; and
- Regional planning model's purpose to explore region-wide growth scenarios for regional plan reviews and support region-wide infrastructure planning

3.4.2 Task 2: Stakeholder Survey Responses

Draft design requirement categories were provided to SEQ regional planning stakeholders via an information package. The information package included a draft report of step 2, an animated video providing an overview of the regional planning model and detailing draft design requirement categories. The stakeholder package also included an online survey for stakeholder feedback to facilitate further discussions and further develop the regional planning model's design requirements.

Survey responses were compiled and examined in a spreadsheet. Key messages from the stakeholder responses were communicated to the Local Government Working Group. Responses were also presented to the Data Modelling Working Group for the group to discuss and provided further feedback and direction. Outcomes of the discussions and initial survey responses guided the preparation of design requirements and content in Steps 1 and 2 of this report.

3.4.3 Task 3: Structured development of design requirements under each category

A structured approach to develop the design requirements under each category was followed. Figure 6 was used to prompt the design requirements for each design requirement category throughout each part of the regional planning model schematic diagram. A detailed description of the method undertaken is as follows:

- The definition for each design requirement category was first used to focus the development of each design requirement, specific to that category.
- The regional planning model schematic (Figure 6) was then used to explore the following questions:
    a) What does each model component need to do to meet the design requirement category definition and purpose of the regional planning model?
    b) What interrelationships between components need to occur to meet the design requirement category definition and purpose of the regional planning model?
- Step 1 and step 2 results were used to inform the preparation of the design requirements, in context of the above questions.

3.4.4 Task 4: Further Stakeholder consultation

Comments from regional planning stakeholders on version 1 of the draft 2020 LSDM report, including this best practice research report, were considered and updates to the draft report were made. This process was supported by a Data Modelling Working Group presentation with open questions as well as one-on-one discussions with stakeholders whom requested further consultation.

3.5 Results

3.5.1 Design Requirements

The regional planning model's design requirements, according to each design requirement category and definition, is presented in Table 5.

Table 5: The Design Requirements of the Regional Planning Model

Design Categories	Design Requirements
Transparent	Opposite of 'black box'. Ability for all stakeholders to view the inner workings of the model.
	- Any assumptions made, details about inputs, processes, outputs or results are made explicit and available. - A blueprint or schematic of the modelling package is available. - An explanation of underpinning theory and methods used, including any limitations and method biases or preferences, can be provided.
Dynamic	Opposite of static. Ability to account for the constant changes occurring in complex urban systems between the many components that interrelate in many ways.
	- Automated processes are preferred when 'running' the model. - Ability to compartmentalise processing tasks. - Can account and explore the interrelations of agent choices and behaviours with land uses across components of the urban system via microsimulations. - Incorporate agent-based and rule-based approaches.
Structured and process driven	Opposite of being based on intuition and judgment. A framework of inputs, processes and calibrations to transparently and explicitly describe the modelling approach.
	- The modelling package integrates input data in a structured manner and prepares scenario inputs based on data-driven approaches that have structure in the way they are assembled and clear processes on how the model runs under a clear framework. - Quantitative approaches are encouraged to use rules, statistics, algorithms, machine learning, probability for data-driven and evidenced based regional planning model outputs.

	- A sound theoretical basis and associated methodologies are encouraged. - Qualitative approaches are encouraged to help calibrate model runs. - Validation of modelled outputs through the comparison of observed 'real' data is essential.
Bottom up	Largely driven by approaches that do not involve the disaggregation of components from larger numbers or areas into smaller ones. Bottom up is largely built from the micro or small area components upwards (sometimes to control totals) to best account for urban complexity.
	- Uses micro data to explore the interrelations of urban system components to best account for urban complexity. - Uses control totals to set targets to help the allocation of growth from the bottom up. - No disaggregation of data, where other alternatives exist. - Property level representation of data.
Current	All model inputs are the most current information and data that can be produced or made available.
	- Model inputs are often maintained to ensure the regional planning model is 'running' based on current data. - Model scenario outputs are rerun often so that current output data is being used to inform regional planning. - The modelling approach is updated in a timely manner to account for any method advancements. - The modelling packages is compatible with current hardware and software and other supporting ICT environments.
Repeatable	Ability to run and rerun, following the same processes, to achieve the same outputs every time.
	- The modelling package inputs and processes produce the same outputs if no changes are made to the configurations. I.e. has a high level of reliability between operators.
Operator interchangeable	The modelling approach can be understood and followed by any person in the discipline to prepare, run, calibrate, validate and maintain the model.
	- The modelling package is intuitive in its interface. - Does not require computer scripting language experience. - Simple graphic user interface. - Follows familiar terminology and uses datasets that are familiar to the planning discipline. - Can configure and reconfigure individual values or settings through a 'front-end' interface.

	- Has a technical guide package with tutorials at a sufficient level of detail and explanation?
Micro	The model is set at a small area level of detail and can explore the interrelations of smaller components.
	- Is a property based model that predominantly runs microsimulations, agent-based and rule-based processing at a property based level from lot plan data available in a digital cadastre database. - Can account and explore agent choices and behaviours.
Ability to run scenarios	Ability to run scenarios from the local planning assumption outputs for regional planning purposes.
	- Can incorporate regional planning scenario inputs to prepare and run scenarios using information such as: different projections, propensity, developable areas, housing type demand, settlement patterns, infrastructure availability, planning scheme zones, employment type demand and residential location choice. - Theory is utilised to support the modelling approach and processes.
Ability to monitor growth	Efficiently measure development, including associated population and employment growth that has occurred to compare against planned growth and other regional planning benchmarks.
	- Can report on residential and non-residential growth at a property level annually or more frequent if the data becomes available. - Can include a variety of measures in the reporting, such as dwelling type, population increase, employment type etc.
Resource efficient	The time and resources used are proportional to the value of the model’s accuracy. An efficient balance between time, resources and accuracy.
	- Users can input, process, calibrate, retrieve and analyse data directly from the modelling package interface in an efficient and timely manner that does not unduly encumber the user. - Preparation time of input data is reasonable as to not impact on the dynamic requirements and ability to run scenarios and monitor growth.
Integrated	Data input, processing, output and calibration components operate in an integrated framework that facilitate compatibility and automated processing at all interfaces
	- Integrates local planning assumption data outputs. - Modules (i.e. scenario input data) come together in the regional planning model and exchange data as required for processing in and out of the regional planning model. - Can run and rerun regional planning scenarios in a primary modelling package with the support of a sub modelling package and other supporting methods in a hybrid approach.

Accessible	The model inputs, processes and outputs are easily accessed to those whom need to use, configure and view the model.
	- The preferred modelling software package must contain an online client whereas stakeholders can directly input their data into the Regional Planning Model from the 'frontend' and can bulk upload from the 'backend'. - The online client is password protected and use other suitable security systems to limit access to unauthorised users. - Online functions are available to authorised users. - Outputs can be viewed via an online interactive dashboard or similar. - The preferred modelling software package can be delivered through a variety of delivery models, such as infrastructure as a service (IaaS), platform as a service (PaaS) or software as a service (SaaS). - The preferred modelling software package can be delivered as either; free and open software (Foss) or by a proprietary software developer. - The model must be based on Geographic Information Systems (GIS) data inputs, processes and outputs.
Easily updated	Modelling components or the whole model can be updated with relative ease in terms of time and resources so that the model can, for example, stay current, monitor growth and run scenarios.
	- The modelling package runs in a timely manner (for example, in less than a couple of days) so that run times do not adversely impact on the dynamic requirements and ability to run scenarios and monitor growth. - The modelling package compartmentalises processing to speed up processing if required. - Data management platforms are in place to efficiently undertake tasks such as data request, tracking, integration, processing, storing, publish etc.
Easily calibrated	Ability to examine and adjust scenario inputs, processes and outputs against observed development or other data that is made available in a timely manner.
	- Integrates process, resource efficiency operator interchangeability, updated data all contribute to easy calibration. - Measures can be easily applied to model outputs to run statistics on model validity. - Ability to 'backtrack' variables from the modeller that may need to be calibrated in a structured and process driven way from the retrieved data supplemented with qualitative observations.
Adaptable	The modelling approach, including all or some data inputs, processes and outputs can be updated to incorporate change as best practices or modelling needs change.
	- Open-source code and programming can be integrated when appropriate to achieving scenarios outputs.

	- The master urban modelling package has the capability of integrating future sub models that operate across diverse discipline silos (i.e. real-estate modelling). - The model will compartmentalise modelling processes to enable the interchangeability of sub-models/components and improve the simulation processing time.

4.0 Step 4 – Assessment to identify preferred modelling packages

4.1 Overview

Step 4 further examines the twenty-three (23) shortlisted modelling packages, identified in Step 2, by assessing them against the Step 3 design requirements. Step 4 completes the Regional Planning Model's research due diligence process by producing a list of preferred modelling packages. The preferred modelling packages are organised according to the primary and sub modelling packages, as discussed in Step 3 (section 3.2.1). The identified primary modelling packages are the most preferred and are supplemented by sub modelling packages, if required, to enhance meeting all design requirements (see Table 7).

4.2 Method

4.2.1 Overview

The step 4 assessment process followed a structured and more detailed review of available material to assess the twenty-three (23) shortlisted modelling packages against the Step 3 design requirements (refer to Table 5). It followed a series of tasks to:

Task 1: consolidate literature material collected from Step 2;

Task 2: prepare design requirement key words;

Task 3: literature material extraction using design requirement key words;

Task 4: rating of extracted literature material;

Task 5: prepare modelling package summaries; and

Task 6: mandatory requirements assessment

4.2.2 Task 1: Literature Consolidation

The following task builds on previous work done during the Step 2 background research for each modelling package. This involved consolidating all available user guides, case studies, model reviews and the input/output table to a new drafting document per available model.

4.2.3 Task 2: Design Requirement Key Words

This task listed key words for each design requirement to examine the consolidated literature. The formation of the key words was guided by the Step 1 literature review and Step 3 design requirements (refer to Table 5). Noting, the applicable terminology in Table 6 includes words and phrases that are contrary to the design requirements to help identify those modelling packages that do not align with that particular design requirement.

Table 6: Design Requirement Key Words

Key Words	Design Requirement
'Transparent', 'User Guide', 'Case Studies', 'Example', 'Open Source', 'Black Box', 'Explicit', 'Theory', 'Method'	Transparent

‘Rule-Based’, ‘Agent-Based’, ‘Graphic User Interface’, ‘Framework’, ‘Judgement’, ‘Intuition’, ‘Structured’, ‘Process’, ‘Method’, ‘Theoretical’	**Structured and Process Driven**
‘Bottom Up’, ‘Macro’, ‘Micro’, ‘Disaggregation’, ‘Aggregation’, ‘Land Units’, ‘Top-down’, ‘Projections’, ‘Micro Simulation’, ‘Controls’	**Bottom-Up**
‘Micro’, ‘Parcel’, ‘Resolution’, ‘Aggregation’, ‘Macro’, ‘Property-Based’	**Micro**
‘Updatability’, ‘Calibration’, ‘Databases’, ‘Integrated’	**Currency**
‘Integrated’, ‘Alignment’, ‘Internal Models’, ‘External Models’, ‘Micro Simulation’, ‘Behavior’, ‘Choice’, ‘Static’, ‘Dynamic’, ‘Automated’, ‘Interrelate’, ‘Agent’	**Dynamic**
‘Process’, ‘Iterative’, ‘Framework’, ‘Graphical User Interface’, ‘Rerun’, ‘Reliability’	**Repeatable**
‘User Interface’, ‘Efficient’, ‘Simple’, ‘Access’, ‘Share’, ‘Procedure’, ‘Steps’, ‘Support’	**Operator Interchangeable**
‘Database’, ‘Accessibility’, ‘Functions’ & ‘User Input’	**Easily Updated**
‘Functions’, ‘User Input’, ‘Output Function’, ‘Diagnostics’, ‘Measures’ & ‘Internal Processing’, ‘Calibrate’, ‘Validity’, ‘Configurations’, ‘Settings’	**Easily Calibrated**
‘Scenario Planning’, ‘Modules’, ‘Compare’, ‘What-if’, ‘Alternate’, ‘Different’	**Ability to Run Scenarios**
‘Measure’, ‘Monitor’, ‘Benchmarks’, ‘Targets’, ‘Track’	**Ability to Monitor Growth**
‘Streamlined’, ‘Efficient’, ‘Timely’, ‘Reuse’, ‘Intensive’	**Resource Efficiency**
‘Online client’, ‘Frontend’, ‘Backend’, Interactive’, ‘Dashboard’, ‘Graphic User Interface’, ‘Security’, ‘Authorised Users’, ‘IaaS’, ‘SaaS’, ‘PaaS’, ‘Service’, ‘Remote Access’, ‘Free and Open Software’, ‘Proprietary’	**Accessibility**
‘Integrates’, ‘Combined’, ‘Interrelate’, Interface’, ‘Compatibility’	**Integrated**
‘Open-Source’, ‘Adapt’, ‘Resilient’, ‘Update’ ‘Flexible’, ‘Compatibility’, ‘Interchangeable’, ‘Integrate’	**Adaptability**

4.2.4 Task 3: Literature Material Extraction Using Key Words

Literature material was extracted using the design requirement key words. User guides and technical papers were given priority over case studies and reviews. Promotional and other non-academic material were given the lowest priority. More recent literature was given preference to capture any enhancements in the latest modelling package versions.

