Final Report
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Introduction

This two-year research project, originally titled, Resource+, funded by the Canada Foundation for Innovation, brought together two of Canada's top modeling groups but with very different business models—a private sector company, whatiftechnologies [1], and a workers cooperative, Sustainability Solutions Group[2]. Key experts were Ralph Torrie, one of the country's foremost energy specialists and modelers, Robert Hoffman and Bert McKinnes, led by the principal investigator, Professor Ann Dale.[3] Research partners included Devin Causley, Canadian Federation of Canadian Municipalities and Mary Herbert-Copley, former Executive Director of 1125@Carleton.

The Vision

The proposed infrastructure will be the first computer-based simulation model to integrate land, water, and energy use with the environmental, social, and economic imperatives for researchers and community decision-makers to assess the implementation of sustainable community development at the community level. The simulation model will consist of a series of interrelated sub-models describing individual processes and include scenario management, data visualization, collaborative multi-user access,
and extensibility.

The infrastructure will build and support local capacity for exercising local agency in a community's implementation of sustainable development, as well as climate change adaptation and mitigation. The infrastructure will be developed with a central focus on supporting innovation in the field of local agency, systems analysis and sustainable development. It will advance our understanding of the physical aspects (energy, water, waste, pollution) and the socio-economic elements (employment, economic output, public health) of sustainability, the

[1] Principals were Michael Hoffman, Marcus Williams and Deryn Crockett
[2] Principal was Yuill Herbert
[3] Team members included Chris Strashok, Techsight Consulting and Robert Newell, Doctoral Candidate, University of Victoria

relationships between them, and the role of local agency in advancing local prosperity, quality of life, public health, and environmental sustainability in Canadian municipalities.

Places and Spaces was designed to examine the evolution of community well-being or sustainability.

One element of sustainability is concerned with the physical well-being of the community. This is indicated by the ability of the community to meet the needs of its residents for housing, nutrition, water, energy, and community infrastructure such as schools, hospitals, transportation and by the ecological impact of the human activities in the community.

A second element is concerned with the financial well-being of the community. The physical needs of the community cannot be met unless the agents in the community have the purchasing power to acquire the needed goods and services they need either from agents within the community or from agents outside the community. The financial viability of the community is indicated by the difference between the inflows and outflows of purchasing power of the community. It is clear that a net outflow cannot be sustained and will cause a downward spiral in community well-being.

The two elements are interdependent: physical well-being depends on financial viability and financial viability depends on the configuration of the activities that serve human needs.

The Method

First, we conducted an environmental scan of other models as we didn't want to duplicate others work, and ideally, build on the best practices. The team then spent over six months discussing the structure of the infrastructure and how to integrate the social, financial and build on the biophysical model that whatiftechnologies had already built. The principal investigator insisted that the model be developed in partnership with case study user communities, an iterative model design. Four communities were identified—Tofino and Colwood, British Columbia; Guelph, Ontario and Moncton, New Brunswick.[4] Guelph, Ontario did not stay with the project due to changing staff and differing priorities.

The next phase involved identifying building archetypes in order to develop a standardized approach to buildings for each community, following which whatiftechnologies and Sustainability Solutions Group began to test the model

[4] We are indebted to Ian Bourhill and Kerri Trace, Colwood, British Columbia; Aaron Rogers from Tofino, British Columbia; and Elaine Aucoin from Moncton, New Brunswick

with staff from the three case study communities. Next, the team refined the model; and a meeting was held in March 2016 to beta test the model with the communities and research partners. The next phase, refinement and model calibration was completed and the model infrastructure, Places and Spaces, v.1, was launched in May 2016.

The Challenges

We anticipated and found that large data gaps existed in local governments including building attributes such as floor area, standardized description of buildings uses, projections of future employment spatially allocated, emigration and immigration, student populations in universities and colleges, energy use in commercial transportation and financial flows in households and businesses at the municipal scale. Google Maps and Streetview were invaluable in validating characteristics of the building stock. Other techniques used to provide municipal scale data included down-scaling provincial level data and using assumptions from other municipalities or background research.

In addition to the large data gaps, other issues included asymmetries of scale between communities, very different rural versus urban contexts, modeling a city-scale from building archetypes, reducing existing model complexities, and making the data easily accessible to diverse decision-makers.