Where required, Google Scholar’s academic database was further searched to obtain more literature about a modelling package. Key search words and phrases used are listed below:

- ‘*insert model’s name* case study’
- ‘*insert model’s name* review’
- ‘*insert model’s name* processing and functions’
- ‘*insert model’s name* & *insert applicable terminology’*
- *‘insert model’s name* & *insert designed requirements’*

Further material was also retrieved from the internal databases or resource libraries that were included in the developer’s web domain.

4.2.5 Task 4: Rating of Extracted Literature Material

During task 4, the extracted literature material, for each design requirement and each modelling package, was assigned a positive (+), negative (-) or neutral (- / +) rating. Each design requirement, for each modelling package, was assigned a rating of either, great, good, fair or poor

Fair was used as a default rating. The positive (+), negative (-) or neutral (+/-) ratings were then applied to increase or decrease the final rating. For example, an urban modelling package, first, has a 'fair' rating for the 'dynamic' design requirement. The rating is then adjusted to 'poor', by applying the negative (-) rating, if the literature material indicated it was not dynamic.

When a modelling package had a distinctly positive rating for a design requirement (i.e. not common in other modelling packages and received only positive notations, the assigned rating would be elevated to 'great'.

4.2.6 Task 5: Prepare Modelling Package Summaries

The following questions were used to prepare a summary for each modelling package for the literature material gathered from Steps 2 and 3:

- What information was gathered during Step 2? (e.g. developer, year of release, country of origin, and acquisition requirements)
- What was the model's general framework? (e.g. sub-models, sub-components and software environment etc.)
- What was the model's key drivers or iterative processes? (e.g. accessibility, attractors and parameters etc.)
- Were there instances of use that are of relevance? (e.g. the model may have been designed for another purpose but has been adapted for land-use change scenarios as detail in case studies)
- What were the general modelling approaches and data inputs detailed? (e.g. cellular automata, vector or raster format etc.)
- Did the model have an available user guide and if not, what material was used during the mandatory requirements assessment?
- What is the principal usage of the model? (Case studies, research projects, proof of concept, use in practice etc.)

4.2.7 Task 6: Mandatory Requirements Assessment

Three mandatory requirements were identified to separate those modelling packages that did not meet the mandatory requirements. The mandatory requirements assessment narrowed the focus of the step 2 available modelling packages to identify preferred modelling packages. Modelling packages that did not meet the mandatory requirements were removed. The mandatory requirements were formed from findings of Step 1-3 and are: 1) GIS-Based; 2) Property-Based; and 3) Online Functionality. Each of the three mandatory requirements are detailed below.

4.2.7.1 GIS based

The model must be based on Geographic Information Systems (GIS) data inputs, processes and outputs. Having a spatial representation and spatial analysis functions of the model inputs, processes and outputs is a 'mandatory requirement'. The regional planning model inputs, processes and outputs must be shared in a spatial format to best inform decision making, stakeholder engagement and support region wide infrastructure and future regional plan reviews.

4.2.7.2 Property-Based

The model must be a property-based model that is derived from lot plan records in a digital cadastre database (DCDB). For example, a community titles scheme with many building format plans and common properties under the same property address is captured as one polygon – the property address. Inputting, processing and outputting data that is derived from the lot plan geometry provides a common comparison point – a universal type of currency. With a property address approach, data can be utilised for other projects, as opposed to a raster geometry (i.e. 100m x 100m grid squares). Vector formatted property address or lot plan polygon data is therefore required. Centroid data or other forms of point data is not preferred due to difficulties in matching it to the DCDB parcel boundaries.

4.2.7.3 Online Functionality

The model must have online functions for inputting data, processing, viewing and distributing outputs. Online functionality includes, but not limited to, the following:

- Model updates provided online
- The ability to connect to online databases
- A user interface that can operate through an internet connection
- Cloud infrastructure
- Online support services
- View model outputs online
- 'Run' modelling processing, set up configurations and calibrations online
- Multiple user login access
- Secure access

4.2.8 Limitations

The assessment of available urban modelling packages was limited to publicly available material and those available with academic literature database subscriptions. For example, user guide and other technical material were only available once the urban modelling package was purchased or subscribed to. The assessment therefore was limited in this regard; however generally, sufficient material was available to undertake the assessment satisfactory, although some assumptions were made to assist with literature gaps. An assumption, for example may be made when available material may not state whether a model can perform a design requirement, but the developer may specialise in providing that service (e.g. online functionality) or the unpinning software environment (e.g. GEONAMICA) can support that function.

4.3 Results

4.3.1 Preferred Modelling Package Results

Final results for the preferred modelling packages are presented as Table 7. The preferred modelling packages are divided into preferred primary and preferred sub modelling packages. The primary modelling packages meet the regional planning model mandatory requirements and rate the best against the general design requirements in Table 5. A number of the sub modelling packages and modelling method inputs (see Table 4) offer further enhancements, to the primary modelling packages, when exploring and preparing data for the regional planning model scenarios. They are not essential; but offer additional capabilities, as the preferred primary modelling packages are generally self-contained (i.e. standalone)

The sub modelling packages and modelling method inputs cannot perform the Regional Planning Model's required functions independently as they do not meet the mandatory requirements. Some of the preferred primary modelling packages would benefit more, and some would benefit less, from the preferred sub modelling packages and modelling method inputs. This is due to differences in their modelling approaches (e.g. agent based versus rule based and different levels of sophistication). The need for, and use of, a sub modelling package would be dependent on the type of scenarios to be considered.

The non-preferred modelling packages are included also in Table 7 and comprise of two general categories. 1) Modelling packages that are principally for purposes other than what is required for the Regional Planning Model; and 2) Modelling packages that cannot sufficiently meet the Regional Planning Model's general design requirements or mandatory requirements.

Table 8 provides a detailed breakdown of the results by presenting the design requirement and mandatory requirements assessment results for each shortlisted modelling package. Five colours are used to represent the ratings: 1) Great = Dark Green; 2) Good = Light Green; 3) Fair = Yellow; 4) Poor = Orange; and 5) Does not meet mandatory requirement = Dark Red. Appendix A further details the mandatory requirements assessment summarised in Table 7.

Table 7: Preferred Modelling Package Results

Preferred Primary*: The primary modelling packages meet the regional planning model mandatory requirements and rate the best against the general design requirements in Table 5. All primary models would benefit from being supplemented with a sub modelling package(s), and modelling method inputs from Table 4, to help explore the regional planning model scenarios.	**UrbanSim**
	Cube Land
	Forecaz Modeller
	What-If Online
**Note: The ordering of the results does not imply one model is preferred over another.*	
Preferred Sub*: A number of the sub modelling packages and modelling method inputs (see Table 4) offer further enhancements, to the primary modelling packages, when exploring and preparing data for the regional planning model scenarios. They are not essential; but offer additional capabilities, as the preferred primary modelling packages are generally self-contained (i.e. standalone). Some of the preferred primary modelling packages would benefit more, and some would benefit less, from the preferred sub modelling packages and modelling method inputs. This is due to differences in their modelling approaches (e.g. agent based versus rule based and different levels of sophistication). The need for, and use of, a sub modelling package would be dependent on the type of scenarios to be considered.	UrbanAPI
	METRONAMICA
	The WISE Model
	Envision
	Modelling method inputs (see Table 4)
**Note: The ordering of the results does not imply one model is preferred over another.*	
Non-preferred*: The non-preferred modelling packages comprise of two general categories; • Modelling packages that are principally for purposes other than what is required for the Regional Planning Model	Vision Illawarra
	Sparc & Index
	What-If 2.0
	CommunityViz

• Modelling packages that cannot sufficiently meet the Regional Planning Model's design requirements or mandatory requirements.	Uplan4
	The Clarke UGM/ SLEUTH
	Moland Model
	RuimteModel/ Space Model
	LanduseSIM
	LTM
	DUEM
	ICity
	Xplorah Model
	FLUS
	CLUE
**Note: The ordering of the results does not imply one model is preferred over another.*	

Table 8: Preferred Modelling Package Results

Preferred Modelling Package Results	Available Modelling Software Packages	Design Requirements & Mandatory Requirements															
		Transparent	Dynamic	Structured and Process Driven (–	Bottom up	Currency	Repeatable	Operator Interchangeable	Micro (mandatory requirement =	Ability to Run Scenarios	Ability to Monitor Growth	Resource efficiency	Integrated	Accessibility (mandatory	Easily Updated	Easily Calibrated	Adaptability
Preferred Primary	What-If Online																
	Forecaz Modeller																
	Cube Land																
	UrbanSim																
Preferred Sub	The WISE Model																
	METRONAMICA																
	Envision																
	UrbanAPI																
Non-preferred	Vision Illawarra																
	SPARC & INDEX																
	What-If 2.0																

Preferred Modelling Package Results	Available Modelling Software Packages	Design Requirements & Mandatory Requirements															
		Transparent	Dynamic	Structured and Process Driven	Bottom up	Currency	Repeatable	Operator Interchangeable	Micro (mandatory requirement =	Ability to Run Scenarios	Ability to Monitor Growth	Resource efficiency	Integrated	Accessibility (mandatory	Easily Updated	Easily Calibrated	Adaptability
Non-preferred	CommunityViz																
	Uplan4																
	The Clarke UGM/ SLEUTH																
	Moland Model																
	RuimteModel/ Space Model																
	LanduseSIM																
	LTM																
	FLUS																
	DUEM																
	ICity																
	Xplorah Model																
	CLUE																

4.3.2 Preferred Primary Modelling Packages

The three preferred primary modelling packages from Table 7 are set out according to the below characteristics:

- Author
- Year of development and updates
- Country of Origin
- Commercial arrangements
- Delivery mechanisms and support (i.e. software as a service)
- Proprietary or not
- Modelling approach (GIS rule based or agent based)
- Underpinning theory
- Methods included
- Key uses
- Mandatory requirements
- Case studies

The three preferred primary modelling packages are similar in some aspects but are distinctly different. This section provides a comparison discussion to set out similarities and differences.

4.3.2.1 Cube Land

The Cube Land model was built from Dr. Francisco Martinez's MUSSA model - a transport modelling package which was developed at the University of Chile in 2000. In 2006, Citilabs - in collaboration with Dr. Martinez – developed Cube modelling software version 1. The Cube software suite includes eight additional extensions; Voyager, Avenue, Land, Cargo, Dynasim, Access, Analyst and Cloud. Between 2019-2020 Bentley acquired Citilabs and redeveloped the Cube software suite. A new version of Cube Land (version 6.5) has since been released. Citilabs is based in the United States of America and has international offices.

Even though Cube Land has since been significantly redeveloped from the MUSSA model; bid-rent theory remains the primary driver for some modelling processes. Cube Land forecasts land use by simulating the real estate market under different economic conditions, as well as taking into account complex aspects like land use externalities. For a user-defined scenario, Cube Land forecasts the supply, location and rents by zone for different types of properties. It also estimates the location of households and non-residential activities for different agent groups.

Cube Land applies an integrated framework comprising the following three sub-models;

- Demand Model (e.g. Bids and Restrictions)
- Supply Model (e.g. Restrictions, Profits and Cost of Production)
- Rent Model (e.g. Land Values)

The above modelling approach follows an econometric land-use allocation model. The methods use a combination of agent-based modelling (e.g. market factors), time series analysis and what-if analysis. Cube Land has been developed for the international market and has extensive use internationally and within Australia.

Cube Land is a standalone model, however, extensions included in the Cube software suite expand upon the model's processing capabilities. For example, Cube Voyager and Cloud are the most relevant extensions for the Regional Planning Model's purpose. Cube Voyager integrates transport planning into the modelling process which informs the allocation component by evaluating the accessibility of parcels. Cube Cloud expands upon the online functionality of Cube Land by providing Cloud Infrastructure.

Case Studies

A research collaboration between the University of Western Australia, Main Roads (WA), The Department of Transport (DOT) (WA) and the Department of Planning Lands and Heritage (DPLH) (WA) is currently underway (2020) for Western Australia. The Western Australia (WA) research program aims to develop modules which better integrate land-use and transport planning using econometric models. Cube Land and Cube Voyager are the subject of this research project. The Cube software suite has been recently acquired by the DPHL for Perth and Peel region (WA) and the department is in the process of preparing the model. DOT WA has been running Cube Voyager as a standalone product for some years and is well established.

The Cube software suite has also been previously used by The Department of Transport (VIC). The Cube software suite was used to inform a rezoning scheme which would cover the entire state but maintain its modelling run times. This research project was completed in collaboration with Citilabs.

Citilabs. 2020. CUBE case study: Victoria Integrated Transport Model: Zone Aggregation.

University of Western Australia. 2020. Econometrics, Land Use Inputs, and Strategic Transport Models.

4.3.2.2 UrbanSim

UrbanSim was developed by Paul Waddell in 2002. The model was prepared under a United States of America legislative planning context. Since its initial release, the model has grown to encompass functions and processes to enable its application in international markets. Price is negotiated with the developers and is influenced by the version of UrbanSim, the included extensions and the population the model is servicing. The model is provided as a software as a service (SaaS) model with payment being subscription-based.

UrbanSim is offered in three different versions with the only difference between them being the scale it simulates. The relevant version for this assessment is the UrbanSim's parcel version. Additionally, UrbanSim is offered with two extensions, UrbanCanvas and Penciler. UrbanCanvas is a suite of enhancement tools and functions for UrbanSim. Penciler is a building scenario planning tool performed at the parcel scale, however, is typically only used for housing development sites to visually represent planning outcomes in 3D and compare economic influences (e.g. construction costs).

UrbanCanvas would be a necessary extension for the regional planning model to accompany UrbanSim. UrbanCanvas enhances UrbanSim's capability by providing the online functionality (i.e. accessibility) design requirement. The cloud infrastructure of UrbanCanvas enables three core features;

- Enables the model to be accessed through a graphical user interface via an online browser
- Enables the processing power to be provided externally and scalable based on computing demand (e.g. removes hardware limitations when running multiple scenario simulations simultaneously)
- Enables the connection to external databases

UrbanCanvas is also responsible for managing the data flow (i.e. Input to Output) of the UrbanSim model and its dissemination to authorised stakeholders. UrbanCanvas, through the above functions, can be used as an online platform to maintain and share input data, development projects and planning assumptions. A two-way feedback loop could also be established between an external transport model and the UrbanSim land-use model.

UrbanSim at a foundational level is a microsimulation engine and an open source simulation platform. The user can access a range of model templates to simulate a range of scenarios. The user may also prefer to develop their own model template. Support can be provided when preparing custom model templates.

A unique attribute of UrbanSim is its application of a hybrid microsimulation modelling approach. The hybrid modelling approach is more dynamic than a simplistic GIS rule-based allocation model as it integrates modelling theory and simulates agents' behaviours and choice into the model's processing.

UrbanSim simulates behaviours by providing a modelling framework that integrates multiple sub-modelling components operating at a small area of detail. The simulation of behaviours is useful for the Regional Planning Model as it enables the user to scenario test for application at a regional planning scale. UrbanSim could perform the Regional Planning Model's design purpose without the usage of sub modelling software package(s). The model's internal processing however has the potential to be enhanced by the inclusion additional modelling method inputs (see Table 4) or a sub modelling software package (e.g. utilising machine learning methods to inform the development of scenarios or help prepare UrbanSim input data).

The simulated behaviours draw upon random utility theory and implements Monte Carlo simulation. Monte Carlo is a Modelling input method that seeks to account for urban complexity by producing a set of randomised values during the prediction process. The models repeatability could be encumbered by this modelling process; but is considered minimal as its application is understood to occur in discrete model modules. Regardless, no superior approach was identified.

Case Studies

A research program commenced in 2012 to adapt UrbanSim for application under an Australian planning context. The research was carried out by Griffith University's Centre for Urban Research. UrbanSim was used in a case study of Meadowbrook, Logan City, South-East Queensland. The results were published in 2013. The process of preparing UrbanSim for usage in South-East Queensland required a part-time resource two years (Brits, A 2013). UrbanSim was able to use Logan City Council planning assumptions and other data types typically available to local governments in South East Queensland. The process however did not cover the entire local government area extent. Nonetheless, it provided a useful and successful proof of concept for practical application in South East Queensland.

Validation is considered a challenge for UrbanSim's application. The findings in Logan City Council were however able to verify results to a reasonable correlation between the simulated and observed population through the usage of history census data. UrbanSim's case study found its strength to simulate and analyse the impacts of draft policy prior to implementation (Biermann, S., Pettit, C. and Brits, A., 2015). Bayesian Melding statistical approach has been implemented into UrbanSim to calibrate the uncertainty of model predictions. No further South East Queensland case study examples were identified since these case studies were published.

Brits, A., 2013. Embedding Urban Growth Modelling in Planning Practice.

Biermann, S., Pettit, C. and Brits, A., 2015, December. Modelling behavioural responsiveness in city structuring. In State of Australian Cities Conference (Gold Coast).

4.3.2.3 Forecaz Modeller

The Forecaz Modeller was developed by Sizztech Consultancy in Australia. The model pricing is available and negotiable by contacting the developer. The model is provided in a variety of forms, depending on the requirements of the customer. It is a proprietary model with no open source.

The Forecaz Modeller was developed in South-East Queensland over the past 5-10 years (see case studies below). It is currently used by a Local Council and Water and Sewerage Utility Providers in South East Queensland. The Forecaz Modeller is considered a sophisticated GIS rule-based allocation model and provides the framework for other modelling methods to be input to enhance its capabilities. For example, it uses Bayesian Network probability to assist with the allocation of growth.

The Bayesian network prepares model's probability values. These probability values determine the likelihood of development per parcel through the application of a desirability index. The Bayesian network is a modelling input method type that is processed outside of the Forecaz Modellers software environment and synchronises with the modeller in the one interface. The model's ability to integrate external modelling processes and manage the data flow between them is a desirable attribute. The Forecaz Modeller presents as a modelling package that can be further enhanced by the usage of other modelling method inputs and sub modelling software packages. The Forecaz Modeller is principally rule based and, based on the publicly available material, does not explicitly simulate agent's behaviours and choices.

Case Studies

The Forecaz Modeller, having been developed in South-East Queensland, has instances of adoption by both local governments and utility providers within the region. Unitywater commenced a project in 2012 to develop an urban growth model in-house with assistance of Sizztech through the Forecaz Modeller. The Unitywater Demand Modeller and Tracking Tool (DMaTT) uses the Forecaz Modeller and has been operational since 2014. The model's online functionality enabled the usage of a live website interface to access the model and can calibrate the following models: 1) forecast model builder, 2) forecast model viewer and 3) forecast demand viewer (Teitzel, C, Susarla, P & Goraya, K 2015).

DMaTT is currently used to model Noosa, Sunshine Coast and Moreton Bay at the parcel scale by UnityWater to assist in the preparation of NetServ Plans (Teitzel., C 2015). DMaTT has also been applied to test scenario outcomes. UnityWater and GHD collaborated run a transit-oriented development scenario for the Sunshine Coast Light Rail Shaping Our Future project (UnityWater & GHD 2018). Noosa Shire Council has also adopted the DMaTT model for usage in preparing planning assumptions. The University of the Sunshine Coast (USC) has used the Forecaz modeller since 2017 to teach students strategic infrastructure planning as part of ENP336. This is part of an ongoing collaboration between USC, Unitywater, Sizztech and UACS Consulting to research, design, teach and provide placement and employment opportunities to students. The Forecaz modeller has also recently been used by a high growth Council in South East Queensland to prepare a new set of planning assumptions, demonstrating its efficacy in local government and utility providers in SEQ.

UnityWater & GHD 2018. Light Rail Infill Development Scenario Modelling Using Unitywater's Growth and Development Forecasting Tool. PIA national Planning Congress Frontiers of Planning, Perth.

Teitzel, C., Susarla, P. Goraya., K 2015. Development of a Demand Modeller and Tracking Tool: Water Journal, Pg.59-61.

Teitzel., C 2015. Development of a Demand Modeller and Tracking Tool: An Automated Growth Forecasting Tool for Local Governments and Utilities. PIA State Conference Townsville.

4.3.2.4 What-If Online

What-If Online was developed by Chris Pettit with the Australian Urban Infrastructure Research Information Network (AURIN). The model can be offered as software as a service (SaaS) from AURIN or downloaded freely and used as an open-source program. AURIN offer the model as a service through establishing a partnership with the user and pricing is arranged through negotiation. The user however can still make general inquiries to AURIN on What-If Online without the need of forming a partnership.

What-If Online builds upon the previous work of Richard Klosterman's 1998-2008 What-If 2.0 model. What-If Online's general modelling architecture is comparable to What-If 2.0, however has been adapted to better align with an Australian legislative planning context. These adaptations include;

- Adapting the polygon spatial data to better suit Australian context (e.g. GFA)
- Enabling the user to decide scenario parameters at any stage of the model's processing
- Enabling the model to be accessible through an online browser

A unique attribute of What-If Online is that the modelling package has been prepared to simulate a range of planning scenarios. The What-If Online model is considered to be, principally, a simplistic GIS rule-based allocation model.

What-If Online comprises two general components to setup and scenarios. The setup component is where all data is prepared. The data is assigned values, control totals set, and growth trends are introduced. The scenario component enables the user to use a pre-existing scenario or prepare their own. Multiple scenarios can be run simultaneously. What-If Online processing requires that all inputted data be comparable across all fields. The model then uses all the inputted data to create a single uniform analysis zone (UAZ). The UAZ is contained to the user defined study area. The What-If Online scenario outcomes are rule based and do not explicitly simulate agent's behaviours and choices. Agent based models are demonstrated in the literature to better account for the complexity of urban systems.

The model could be enhanced by any sub-modelling packages that output in vector formatted polygons in GIS compatible file types.

Case Studies

In 2015 What-If Online was applied as a case study to the Wanneroo and Joondalup suburbs of North-West Perth, Western Australia (Pettit, C, Shyy, T.K. and Stimson, R 2012). In 2005, What-If Online was also used to prepare Hervey Bay's sustainable-development land-use strategy until 2021 (Pettit, C 2005).

What-If Online in these instances used suitability, demand and allocation modules that were driven by demographic population projection control figures. The online functionality of the What-If Online enabled stakeholders of the case study to observe changes to the model's calibration in real-time. The model implements a standard multi-criteria analysis which is largely a qualitative exercise.

In 2020 What-If Online was used to simulate scenario outcomes for both Melbourne and Perth's wider metropolitan areas. Perth's metropolitan area was tested with the following scenarios: 1) pro-urban growth scenario (i.e. urban sprawl in greenfield sites), 2) all infill compact city scenario (i.e. redevelopment and infill), 3) likely city scenarios (i.e. business as usual), 4) transit city scenario (i.e. transit-oriented development) and 5) activity center city scenario (i.e. activity-center driven) (Pettit, C, Biermann, S, Pelizaro, C and Bakelmun A 2020). The above scenarios were prepared using 2050 population projections provided by the state government. Melbourne's metropolitan area scenario test was more limited in scope and applied a scenario prepared by the Center for Urban Research at RMIT to simulate infill developments impact on environmental systems in the peri-urban (AURIN 2020). The above scenario was informed by the Plan Melbourne 2014 and was projected to 2031.

What-If Online is considered a policy responsive simplistic GIS rule-based allocation model. The model is however encumbered by not being able to simulate future scenarios where the parameter weights are not already pre-known. The Wanneroo and Joondalup case study overcame these limitations by exporting scenario results from a sensitivity analysis performed as a separate GIS process. The model is also challenged by not encompassing a validation model to empirically validate scenario outputs.

Pettit, C.J., Klosterman, R.E., Delaney, P., Whitehead, A.L., Kujala, H., Bromage, A. and Nino-Ruiz, M., 2015. The online what if? Planning support system: A land suitability application in Western Australia. *Applied Spatial Analysis and Policy*, *8*(2), pp.93-112.