The Model Infrastructure

Places+Spaces has a biophysical foundation that represents population and demographics; buildings and urban form; physical infrastructure and services (transportation, water, waste, energy). The model accounts for social infrastructure and service (education, healthcare, recreation); as well as economic activity (labour, products and services) and attempts to account for the financial states and activities of the public sector, private sector and households within the community and financial flows leaving and entering the community. The level of experimentation increased from the biophysical sphere out to the financial spheres, for which methods and data are novel and are therefore discussed in detail below.

The financial aspects of the model operate at the level of agents—individuals, households, institutions, businesses, and governments. These agents own and control bits and pieces of the biophysical world and engage in exchange with other agents both inside and outside the boundary in order to achieve their objectives. Exchange is accounted for in monetary units. Agents keep track of exchange by keeping books, represented in the model as incomes and outlays and stocks of assets and liabilities. Agents can only spend from the income they receive or by incurring debt. Agents' ability to engage in exchange is limited by their ability to generate money income or incur debt. Often agents' activities are not confined to the community, so the accounts may be partial.

The model tracks household income from employment, pensions, interest and dividends and expenditures for goods and services, taxes, interest on debt. Municipal government, schools, hospitals, and care facilities receive income from fees for service, taxes and transfers from other governments and make expenditures on salaries and benefits for employees and for the acquisition of goods and services. Businesses receive income from the sale of goods and services and make expenditures on salaries and benefits for employees, taxes, and for the acquisition of goods and services. By keeping separate transactions between agents in the community and the rest of the world, the model is designed to calculate the net inflow/outflow of purchasing power of the community.

This framework allows for a wide range of potential inquiries—for example, the analysis of the distribution of households by income levels which is affected by and affects taxes and transfers, as income distribution is itself an indicator of community well-being.

While the framework for the financial analysis was developed in this project, it was not validated for a community, primarily because of significant data gaps that exist with respect to financial flows at the municipal scale.

What Worked

In order to capture the physical infrastructure of a community with a high level of detail, building archetypes were used. The building archetypes approach enables the analysis of buildings in a community with some accuracy without having to model the characteristics of each individual building. Each archetype was used to categorize a specific set of building characteristics associated with a set of buildings. This allowed the model to understand how each building functioned with regards to population size and resource use. The model then allows these archetypes to be placed within the community's boundaries, which we called "pins on the map" allowing planners to create and explore various community configurations. The model has 85 building archetypes, 32 representing residential buildings and 55 representing commercial and industrial buildings.

An unanticipated outcome of bringing together the two parties was twofold. First, the private company decided to release an open source version of its model platform in order to stimulate business innovation and second, an ongoing partnership was established between the two parties. Further a spin-off model was developed, called CityinSight, that integrated previous modeling work of Sustainability Solutions Group (SSG) and the conceptual work of Places and Spaces. CityinSight was launched in December 2015 at COP 21 in Paris and is currently being used by cities across Canada. The partnership has subsequently received a large contract from the City of Toronto to use the model in their sustainable planning for the coming year.

What Didn't Work

First, the validation of the integration of the biophysical elements with financial accounting was limited to the relationship between the built environment and municipal costs and revenues. This outcome was disappointing as the full integration between household income and biophysical elements was not validated in the case studies, a crucial function of a sustainable development analysis.

Second, another major driver of model deviation was due to the data that was available or the lack of data altogether. This is always a challenge when using data that was not collected specifically for the intended purposes. Often the shape of the data had to be processed to address the requirements of Places+Spaces and in other cases the dataset was partially complete. Data issues were the primary cause for the lack of an integrated financial model as the data that the team initially considered to be appropriate for the project was inadequate.

Third, the engagement of the case study communities was not effective, and instead of being engaged as partners, they were more of a resource for supplying data. Since the openness of the model and user friendliness was an important research goal, community engagement needed to be stronger and more sustained and situated in the context of key policy decisions such as the development of official plans. Time constraints for both the modelling team and the case study municipalities also contributed to limiting the depth of engagement with the case study communities.