Pettit, C., Biermann, S., Pelizaro, C. and Bakelmun, A., 2020. A Data-Driven Approach to Exploring Future Land Use and Transport Scenarios: The Online What If? Tool. *Journal*

AURIN, 2020. Using What-If? To Guide Appropriate Infill Development: aurin.org.au

Pettit, C.J., 2005. Use of a collaborative GIS-based planning-support system to assist in formulating a sustainable-development scenario for Hervey Bay, Australia. *Environment and Planning B: planning and design*, *32*(4), pp.523-545

Pettit, C., Shyy, T.K. and Stimson, R., 2012. Regional Planning Scenarios. *Planning Support Systems in Practice*, p.331.

4.3.3 Preferred Sub Modelling Packages

Four modelling packages have been included as preferred 'sub' modelling packages. The models present as useful to enhance the preferred primary model for the purposes of the regional planning model. Below is a brief overview of each.

UrbanAPI

The UrbanAPI model was developed by UrbanAPI consultancy (2014) in Bulgaria. The model is unable to serve as a primary modelling package for the Regional Planning Model due to requiring raster formatted data for the land-use modelling component. The UrbanAPI software package contains the Urban Development Simulator which was developed in the MASGISmo software environment. The model uses a combination of cellular automata and multi-agent system modelling approaches. The model contains a series of attributes that could potentially enhance a primary modelling package in the preparation of regional planning scenario inputs.

METRONAMICA

The METRONMAICA model was developed by the Research Institute for Knowledge Systems (RIKS) (2014) in The Netherlands. The model is unable to serve as a primary modelling package for the Regional Planning Model due to requiring raster formatted data for the land-use modelling component. METROMAICA model was developed in the GEONAMIC software environment and currently serves as the foundation model for a range of other modelling packages. The model operates a framework under which it integrates various sub-modelling components (e.g. demographic, economic and transport) to mutually complement each sub-model processing of data. The attributes of this integration process and its software environment could potentially enhance a primary modelling package in the preparation of regional planning scenario inputs.

The WISE Model

The Waikato Integrated Scenario Explorer (WISE) model was developed by Waikato Regional Council (2010) in New Zealand using the METRONMAICA model as a foundation. The model’s usage of the METRONMAICA has encumbered the model’s ability to serve as the primary modelling package due to the shared limitation of requiring raster formatted data in the land-use change modelling component. The WISE has since expanded to integrate more environmentally orientated sub-modelling components. Other changes of the WISE model from METRONAMICA is the standardisation of data types to better reflect a New Zealand planning context. Due to the model expansion of METRONMAICA, attributes and the inclusion of environmental processes this modelling package could potentially enhance a primary modelling package in the preparation of regional planning scenario inputs.

Envision

The Envision Model was developed by Oregon State University in the United States of America. The model is unable to serve as a primary modelling package for the Regional Planning Model as it does not contain online accessibility. Envision was developed as an open-source GIS-based tool however the model no longer offers any developer support. The model serves as a generic framework that can integrated ‘plug-ins’ to expand its processing capabilities. An agent-based modelling approach is utilised in Envision through a range of sub-modelling components. Envisions usage of an agent-based modelling approach using vector formatted data could potentially enhance a primary modelling package in the preparation of regional planning scenario inputs.

4.4 Next steps

- After completing the 2020 modelling package due diligence process a procurement process is proposed to be undertaken. The due diligence process was prepared to collaborate with regional planning stakeholders on the design requirements for a RPM before going through any formal procurement process. Going straight to procurement would not have resulted in a collaboratively prepared set of design requirements for procurement assessment. The due diligence process also provided the opportunity to check if there were any known approaches that would meet the RPM requirements. It provided the opportunity to identify potential tenders for invitation but also provide the flexibility to still go out to ‘open market’ to consider any modelling packages that may not have been identified in this extensive search and collaboration with stakeholders.
- Investigate acquisition processes to obtain the preferred modelling package
- Once a preferred modelling package is identified and confirmed, processes to acquire the package, develop, compile data, implement and test a regional planning model with stakeholders.

4.5 Limitations

The urban modelling packages captured are limited to those that were identified from the structured approach to identify modelling packages (refer to Section 2). All efforts, within the limits of the time and scope available, were undertaken to identify all applicable modelling packages. However, as with any review, not all targeted search results may have been retrieved.

During updates of the draft version 1 report, a resource library of planning support systems published by AURIN was located and is included as Appendix B. The resource library includes urban modelling packages as well as other modelling package categories (e.g. transport, demographic, environmental). Appendix B modelling packages provide an indication of modelling packages that were not retrieved, and therefore not included in this due diligence process.

The extent of urban modelling packages in this list, which meet the purpose of the regional planning model, has not been established. Following this report, it is recommended procurement processes are extended to the open market. This is to include suitable urban modelling packages that may have not been retrieved and included as part of this due diligence process.

Appendices

Appendix A: Task 5 Results: Prepare Modelling Package Summaries

Available Modelling Software Packages	Modelling Package Overview	Mandatory Requirement Assessment Comments
CLUE	The CLUE model is an open-source urban growth model developed by Tom Veldkamp & Louise Fresco 1996 in Amsterdam. The model is currently being distributed freely by the Institute for Environmental Studies in Amsterdam. The CLUE model has been designed as a generic land-use modelling framework that has since been recreated into CLUE-S, Dyna-CLUE and CLUE-Scanner being other frequently applied land-use models. The CLUE model framework operates under its user interface that is compatible with ArcGIS. However, given the age of the model, it has yet to be confirmed if the model is still supported and remains compatible with an updated version of ArcGIS. The model's user guide is made freely available however examined case studies have since become dated. The user guide has also been developed using an agricultural scenario rather than a more urban planning originated scenario. This has encumbered the reviewing process for the design requirements. The principal usage of the model is to provide a simplistic framework that can project basic land-use change functions.	**<u>GIS Compatibility:</u>** The CLUE-S Model applies statistical analysis to define the suitability of locations under different land-uses classes. The suitability is developed from specific influential location factors. This function requires that a standard statistical package need to be used (external tools). As most statistical packages at the time of the user guide publication do not support GIS data several conversions are required to translate the data (external tools). CLUE-S does provide an application (convert.exe) that assist this conversion. Given the age of the publication, the application (i.e. convert.exe) effectiveness with a more modern statistical package is not detailed. This represents a fatal flaw to the Regional Planning Model's purpose. **<u>Property-Based Model:</u>** The CLUE model was developed to operate on a national scale. The CLUE framework eventually grew to encompass the CLUE-S component that operates as a conversion tool allowing for regional-scale scenario planning. The functional design and data implementation methodologies have not however changed. The model is also limited to raster formatted data as such cannot apply vector-based parcel data types. This represents a fatal flaw to the Regional Planning Model's purpose. **<u>Online Functionality:</u>** The CLUE model's framework does not have an online functionality component. An online client is essential to achieving the Regional Planning Models purpose of integrating stakeholders under a single regional model. This represents a fatal flaw to the Regional Planning Model's purpose.

CommunityViz	The CommunityViz model was developed by City Explained Inc 2001 in the United States of America. The model is available by an annual subscription-based service. CommunityViz contains several in-built modelling components for application in land-use planning. CommunityViz's strength is in the ability to create dynamic custom scenarios and models through available tools. These tools have been designed to explore a range of land-use scenarios and are presentable in 2D or 3D formats. However, CommunityViz usage is more suitable for preparing master plans rather than modelling for a regional scale. The models typically present "indicators" (i.e. vehicle trips per day) that enable the user to make comparison decisions between suburbs. The indicators however are only partially prepared by the model and often require the user to implement them. When preparing outputs CommunityViz has a range of presentation functions. Outputs can be exported online (i.e. HTML links, Google Earth) and can interchange its format of presentation (i.e. Spreadsheets, figures and tables). The model is suitable at measuring growth and advanced in developing scenarios. CommunityViz has a user guide/ tutorial that is available for viewing before the acquisition. Case studies have also been provided regarding its usage in South-East Queensland and other regional planning examples. These case studies, however, do not present the methodologies scenario development but are rather intended to illustrate what scenarios CommunityViz can perform. The principal usage of the model is to provide a suite of GIS and scenario creation tools at a suburb scale.	**<u>GIS Compatibility:</u>** CommunityViz is encompassed entirely within ArcGIS. The model is essentially an extension of ArcGIS as such compatibility can be guaranteed across stakeholder groups. The modelling framework is not limited to ArcGIS as external models can be integrated into the platform. The only requirement of external model usage is that it remains GIS compatible. However, external model usage is not a requirement for scenarios testing as CommunityViz can create custom models internally. This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **<u>Property-Based Model:</u>** CommunityViz has been designed as a vector-based model. Parcel data in vector format is a preferred data type as examined in the user guide. Raster data is primarily only applied when projecting to 3D imagery as a surface texture (i.e. represents elevations and ground qualities). The model is also not limited to geospatial data and can integrate a range of data types (i.e. census results, photos, excel spreadsheets). This conforms to the requirement of a parcel-based driven process for the Regional Planning Model's purpose. **<u>Online Functionality:</u>** The user guide/ tutorial, CommunityViz whitepaper and case studies were examined to determine the extent of online functions. No reference was made that CommunityViz can produce an online client that would enable stakeholders to update their data without transferring it through a third-party delivery system (i.e. email, cloud storage). The model does have the capability of using HTML links to display any component of processing (i.e. outputs) to a website. These can be presented in presentations, graphs or interactive maps. Without an online client, the model would receive a fatal flaw. An assumption however has been adopted that the model can have an online client developed by the City Explained Inc at minimal expense. This conforms to the

		requirement of online functionality for the Regional Planning Model's purpose.
Cube Land	The Cube Land model was developed by Citilabs and Bentley between 2006 and 2020 in the United States of America. The model is a proprietary model with no open source. The pricing is negotiated with the developer and is dependent on the included extensions. Additionally, the Cube Land model has a consultancy attached to the product and also provides support services (e.g. training and data calibration). The Cube software suite includes eight additional extensions; Voyager, Avenue, Land, Cargo, Dynasim, Access, Analyst and Cloud. The Cube software suite was developed from the foundation of the MUSSA model (2000). The Cube Land model has since been redeveloped; however, bid-rent theory remains the driving influence in the model simulation. Cube Land applies this theory through an integrated framework comprising the following three sub-models; • Demand Model (e.g. Bids and Restrictions) • Supply Model (Restrictions, Profits and Cost of Production) • Rent Model (Land Values) These sub-models determine land-use through market factors and consumers' willingness to pay. The methods of simulation rely on agent-based modelling (e.g. market factors), time series analysis and what-if analysis. The Cube software suite pairs the functions of Cube Land with Cube Voyager. Whereas Cube Land simulates land-use patterns while Cube Voyager simulates transport. These mutually complement the processing of the other. For example, Cube Land provides the destinations while Cube Voyager provides accessibility. Cube Land can, however, be acquired as a standalone product. The Cube Land model is not provided with a user guide before acquisition or contact with the developers. The models ranking was assessed by available promotions material, case studies, and academic material. Its principle usage is to provide an econometric land-use allocation model.	**GIS Compatibility** Cube Land is promoted as an urban model which adapts its processing to the user's available data. Cube Land is compatible and can be integrated into other modelling software packages (e.g. Uplan). Additionally, this model has been applied in practice in Australia. This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **Property-Based Model:** Cube land simulates land-use change and allocation which requires datasets at both the macro and micro scale. For example, control totals and baseline land-use datasets are inputted at the macro scale while zonal data is scalable depending on the user's requirements. Cube Land can implement vector-based parcel data to fulfill the zonal data input requirement. The model then runs its simulation and outputs disaggregated land-uses at the micro scale. This conforms to the requirement of a parcel-based driven process for the Regional Planning Model's purpose. **Online Functionality** Cube Land is a standalone model and enables users to publish web-based outputs through ArcGIS. The Cube Cloud extension expands upon this online functionality. The extension provides cloud-based infrastructure which enables users to manage multiple scenarios, increase the model's accessibility and publish outputs online. This conforms to the requirement of online functionality for the Regional Planning Model's purpose.
Dynamic Urban Evolution Model (DUEM)	The Dynamic Urban Evolution Model (DUEM) was developed by Xie Yichun 1997 in the United States of America. The model is available as freeware and has	**GIS Compatibility:** The DUEM model operates under its interface with 'loose coupling to GIS with the

	contemporary usage as a teaching resource rather than a real-world application. The DUEM model operates under its user interface with a simple rule-based approach. The current land-use is inputted into the model at one of three scales; local neighbourhood, district to regional. The inputted data is then subjected to a series of condition checks then is validated against regional control check (i.e. Policy checks). After validation, the model generates new land-use cells and the process is restarted. The model is freely accessible and is provided with a brief user guide that serves an illustrative purpose rather than an informative guide. The model is imposed with limitations on the number and types of land-uses that can be inputted. The guide does not indicate the extent to which the study boundary can be projected into the future or the application of scenario planning. The principal usage of the model is as an educational resource for cellular automata models.	importation of raster files'. The extent of GIS compatibility with the model is not detailed. This has encumbered the assessment of design requires. However, the model's age, simplicity and that no user support is provided an assumption can be made that the model is no longer GIS compatible. This represents a fatal flaw to the Regional Planning Model's purpose. **<u>Property-Based Model:</u>** The DUEM model operates at one of three scales. These scales do not operate at the micro (i.e. parcel) level. The primary data input is macro statistical data and land-use maps. The model applies this data under a top-down approach using cellular automata. This represents a fatal flaw to the Regional Planning Model's purpose. **<u>Online Functionality:</u>** The model was designed with no online functionality or any other processes that would enable stakeholder access to the model remotely. The model contains no functions that would enable streamline data sharing or integration. This represents a fatal flaw to the Regional Planning Model's purpose.
Envision	The Envision Model was developed by Oregon State University in The United States of America. The model is available freely with source-code available through contacting the developers. The Envision model was developed as a GIS-based tool to test a range of scenarios common in regional urban and environmental planning. The model serves as a generic framework that can integrate plug-in models to expand its scenario test capabilities. The developers provide pre-existing external models to enable typical scenario calibration. The model however also facilitates the usage of custom developed or other external models. The following models or modules are accounted for within the modelling architecture; • Process models (i.e. describing landscape change dynamics)	**<u>GIS Compatibility:</u>** Envision hosts its own user-interface however the model is developed as a GIS application. The model requires the usage of vector formatted data. The processing, inputting and outputting of data is entirely performed with GIS compatibility data types files. Raster formatted data is not detailed in available materials. The integration of external models may be required for raster formatted data inclusion. This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **<u>Property-Based Model:</u>** The Envision model's user guide describes the model as being suitable to run using whatever scale is necessary by user discretion. The inclusion of parcel-based

	• Evaluative models (i.e. report landscape production metrics) • Visualizers (i.e. representing spatial data and inputs) • Analysis modules (i.e. processing data or generating outputs) The Envision model uses an agent-based modelling approach. The agent's value is conditioned by policy constraints and distinguishes between statutory or voluntary implementation. The model contains a "dynamic spatial engine" that enables future scenario application as informed by the agents assigned value. The "dynamic spatial engine" requires polygonal, network, point, and grid-based landscape characteristics data inputs. These are attributes of a vector formatted model. The extent of which raster data can be integrated within the model is not detailed. The Envision model is provided with a comprehensive user guide. The models available case study material consists of mostly environmental applications as observed in their web-domain. The model however expresses the ability to measure land-use change, population and economic growth. The principal usage of Envision is to serve as a modelling framework to perform human/natural system analyses as indicated by policies measures.	data is represented as a possible input during data layer integrated. The only requirement during this process is that the vector input (i.e. parcel) is vector/ polygon formatted. This conforms to the requirement of a parcel-based driven process for the Regional Planning Model's purpose. **<u>Online Functionality:</u>** The user guide for the Envision model has no mention of online functionality. This includes no mention of web-portals, infrastructure for cloud storage or the ability to connect to national databases. The inclusions of external models produced no assumptions of online functionalities due to the discontinuation of URL links through the web-domain which further elaborate on these processes. This represents a fatal flaw to the Regional Planning Model's purpose.
Future Land-Use Simulation (FLUS)	The Future Land-Use Simulation (FLUS) model was developed by Guangdong Key Laboratory for Urbanization and Geo-Simulation 2017 in China. The model is available as opensource software. The FLUS model operates under its user interface with separate but integrated data modelling approaches. The land-use change model is cellular automata (CA) that analyses change based on the patterns of recent land-use. This means that the model does not need to observe change across two different timeframes to predict patterns. The artificial neural network (ANN) measures human activity against ecological effects to create land-use patterns. The model uses self-learning mechanisms to measure real-world LUCC dynamics.	**<u>GIS Compatibility:</u>** The FLUS models run under its interface with no mention of GIS compatibility. The FLUS model itself is essentially a foundation layer that requires external models to function as a future land-use model. However, there is no specification of which models are needed to enable GIS compatibility or even if integration would produce the intended results. This represents a fatal flaw to the Regional Planning Model's purpose. **<u>Property-Based Model:</u>** The user guide does not present information on the required scale of the data inputs. The assumption applied for the FLUS model is that input data is the responsibility of an

	The FLUS model by itself is a spatial simulation model but requires the GeoSOS-FLUS extension (i.e. a user interface) to facilitate multiple land-use change simulations (i.e. scenario analysis). These are projected onto a raster format through grid cells. The land-use simulation component requires external models or modelling approaches (e.g. SD model or Markov Chain) to act as land-use demand inputs. The ANN approach uses the opensource Shark 3.1.0 library, the user interface uses the opensource Qt 4.8.5 library while the raster creation (i.e. geographical coordinate information) use the opensource GDAL 1.9.2 library. The FLUS model in this way acts more of a foundation model whereas external models and libraries are required for it to achieve the scenario analysis. The FLUS model is provided free with a short user guide. The user guides limited content and without regional planning case studies has encumbered the review of this model. The model can monitor and project growth across different timeframes if provided with external models. The model's data approach would require an experienced operator that understand what data should be inputted initially to train the model's self-learning components. The principal usage of the model is to act as a foundation for other open-source software to project land-use change.	external model and processed at user discretion. The assumption was informed by the context of available assessment material. The model is suggested to be parcel-based but without further evidence this represents a fatal flaw to the Regional Planning Models purpose. **Online Functionality:** The user guide does not detail any online functionality or any components that would assist the model's accessibility to stakeholders. No information was provided on how the model's outputs could be exported outside of the user interface. This represents a fatal flaw to the Regional Planning Model's purpose.
Forecaz Modeller	The Forecaz Modeller was developed by Sizztech Consultancy in Australia. The models pricing is available after contacting the developer. The Forecaz modeller is an urban growth forecasting and demand allocation model. Bayesian network algorithms are applied to determine the probability of development per parcel based on a desirability index (i.e. values). Desirability is informed by a range of influential drivers (i.e. proximity to trunk infrastructure etc.). The model requires the inputting of parcel-level detail that is aggregated. The population, employment and infrastructure outputs are then verified and allocated based on control totals. The model is highly automated and repeatable model that can generate a range of forecasts; • Dwellings • Population	**GIS Compatibility:** The Forecaz modeller's assessment against GIS compatibility has been encumbered by not having access to a user guide. The available material indicates that the Forecaz modeller is highly compatible with GIS files and the inputted data types are commonly used in South-East Queensland. The integration process of raster or vector formatted data (i.e. conversion tools) cannot be confirmed. This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **Property-Based Model:** The Forecaz modeller is designed to require parcel-level data in vector format. The modelling outputs are driven by desirability values assigned per parcel using bottom-up and top-down data approaches. This

	• Floor space (GFA) • Employment • Network demand The model can also operate multiple "what-if" scenarios at user discretion with growth and density parameters. The model requires the following data inputs; • Baseline land use • Development approvals • QGSO projections • Gross floor area projections • Lot level inputs The Forecaz modeller is not provided with a user guide before contacting the developer. This has encumbered the assessment process. The ranking was assessed based on the promotional material and available technical reports of Unitywater's DMaTT which was developed in-house with Sizztech. The principal usage of the model is to capture existing and future demand then allocate growth according to user controls.	conforms to the requirement of a parcel-based driven process for the Regional Planning Model's purpose. **<u>Online Functionality:</u>** The promotional material for the Forecaz modeller has no mention of online functionality. This, however, is not a fatal flaw as an assumption is applied that either web-based applications are available or easily developable. The assumption is based on Sizztech's business focus of providing web-based geospatial solutions and the availability of online functionality within the DmaTT model. This conforms to the requirement of online functionality for the Regional Planning Model's purpose.
ICity	The ICity model was developed by Daniel Stevens 2007 in Canada. The model is made freely available by contacting the developer. The ICity model is embedded into the ArcGIS platform with a supporting user interface designed to interchange modelling logic (i.e. design parameters). The ICity model is currently in the prototype stage of development and acts as a planning support system rather than a standalone model. The modelling approach has developed extensions on the typical cellular automata (CA) models that diversify the available spatial and temporal functions. The usage of an irregular cellular automata modelling approach has also enabled the inclusion of vector formatted data without requiring data conversion. The ICity model is distributed in two versions; an executable or as source code. The executable would not allow for the modification of the model's logic (i.e. parameter settings). The source code would enable modification of the model's logic however ArcGIS functions that ICity applies are not interchangeable. The model is principally used to formulate the allocation of land parcels through multiple iterative processes.	**<u>GIS Compatibility:</u>** The ICity Model is embedded within ArcGIS using a hard-coded list of available parameters and total controls. This is supplemented with a user interface that organises the inputted and outputted data. The modelling process allows for the usage of both vector and raster data without the need for external conversion tools. The ICity model, as a result, is compatible with ArcGIS data however the parameters and total control options regarding how this data is integrated are not interchangeable. This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **<u>Property-Based Model:</u>** The academic article that was sourced for the ICity model references that application of micro detailed data inputs. These are inputted with an assigned value that dictates the allocation (i.e. sequence) process. The value system is a bottom-up process with the parameters and total control acting as a top-down verification process. The modelling framework operates as an iterative process across three land-use types (i.e. Residential,

	An iterative process is performed per land-use type using an allocation hierarchy that consists of three categories (i.e. Residential > Park > Commercial). The model requires that a value be assigned to each parcel at which the model prioritises the highest value for development (i.e. sequencing). Road infrastructure is applied as an accessibility function that increases land-use parcel value is dependent on the value of the road. Top-down controls must also be implemented that assign the required allocation totals per land-use type. When land cannot be allocated based on the assigned values road infrastructure is promoted to be developed or upgraded. The iterative process is performed over an assigned timeframe with one month being the minimum. The ICity model was sourced through an academic article which comprises the entirety of available material. The modelling process was described transparently however no external material exists to examine the real-world application. The described modelling process does not monitor growth across timeframes but rather assigns growth. The model's usage of a hard-coded rule-based system would encumber the Regional Planning Model's design purpose. The principal usage of the model is to allocate three land-uses types using a basic rule-based approach.	Park & Commercial). The framework is a top-down process that assigns allocation to residential first that informs park allocation which finalises with commercial allocation. The limitations of the framework being hard-coded represents a fatal flaw to the Regional Planning Model's purpose. **Online Functionality:** The academic article does not detail any online functionality or any components that would assist the model's accessibility to stakeholders. No information was provided on how the model's outputs could be exported outside of the user interface. This represents a fatal flaw to the Regional Planning Model's purpose.
Land Transformation Model	The Land Transformation Model (LTM) 2011 was developed by Purdue University in the United States of America. You can acquire the model if you have a GNU licence agreement. The model is more commonly applied and promoted to capture land-use changes regarding environmental scenario planning. The model, however, has case study examples of measuring urban growth at a regional scale across an extended timeframe. The assumption is adopted that the LTM enables the user to make adaptable usage of the land-use change component. The LTM is a land-use forecasting model that combines; • GIS data • Artificial neural networks modelling approaches • Cellular Automata • Rule-based interactions (i.e. drivers)	**GIS Compatibility:** The Land Transformation Model (LTM) assessment against GIS compatibility has been encumbered by not having access to a user guide. The available material only mentions GIS and remote sensing data as the only user data types. The model is a raster-based cellular model with no mention of vector formatted data integration potential. This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **Property-Based Model:** The Land Transformation Model (LTM) assessment as a parcel-based model has been encumbered by not having access to a user guide. The usage of artificial neural network suggests that values or drivers are assigned to cells to perform machine learning. However, the processing and