What We Learned

The vision for the model infrastructure was truly integrative of the ecological, social and economic imperatives of sustainable community development. Modeling is a complex process, and an environmental scan revealed there are no other fully integrated models at the municipal or regional scale. Another objective was to produce a model that was elegant, and easy to use by planners. The level of integration introduced through sustainability then brought a level of complexity to the modeling design and process that was impossible to resolve in a two-year period.

As well, working with a private sector company has its own complications. First, they had to be sensitized to the research process and second, to working in partnership and with community partners. The magnitude and complexity of the task also exceeded the resources available for the project. In the end, the bottom line prevailed for both research partners, and insignificant time was devoted to developing a fully integrated model. Looking back at the vision that was created at the beginning of this project, the biggest success is the theoretical construction of an integrated biophysical and financial model. The project team was able to design a model that can explore the direct effects of community development such as land use, modes of transportation, a community's energy, water use, and waste production and the financial implications of these aspects for municipal operations. All of these effects were driven by both demographic and economic based considerations.

The case studies were successful by many measures. We were able to build comprehensive and integrated development trajectories for three case study community that had never previously spatially allocated future population and employment for different scenarios. These projections were revealing, for example, in the case of Moncton, in their illustration of the financial implications of servicing the projected development patterns. In the case of Tofino, detailed analysis of current and future water consumption and current and future provision of water provided new insights into the need for curtailing water use.

Less successful was keeping track of households by income level. The distribution of household income at a point in time depends upon the age structure of households and parameters such as wage rates and taxes/transfers that can vary with time. All other things being equal, the distribution of income and expenditure reflects the life cycle of income and expenditures. For example a household consisting of a retired couple will have a different pattern of income and expenditure then a young family with two income earners. The attempt to deal with changing income distributions over time using a time series of quintiles was not successful insofar as this approach does not reveal the dynamics of changes in the distribution. The conclusion was reached that this approach was not worth pursuing.

While this approach was abandoned two alternative approaches for the household financial accounting were identified for future development and for this reason are described in detail here. The first is a micro-analytic simulation approach which would keep track of a population of individuals/households over time. In each time period the population is augmented by births and immigrants and diminished by emigrants and deaths. At each time step, individuals in the population are aged and their incomes, expenditures and stocks of assets and liabilities change as a function of age and past accumulations. It is not sufficient to keep track of a sample because future sample weights would be subject to (unknowable) change.

A second approach might make use of the concept of household archetypes. All individuals in the population would be assigned to one of 20-30 household archetypes where archetypes would be differentiated by age as well as income expenditure patterns such. At each time period, a fraction of the individuals in archetype 'x' would stay in 'x' and the rest would be transitioned to other archetypes. Of course some of the transitions might not be possible. For example an individual household belonging to older archetype could not transition to a younger one.

Research Outcomes

1. Development of an integrated model infrastructure, v. 1.0, http://placesandspaces.ssg.coop/
2. Implementation of the model for biophysical and limited financial and social spheres.
3. Model infrastructure website and open-source platform
4. Development of financial calibrations, integration finalized in v 2.0.
5. Ongoing scenario development, issue-specific, v. 2.0
6. Data visualizations
7. Issue specific scenarios
8. Commercial spin-off of a GHG emissions model, CityinSight
9. On-going private/public sector business partnership between whatifTechnologies and Sustainability Solutions Group
10. Model infrastructure presentations to FCM, ICLEI, CPI and QUEST
11. Commercial spin-off model, CityinSight, http://cityinsight.ssg.coop/

Conclusion

While an ambitious and visionary project, and without fully integrating the economic/financial imperatives, nevertheless, significant outcomes were achieved. The model infrastructure has now been built and does integrate the biophysical and some meaningful financial and social dimensions. This project could be considered analogous to the development of GIS. When GIS was first being developed it was being driven by those passionate about geographic mapping tools and was limited to the sphere of the expert. As the software became less clunky and value from using the tool could be seen by professionals it moved into the sphere of the novice and became a tool that planners relied on as part of their work process.

Thus, the infrastructure was released as open source and as version 1.0. Although currently it remaIns in the realm of the expert, the project team, now led by Yuill Herbert from Sustainability Solutions Group, intends to keep refining the infrastructure and achieving full integration of the ecological, social and economic imperatives of sustainable community development in subsequent versions. Ideally, the model infrastructure will become as useful to local government decision makers and as ubiquitous as GIS in the future.