	The LTM is not provided with a published user guide but rather with an interactive tutorial/ video presentation. The model ranking was encumbered by the format of the tutorial. The models ranking was assessed by promotional material and a Michigan land-based industries case study. The principal usage of the model is to test human spatial interactions with environmental conditions.	spatial extent of cells are not detailed. The inclusion of vector formatted parcel data is also absent in available material. An assumption cannot be made with the available evidence. This represents a fatal flaw to the Regional Planning Model's purpose. **Online Functionality:** The Land Transformation Model (LTM) has no online functions as describe by the available material. The model does not support any functions that would assist stakeholder's involvement in calibrating or viewing outputs. This represents a fatal flaw to the Regional Planning Model's purpose.
LanduseSim	The LanduseSim model was developed by Sepuluh Nopember Institute of Technology 2013 in Indonesia. The models acquisition requires contacting the developers to access a license that typically costs $3,500 USA for organisations. This includes technical support for one year further ongoing support may require a subscription. The LanduseSim model was developed as a GIS-based tool to predict land-use change. The LanduseSim model uses cellular automata modelling approach. The user guide details no integration of population or economic drivers. The model rather uses the existing land-uses and subjects them to a four-step iterative process. The four-step framework is as follows; • Land use map (i.e. first cycle is pre-existing the following cycles represent land-use change until scenario requirements are met) • Accessibility of driving-factors (i.e. a transport component) • Suitability Map (i.e. planning policies and general constraints) • Set of transition rules, neighbourhood filter and time-step operation (i.e. the implemented scenario and timeframe) The LanduseSim model is not provided with a single user guide but rather multiple practice manuals. The principal usage of the model is to measure growth and assign allocation using a simple framework.	**GIS Compatibility:** The LanduseSim was designed as a GIS-based tool. The developers released a toolbox for ESRI ArcGIS that directly integrates data into the model. A cellular automata modelling approach is used as such raster formatted data is a requirement. Vector formatted data must use PolygonToRaster through ArcGIS prior to integrating into the model. This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **Property-Based Model:** The LanduseSim model relies on transition rules as dictated by assigned values by external documents (i.e. planning schemes). The model implements these values onto spatial boundary mapping data. The output is projected onto broad land-use types. The model does not detail the application or processing of the following data types; • Population • Economic • Employment • Land-use (i.e. pre-exiting before first cycle) The model does not support vector formatted parcel-based data. This represents

		a fatal flaw to the Regional Planning Model's purpose. **<u>Online Functionality:</u>** The LanduseSim model requires an internet connection to assert the validity of the user's licence. No other online functionality is present in the practice manuals. This represents a fatal flaw to the Regional Planning Model's purpose. **(Rank: Poor)**
METRONAMICA	The METRONMAICA model was developed by the Research Institute for Knowledge Systems (RIKS) 2012 in The Netherlands. The stand pricing package (i.e. including a three-day training session & Licence) costs $43,500 AUD. Alternativity the software pricing is $26,200 AUD for the model, $3,500 AUD annual payment for a maintenance contract with training and model extension (i.e. pre-existing or custom developed) available on request. Personalised pricing offers are available upon contracting RIKS. The METRONMAICA model was developed in the GEONAMICA software environment. The GEONAMICA software environment comprises two product tools an integrated user interface and a map comparison kit (i.e. used for the analysis of models results). Both tools use data formats that are compatible with ArcGIS. The model uses a Cellular Automata approach and the extent of vector data inclusion is not detailed within the user guide. The METRONMAICA model primarily modelling function is for spatial land-use change. This acts as a foundation layer whereas other extensions or models can be optionally included (i.e. regional migration, transport and environment modelling). Numerous pre-existing extensions are made available with the license and custom extensions can be developed at request. Simulated changes are based on the values assigned to drivers (i.e. accessibility, attractiveness, social-economic factors and control totals) at the user's discretion. The model requires two base years to calibrate historic land-use change. Scenario planning can be	**<u>GIS Compatibility:</u>** The METRONAMICA model supports two GIS compatible raster formats; ArcInfo ASCII Grid format & Idrisi byte binary image format. These formats are used in the land-use model. The user must provide at least two ArcGIS maps at differing dates to enable the model to be calibrated for growth (i.e. Historic data). The two sets of maps must be comparable in size and land-use types. This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **<u>Property-Based Model:</u>** The user guide suggests that METROMAICA is a bottom up process driven model. The model however applies a strictly cellular automata approach that doesn't enable the user to implement vector formatted data. This encumbers the model's ability to integrate parcel data types common in South-East Queensland. This represents a fatal flaw to the Regional Planning Model's purpose. **<u>Online Functionality:</u>** The GEONAMICA software environment contains tools that allow the user to; • ''Disseminate or collaboratively manage model data over a network or internet'' Online functionality although is not presented in METROMAICA's available

	experimented with after this process using supplementary data (i.e. policies & external influences). These are then compared against the baseline scenario. The model is limited to fifty land-use types with sixteen driver functions. All optional model includes separate required data input. Each model included in the scenario planning informs each processing stage. The METRONMAICA model user guide is comprehensive and freely available. The foundation model and the pre-existing optional extensions were detailed in their requirements and limitations. The principal usage of the model is to test scenario planning using land-use change at a regional scale.	materials. The model outputs are exportable to excel, an animated map format and into the Map Comparison Kit tool through GIS compatible files. An assumption however has been adopted that the model can have an online client developed by RIKS through their extension program. This conforms to the requirement of online functionality for the Regional Planning Model's purpose.
Moland Model	The Moland Model was developed by Research Institute for Knowledge Systems (RIKS), The European Union Joint Research Center & ERP-Maptec Ltd 2000-2009 in The Netherlands. The model is made available by contacting RIKS the price, however, is confirmed after negotiation. The Moland Model was developed in the GEONAMICA software environment. The model completed development in 2009 as such assumptions regarding GEONAMICA made under the METRONAMICA 2012 model will not be applied. This limitation on assessment is reasonable as the Moland model does not come with a user guide to provide additional context regarding assumptions. The model operates at two different scales; neighbourhood and regional. The modelling approach applied is cellular automata. The model operates with micro dynamics and macro constraints. The model similarly to other RIKS models acts as a foundation model whereas other extensions to the modelling process can be added to create alternative feedback to land-use change (i.e. climate modelling & infrastructure). The Moland Model applies four components in its land-use change simulations (i.e. economy, land-use, demography and traffic). The Moland Model does not come with an available user guide. The design requirements were assessed through the examination of white papers and available case studies throughout Europe. The principal usage of the model is to serve as generic land-use change	**<u>GIS Compatibility:</u>** The Moland Model operates its user interface as provided from the GEONAMICA. The model's design purpose was to serve as a generic urban growth model that could be applied throughout Europe. The design purpose and the white papers suggests that a flexible approach to GIS compatibility was a design requirement for the Moland Model. This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **<u>Property-Based Model:</u>** The Moland Model uses both micro and macro modelling approaches to mutually inform the land-use change process. The micro-level model determines the fate of each parcel based on individual characteristics. The macro-level acts to serves as constraints through trends and control totals. The usage of a cellular automata approach suggests that vector formatted parcel data is not compatible with the model. This represents a fatal flaw to the Regional Planning Model's purpose. **<u>Online Functionality:</u>** None of the available literature material examines any online functionality or details the exportation of modelling outputs. This represents a fatal flaw to the Regional Planning Model's purpose.

	model for application across different European cities.	
RuimteModel	The RuimteModel was developed by Vlaanderen 2007 in Flanders. The model is available by contacting the developers for acquisition. The RuimteModel was developed to test land-use change simulations over a fifty-year timeframe in Flanders. The modelling approach is cellular automata. Between 2007 and 2018 the model underwent updates that made improvements to processing capabilities and streamline data integration. The model can support up to fifty land-use types in raster format. The model also supports various extension produced by Vlaanderen (i.e. Regional modelling, climate etc.) The RuimteModel model comes with a user guide however it has not been translated into English. The material available on this model is limited to their web domain through google translate. These factors have encumbered the model during the assessment of design requirements. The RuimteModel is principally designed to measure land-use change using timeframe-based scenarios.	**GIS Compatibility:** The RuimteModel was developed for usage in Flanders and Brussels. The model was designed to use the available data by the relevant planning authorities which primarily consisted of GIS data. The RuimteModel is advertised as GIS compatible however the extent of how GIS data is incorporated into the processing cannot be confirmed without a user guide. This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **Property-Based Model:** The assessment of the model's ability to operate at a parcel level has been encumbered by the absence of a user guide. The model's material suggests that user discretion is applied to design the model as is required for the scenario. The user discretion however is limited to raster formatted data types. The limitation is implied due to the usage of a cellular automata modelling approach. Vector formatted parcel data is not compatible with this modelling approach as detailed within available material. This represents a fatal flaw to the Regional Planning Model's purpose. **Online Functionality:** The web domain does suggest that Vlaanderen has conducted online-GIS database portals research/development for the Flanders authority of planning. However, no evidence directly links this to the RuimteModel. This represents a fatal flaw to the Regional Planning Model's purpose.

SPARC & INDEX	The SPARC & INDEX model was developed by CRITERION Planners 1994 in the United States of America. The model is available as a subscription-based service with pricing dependant on negotiation with developers. The SPARC & INDEX model comprises two main components. The SPARC component is a cloud-service for GIS data management. The INDEX component is a scenario planning toolset. The model uses vector data which is typically applied for land-use change scenarios. The SPARC & INDEX model had previously come with a user guide however the web domain hosting the guide has not since been renewed. The assessment of this model is performed using promotional material available through their web domain. The promotional material includes cases studies and video tutorials. This has encumbered the model during the assessment of design requirements. The principally usage of the model is for GIS data management and a scenario planning toolset.	**GIS Compatibility:** The SPARC & INDEX model is developed principally for GIS data management and integration. The model can store, transform and integrate GIS data through a suite of tools. This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **Property-Based Model:** Without a user guide the extent to which the model can process micro (i.e. parcel) data cannot be confirmed. The video tutorials and advertisement of services included mention that the model can operate with parcel data when performing regional planning. The model's usage of vector data (i.e. polygons) is in alignment with typical data available in South-East Queensland which will be considered during ranking. This conforms to the requirement of a parcel-based driven process for the Regional Planning Model's purpose. **Online Functionality:** The SPARC & INDEX model is operated through an online portal. The advertisement highlights that the model is designed for the primary purpose of allowing the sharing of data scheme and integration across differing planning departments. The model contains numerous online functions; • The ability to connect with national databases • The reduction of data files sizes through a geometer model • Integration of multiple datasets onto one land-use map through online tools • Cloud infrastructure and data storage This conforms to the requirement of online functionality for the Regional Planning Model's purpose.

The Clarke Urban Growth Model/ SLEUTH	The Clarke model was developed by Keith Clarke in 1997 in the United States of America. The model is available freely as open-source code with currently no availability of further support. The Clarke model was developed with the Land Cover Deltatron Model code included which informs the urban growth model. The modelling approach uses cellular automata with six primarily data inputs/calibration parameters. The inputs requirements are what comprises the SLEUTH acronym; • Slope • Land cover • Exclusion • Urbanisation • Transport • Hillshade Research on this model is still being conducted at the University of California. The model requires a minimum of five types of greyscale gif image files that are assigned a value between zero and two-hundred and fifty-five. These values are what determine the processing extent of land-use change scenarios (i.e. constraints and attractors). The model must be consistent across all inputs regarding several fields represented. For statistical calibration of the model, a minimum of four timeframes is required. The output of the model is presented in an image file (Land-use) and as a log file (Statistical Output). The Clarke model does not come with a standard user guide but rather all information during assessment was sourced from the web domain and a SLEUTH master class tutorial. The web domain also provides a list of the Clarke models usage and application presented in academic literature. The principal usage of the model is a basic land-use change model.	**<u>GIS Compatibility:</u>** The Clarke model is designed to use greyscale raster image files as its input type. This would suggest that it is GIS compatible as it would be necessary to ensuring data is comparable (i.e. fields). The model is not able to support GIS data inputs that are typically used in South-East Queensland (i.e. Vectors). The model is thus limited to image files and statistical inputs (i.e. excel). This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **<u>Property-Based Model:</u>** The model during the land-use stage requires the user to provide a value for each separate land-use type. The value range is between zero and two-hundred and fifty-five and is presented as (R, G, B) colour codes on the greyscale image. For example, (R=1, G=1, B=1) = Urban while (R=2, G=2, B=2) = agriculture. This process enables the model to be as micro-based as the user decides. The model however cannot implement vector formatted parcel data types. This represents a fatal flaw to the Regional Planning Model's purpose. **<u>Online Functionality:</u>** None of the available literature material examines any online functionality besides the availability of online forums. The model's outputs are only presentable in images file or excel documents. This represents a fatal flaw to the Regional Planning Model's purpose.
The WISE Model	The Waikato Integrated Scenario Explorer (Wise) model was developed by Waikato Regional Council 2010 in New Zealand. The models next major update is in July 2020 (i.e. Version 1.6) and a trial version is freely available. The acquisition of the model requires contacting Dr Beat Huser in the Waikato Regional Council.	**<u>GIS Compatibility:</u>** The WISE model uses GIS data as the primary input for its land-use change sub-model. The model first accepts vector (i.e. polygons) then provides value to each land-use type. These are then union together creating a shapefile per land-use types based on the value inputted into the field. The model then converts these inputs into raster data (i.e. cells). This process is in alignment with data

	The WISE model was developed in the GEONAMICA software environment. As such the model contains a user interface and remains GIS compatible. The modelling approach is cellular automata but is not limited to raster data as it can also implement vector data or statistical inputs. The purpose of the WISE model (i.e. Version 1.0) was to inform integrated regional policy development while assessing economic, environmental, and social outcomes trade-offs. The WISE model is best described as a master model that contains various sub-models mutually informing each stage of processing. These sub-models are listed below: • Climate Change (Global) • Demographics (District) • Economic (Regional) • Hydrology (Regional) • Land Use Change (Local) • Terrestrial Biodiversity (Local) • Water Quality (Regional) The above sub-models can be further broken down into subcomponents (i.e. supply and demand modelling, attractors, agent modelling, transport modelling and residential demand modelling). The sub-models also operate at different scale as a label in the list however the output is present at the scale required by the user. The land-use change model is limited to twenty-five land-use types with the designed timeframe operating over fifty years. The WISE model can optionally perform a Monte Carlo analysis under the land-use model. Usage would encumber repeatability. The approach produces random values during the prediction process meaning outcomes cannot be replicated for comparison. The outcome of Monte Carlo within the WISE model is a set of maps using a probability of occurrence of each land-use. The WISE model is provided with an extensive user guide for version 1.4. The current version 1.5 does not have a user guide however brief mentions of improvements are included in user guide 1.4. The principal usage of the model is to inform regional planning policy through scenarios by multiple stakeholder department.	types typically used in South-East Queensland and converts them for model application without the need for external tools. This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **<u>Property-Based Model:</u>** The WISE model is a bottom-up process through the local scale sub-models. The data entry relies on parcel inputs that aggregate together to influence micro-scale dynamics. The outputs are applied to the demographics, economics and infrastructure-based components/ models. The inclusion of vector formatted parcel data through this process would typically conform to the Regional Planning Model's purpose. The usage of conversion functions of vector to raster (i.e. a cellular automata modelling approach) would cause inaccuracies when modelling at a regional scale. This represents a fatal flaw to the Regional Planning Model's purpose. **<u>Online Functionality:</u>** The user guide for version 1.4 refers to future enhancements that the model will include. The following quote is considered for the assessment of this fatal flaw: • "Plan and implement the installation of WISE on the internet such that external users can access, and experts can maintain their model dynamically" Although accessing the WISE model through an online portal was not available in version 1.4 an assumption is applied. The assumption is that this online functionality has been included in either version 1.5 or the soon to be release version 1.6. This conforms to the requirement of online functionality for the Regional Planning Model's purpose.

Uplan4	The Uplan4 model was developed by the Information Center for the Environment 2007 in The United States of America. The model is freely available as open-source code. The Uplan4 model was developed within ArcGIS. The design intention for Uplan4 is to visualise potential future growth patterns. The model is better suited for small scale study area using bottom-up localised data. The model is limited in its capacity to address complex interregional interactions. Python script is applied to the model with vector formats required for data input. The modelling approach uses simple rule-based decisions as to be transparent to the user. The usage of historic data is not required to create a growth trend but rather the model only needs existing land-uses. Population totals are converted into employment totals and occupancy rates. The new expansion (i.e. allocation) is limited by the input policy parameters and locations are given preference by attractors such as infrastructure or accessibility. Constraints mapping is also applied to the model. The above contains the only influencing factors the model applies when projecting future growth. The Uplan4 model is provided with a user guide that was written with the assumption that the user is experienced with ArcGIS model builder. The principal usage of the model is to inform future growth onto a parcel level using top-down population totals.	**GIS Compatibility:** The Uplan4 model was developed as an ArcGIS toolbox. The tools were limited to seven functions that comprise the Uplan4 modelling process. The required data format is vector and the usage of raster is no longer supported with external conversion tools. This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **Property-Based Model:** The Uplan4 model primarily uses vector formatted parcel-based data when capturing existing and future growth. The model also prefers localised data when multiple study areas are containing within the spatial boundary. The land-use demand component, however, replies on population totals to be converted into numerous influential factors. This suggests that many components within Uplan4 use one data input to predict future growth. The above process does not align with a model that is micro-based, dynamic or bottom-up. This represents a fatal flaw to the Regional Planning Model’s purpose. **Online Functionality:** None of the available literature material examines any online functionality. The model’s outputs are only presentable in ArcMap. This represents a fatal flaw to the Regional Planning Model’s purpose.
UrbanAPI	The UrbanAPI model was developed by UrbanAPI consultancy 2014 in Bulgaria with funding from the 7th Framework Programme of the European Commission. Model acquisition and pricing are dependent on negotiation with the consultancy. The UrbanAPI software package contains two products. The Urban Development Simulator is a pre-built model that operates through a web-browser and projects land-use change in either 2D or 3D visualisation. The UrbanAPI toolkit is a scenario planning toolset that has been designed using generic approaches to allow it to be adaptable to	**GIS Compatibility:** The UrbanAPI model’s data integration is designed to integrate raster formatted data without any other attachments or services. The integration/ conversion of vector data for application in the model can be achieved in the MASGISmo software environment. The MASGISmo acts as a foundation to which other services can be included such as OpenJump for vector data integration. The available material does not make it clear whether OpenJump is integrated into the model upon acquisition or not. The requirement of external services to allow for

	user requirements. The toolkit is applied to create policy scenarios while the simulator is used to examine these affected land-use change. The Urban Development Simulator was developed using the MASGISmo software environment. The model uses a combination of cellular automata and multi-agent system modelling approaches. The MASGISmo software environment includes an online database connection to PostgreSQL. This database is how data is stored using this model. The Model uses GIS compatible raster formatted data (i.e. ASCII grid files). It is possible through the MASGISmo software environment to connect the model onto other services. Establishing a connection between OpenJump and the model allows for the usage of vector formatted data (i.e. ESRI-Shapefiles). The model was developed as a generic or adaptable solution to apply to any city or region it is implemented. The UrbanAPI model is provided with a list of product deliverables rather than a single user guide. It is suggested that this format is a result of how the model was funded. The city of Ruse in the available material is the most compatible case study for South-East Queensland due to similarities of available data types (i.e. census, vector format etc.). The principal usage of the model is to measure land-use change as informed by policy parameters during calibration.	vector compatibility will be reflected during ranking. This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **<u>Property-Based Model:</u>** The available product deliverables do not detail the extent of integrated data or the spatial requirements as an input. An assumption is made that the model is micro-based at the user discretion. The assumption was received based on the context of available material: • Multi-Agent System • The usage as a generic model • The described modelling process (i.e. aggregation & bottom-up components) The modelling approach uses a multi-agent system in which data must have micro-level factors encoded within them. The factors must include attractiveness patterns at either local or regional scales. The model then uses a cellular automata modelling approach when projecting future growth. The verification of the projection process is performed by statistical and census data being disaggregated to produce buildings onto the spatial extent then aggregating them to 500m raster cells. The inclusion of vector formatted parcel data through this process would typically conform to the Regional Planning Model's purpose. The usage of conversion functions of vector to raster (i.e. a cellular automata modelling approach) would cause inaccuracies when modelling at a regional scale. This represents a fatal flaw to the Regional Planning Model's purpose. **<u>Online Functionality:</u>** The model is designed with a user interface that can be integrated into a standard web browser. Other online functions include the ability to connect to online databases accessible by any stakeholder. These functions are enabled by the MASGISmo software environment. This conforms to the requirement of online functionality for the Regional Planning Model's purpose.

UrbanSim	The UrbanSim model was developed by Paul Waddell 2002 in The United States of America. Model acquisition and pricing are dependent on negotiation with developer. The pricing is dependent on the scale the model will use (i.e. parcel, zone or census block) and what extensions are included (i.e. UrbanCanvas or Penciler). Pricing is subscription-based and is also influenced by the population that the model is servicing. The UrbanSim modelling suite allows for two additional extensions; UrbanCanvas and Penciler. The UrbanSim model at a parcel level uses three sub-models that mutually inform each other; • Household model • Employment model • Real estate model These models are influenced by parameters and inputted data at user discretion (i.e. infrastructure, housing affordability, traffic and constraints mapping). UrbanCanvas acts as an additional scenario creation and calibrating tool. UrbanCanvas provides the user interface that allows for the UrbanSim connection to cloud infrastructure. The output projections by UrbanCanvas are available in 2D or 3D layouts. All outputs are available through a web browser. Multiple scenarios can run together and typically uses a 30-year timeframe. The model runs each year during the timeframe and adjusts accordingly with populations of three to five million taking two to four minutes per year. Penciler is a building scenario planning tool performed at the parcel scale. Penciler is a web-based tool to test housing development designs as informed by constraints and planning requirements. Multiple building designs can be prepared and compared for their economic influences. The UrbanSim model applies Monte Carlo simulation to make model predictions. This encumbers the model's repeatability. The approach produces random values during the prediction process	**<u>GIS Compatibility:</u>** UrbanSim has been scenario tested within South-East Queensland using local data. This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **<u>Property-Based Model:</u>** The UrbanSim model is provided in three versions. The version of that relates to this assessment is the parcel level model. The model applies data types that are typical of South-East Queensland current modelling practices; • Control Totals for population and employment • Overlays of infrastructure • Lot plans Older versions of UrbanSim were limited to only raster formatted data. Newer versions have since been released that enable vector formatted data's usage. This conforms to the requirement of a parcel-based driven process for the Regional Planning Model's purpose. **<u>Online Functionality:</u>** The UrbanCanvas extension enables the UrbanSim model to access cloud infrastructure and expands upon the available online functionality. The model can run through a web browser that can provide access to the model by all involved stakeholders. Additionally, the model is capable of both connecting to private or governmental databases and run automated calibration tools through the cloud infrastructure. This conforms to the requirement of online functionality for the Regional Planning Model's purpose.

	meaning outcomes cannot be replicated for comparison. The usage of Monte Carlo simulation is mentioned in academic material that has since become dated. The role that Monte Carlo simulations play into the modelling framework is however not known. Without a user guide to describe the current approach it is assumed Monte Carlo simulations are still applicable. The UrbanSim Model is not provided with a user guide before acquisition or contact with the developers. The models ranking was assessed by available promotional material, case studies available through their web domain and academic material by Paul Waddle. The principal usage of the model is to measure land-use change using population and employment totals with scenario planning supported by UrbanCanvas.	
Vision Illawarra	The Vision Illawarra model was developed by the University of Wollongong Australia 2016 by expanding upon the METRONAMICA model by The Research Institute for Knowledge Systems (RIKS). The model is available as a subscription-based service with pricing negotiated by contacting the developers. The Vision Illawarra model used the METRONAMICA model as a foundation to produce an urban growth model applicable to the Illawarra region (South of Sydney, Australia). The model uses four sub-models to inform scenario planning; • Economic model • Population model • Land use model • Transport model The economic model drivers inform the population model (i.e. employment and migration requirements). The land-use model then captures the existing and expected future demand as informed by the economic and population models. The transport model influences and is in turn influenced by the above model by output drivers (i.e. accessibility and attractor values). The Vision Illawarra as such acts more as a master model that integrates other modelling software packages. The economic open model is a computable general equilibrium model (CGE) named cadence economics general equilibrium model (CEGEM). The model calculates the yearly growth or decline of nine-teen	**<u>GIS Compatibility:</u>** The Vision Illawarra model's assessment against GIS compatibility has been encumbered by not having access to a user guide. The available material does not mention specific data types the model processes as such GIS compatibility cannot be assessed. An assumption is adopted that as an Australian model it would implement data types (i.e. GIS data) that are common for local governments. However, the requirement for additional information will be considered during ranking. This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **<u>Property-Based Model:</u>** The Vision Illawarra model's assessment against parcel-based processes has been encumbered by not having access to a user guide. The available material does not mention required type types but uses general terms. The white paper describes processes of aggregation implying a bottom-up process. The model using an agent-based approach implies micro-scale data requirements. The land-use model however operates with cellular automata modelling approach suggesting that a vector to raster process occurs. The usage of conversion functions of vector to raster (i.e. a cellular automata modelling approach) would cause

	industries. The outputs are used for the population model through inputting job numbers expected to drive migration. The aggregated process uses four industries; commercial & services, industrial, agricultural and mining. The land-use model uses these aggregated industries to allocate land for these employment types. The population model (i.e. Synthetic population) applies an agent-based modelling approach to produce inputs for the land-use model (i.e. occupancy rates). The land-use model uses a cellular automaton modelling approach that is typically used with twenty-three land use types. The land use model provides the inputs to determine destinations for the transport model. The transport model informs accessibility drivers to the land use. The Vision Illawarra model is not provided with a user guide before acquisition or contact with the developers. The models ranking was assessed by the Vision Illawarra web domain and a short summary white paper that provides guidance for further academic material on each sub-model. The principal usage of the model is to test scenarios in the Illawarra region.	inaccuracies when modelling at a regional scale. This represents a fatal flaw to the Regional Planning Model's purpose. **<u>Online Functionality:</u>** The Vision Illawarra model has two online functions; web browser access and an online dashboard. The web browser can provide access to each sub model by stakeholders. The online dashboard exports outputs of the model in table, figure and chart forms for public display. This conforms to the requirement of online functionality for the Regional Planning Model's purpose.
What-If online	The What-if online model was developed by Chris Pettit & Australian Urban Infrastructure Research Information Network in Australia (AURIN). The model is available for free but requires creating an account through AURIN. Model support, training and project opportunities are available through negotiation with the developer. What-if online comprises two main components; Setup and scenarios. The setup component adds values to data, control totals are set, and growth trends are introduced. The scenario component enables the user; to use a pre-existing scenario, to create project-specific scenarios or run multiple scenarios. What-if Online is designed after the framework of What-If 2.0 however adapted to contain online components and to be more streamlined under an Australian planning context. What-if online uses vector formatted data and requires that values are aligned across similar data types (i.e. Slope, environmental constraints and existing or future road infrastructure) across all inputted data. The inputted data is then combined	**<u>GIS Compatibility:</u>** What-if online models processing requires GIS data and common GIS software packages functions (i.e. Union, RasterToPolygon from ArcGIS). The model requires all data types to be vector formatted (i.e. polygon) before using the union function to create the uniform analysis zone (UAZ). This does not limited raster data but rather instead requires them to use the RasterToPolygon function before union. This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **<u>Property-Based Model:</u>** What-if online model's data processing is left to user discretion. The model as such can be as micro-based as the user decided. Case studies confirm that parcel-level data has previously been used throughout Australia with this model. Although the inputted data must be comparable to its assigned value across all aspects in the UAZ. The model then uses aggregation processes that are verified

	through GIS to create a uniform analysis zones (UAZ). The What-if Online model and their UAZ's are designed to determine the effects of policy scenarios on existing/future land-use. The model is not suitable for predicting future conditions of land-use without prior assumptions of future conditions and a policy scenario under which to test the UAZ. The What-If online model is provided with a user guide and the web domain provides Australian case studies of application. The models ranking was also assisted by what-if 2.0's user guide that uses the same modelling framework. The principal usage of the model is to serve as a policy-oriented planning tool that is utilised after assumptions of future conditions are made.	by control totals. This conforms to the requirement of a parcel-based driven process for the Regional Planning Model's purpose. **<u>Online Functionality:</u>** What-if online model supports online accesses via a web browser. This requires an account with Australian Urban Research Infrastructure Network (AURIN). The potential of using a private web portal not linked to AURIN to access and calibrate the model cannot be confirmed with available materials. A private web portal although is assumed to be likely through contacting the developers. This conforms to the requirement of online functionality for the Regional Planning Model's purpose.
What-If 2.0	The What-if 2.0 model was developed by Richard Kolsterman 1999-2008 in the United States of America. The model is available for free but provides no user support. What-if online comprises two main components; Scenarios and Setup. The scenario component enables the user; to use a pre-existing scenario and to create project-specific scenarios. The setup component adds values to data, control totals are set, and growth trends are introduced. What-if 2.0 requires the user to decide upon a scenario for analysis before the setup component. What-if 2.0 is used vector formatted data and requires that values are aligned across similar data types (i.e. Slope, environmental constraints and existing or future road infrastructure) across all inputted data. The inputted data is then combined through GIS to create a uniform analysis zones (UAZ). The What-if 2.0 model and their UAZ's are designed to determine the effects of policy scenarios on existing/future land-use. The model is not suitable for predicting future conditions of land-use without prior assumptions of future conditions and a policy scenario under which to test the UAZ. The What-If 2.0 model is provided with an extensive user guide that details all possible data types and configurations. The principal usage of the model is to	**<u>GIS Compatibility:</u>** What-if 2.0 models processing requires GIS data and common GIS software packages functions (i.e. Union, RasterToPolygon from ArcGIS). The model requires all data types to be vector formatted (i.e. polygon) before using the union function to create the uniform analysis zone (UAZ). This does not limited raster data but rather instead requires them to use the RasterToPolygon function before union. This conforms to the requirement of GIS compatibility for the Regional Planning Model's purpose. **<u>Property-Based Model:</u>** What-if 2.0 model's data processing is left to user discretion. The model as such can be as parcel-based as the user decided. The model's user guides detail how parcel-level data can be integrated for different scenarios. Although the inputted data must be comparable to its assigned value across all aspects in the UAZ. The model then uses aggregation processes that are verified by control totals. This conforms to the requirement of a parcel-based driven process for the Regional Planning Model's purpose. **<u>Online Functionality:</u>**

	serve as a policy-oriented planning tool that is utilised after assumptions of future conditions are made.	What-If 2.0 has no online functions. The model does not support any functions that would assist stakeholder's involvement in calibrating or viewing outputs. This represents a fatal flaw to the Regional Planning Model's purpose.
Xplorah Model	The Xplorah model was developed by the Research Institute for knowledge systems (RIKS) 2001-2009 in The Netherlands. The usage and pricing of this model would require contacting the developers. The Xplorah model was developed within RIKS Geonamica software environment. The Xplorah model integrates four scales; • Global (i.e. Climate change) • National (i.e. Scenario Builders for population and economy) • Regional (i.e. Population, economy and land claims) • Local (i.e. Land Use and spatial indicators) The global and national scales are ''not true models'' but rather serve as the component of processing were externally sourced assumptions are inputted into the model. This component enables users to alternativity implement external models for population and economy. Whether control totals (i.e. assumptions) or external models are used the population and economy inputs mutually inform each other. The Regional-scale applies three models a spatial interaction model, a transport model and a land-use demand component. The spatial interaction model allocates control totals across municipalities. The transport model calculates the main transport routes across locations (i.e. accessibility). The land-use demand component converts regional-scale information for usage at the local scale. The local scale uses a cellular automaton modelling approach which cell resolutions of 250m2. The model uses the dominant land use per cell as such mixed-use developments are not supported. The model is limited to nine-teen land-use types. The model at this scale uses four criteria when allocating future land-use demand;	**<u>GIS Compatibility:</u>** The Xplorah model's assessment against GIS compatibility has been encumbered by not having access to a user guide. The available material does not mention specific data types the model process as such GIS compatibility cannot be assessed. The model's process as described by available material implies a top-down approach using external assumptions and model outputs. Other urban modelling software packages developed in the Geonamica software environment are described as GIS compatible platforms. The Xplorah model, however, pre-dated these models as such no assumption was not adopted. This represents a fatal flaw to the Regional Planning Model's purpose. **<u>Property-Based Model:</u>** The Xplorah model's assessment against parcel-based process has been encumbered by not having access to a user guide. The available material suggests that the model relies predominately on macro and top-down process. The model is also unable to separate mix-use development as each cell size represents a 6.25ha spatial extent with the primary land-use assigned to the cell. The usage of a cellular automata modelling approach suggests that vector formatted data cannot be implemented within the model. This represents a fatal flaw to the Regional Planning Model's purpose. **<u>Online Functionality:</u>** Xplorah has no online functions as described by the available material. The model does not support any functions that would assist stakeholder's involvement in calibrating or

	• Physical suitability (i.e. constraints and spatial requirements) • Zoning or institutional suitability (i.e. planning schemes) • The accessibility (i.e. informed by transport model) • Dynamic on surround cells (i.e. parameters and spatial rules) The Xplorah model is not provided with a user guide before contacting either the developer or the original customer (Puerto Rico's Planning Board). The models ranking was assessed by academic material that was presented as case studies, a peer review and summary of models processing. The principal usage of the model is to test scenarios that consist of external factors and policy introduction onto assumed land-use changes.	viewing outputs. This represents a fatal flaw to the Regional Planning Model's purpose.

Appendix B: AURIN's PSS Library Resource

Flowmap Irregular City (iCity) and Agent iCity	UrbanSim
CommunityViz	CLUMondo
Cube Land	CorPlan
DELTA	DSCMOD
Land Change Modeler	Envision Tomorrow
Online What if?	Land Use-based Integrated Sustainability Assessment modelling platform (LUISA)
SLEUTH	Luci2 Urban Simulation Model
UPlan	Spatial and Transport Emissions Assessment Module (STEAM)
California Urban Futures I/II Model (CUF-1/2)	Sustainable Urban Structure Transport and Infrastructure Networks (SUSTAIN)
Chicago Area Transportation Land use Analysis System (CATLAS)	Techniques for Optimal Placement of Activities in Zones (TOPAZ)
Common-pool Resources and Multi-Agent Systems (CORMAS)	Vacancy Chain Models for Housing Needs and Impact Assessments
Conversion Land Use and its Effects (CLUE/-s)	ALCES
Disaggregated Residential Allocation Model of Household Location and the Employment Allocation Model (DRAM/EMPAL)	Amersfoort
Dynamic Urban Evolutionary Model (DUEM)	Brisbane Urban Growth Model (BUG)
Dyna-CLUE model	California Urban and Biodiversity Analysis (CURBA)
Envision	CityEngine
INDEX	Computer-Aided Land-Use Transport Analysis System (CALUTAS)
Land Transformation Model (LTM)	Constrained Cellular Automata model
Land Use Change (LUC) model	Criem/GIS
MEPLAN	DSSM
Metronamica	Environment Explorer (LOV)

Metropolitan Integrated Land Use System (Metropilus)	Envision Scenario Planner (ESP)
MOLAND	EU-ClueScanner (EUCS)
Multi-Agent-based Behavioral Economic Landscape (MABEL)	EZ-IMPACT
Mussa	GeneticLand
Transportation and Land Use System (TRANUS)	GEOMOD2
UrbanCanvas	GeoPlanner
Growth Simulation Model (GSM)	Metrosim
Harvard Urban Development Simulation (HUDS)	MODULUS
Hedonic Pricing Model	Mutopia
Housing Development Tool	NBER
IFS model	NYMTC-LUM
ILUMASS	Online Envision
Integrated Infrastructure Planning Tool (IIPT)	Osaka
Integrated Land Use, Transportation and Environment (ILUTE) model	PLUM
Integrated Model Prediction European Landuse (IMPEL)	Predicting Urban Population (PUP) model
Integrated Model of Residential and Employment Location (IMREL)	Production, Exchange, and Consumption Allocation System (PECAS)
Integrated Transportation and Land Use Package (ITLUP)	Projective Optimisation Landuse Information System (POLIS)
Interactive Multivariable Analysis Tool (IMAT)	PUMA
I-Place3S	Ramblas
IRPUD (Dortmund)	Random-Utility Urban (RURBAN)
KIM	RapidFire
LAND	SALOC
Land Use Change Analysis System (LUCAS)	SIMLUCIA

Landuse Evolution and Impact Assessment Model (LEAM)	Smart Growth INDEX
Land Use Scanner	Smart Places
Land Use Scenario DevelopeR (LUSDR)	Spartacus
Large Scale Urban Model	Spatial Vision's peri-urban model
LILT	Sub-Area Allocation Model-Improved Method (SAM-IM)
Lustre	Transportation Economic and Land Use System (TELUS)
Luti	UGrow
MARXAN	UrbanFootprint
MENTOR	Urban Housing Growth Model
MetroScope	