3-14-2013

A regional spatial-retrofitting approach to geovisualise regional urban growth: An application to the Golden Horseshoe in Canada

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A regional spatial-retrofitting approach (RSRA) to geovisualise regional urban growth: An application to the Golden Horseshoe in Canada

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Abstract

Understanding urban change in particular for larger regions has been a great demur in both regional planning and geography. One of the main challenges has been linked to the potential of modelling urban change. The absence of spatial data and size of areas of study limit the traditional urban monitoring approaches, which also do not take into account visualization techniques that share information with the community. This is the case of the Golden Horseshoe in southern Ontario in Canada, one of the fastest growing regions in North America. An unprecedented change on the urban environment has been witnessed, leading to an increased importance of awareness for future planning in the region. With a population greater than 8 million, the Golden Horseshoe is steadily showing symptoms of becoming a mega-urban region, joining surrounding cities into a single and diversified urban landscape. However, little effort has been done to understand these changes, nor to share information with policy makers, stakeholders and investors. These players are in need of the most diverse information on urban land use, which is seldom available from a single source. The spatio-temporal effect of the growth of this urban region could very well be the birth of yet another North American megacity. Therefore, from a spatial perspective there is demand for joint collaboration and adoption of a regional science perspective including land use and spatio-temporal configurations. This calls forth a novel technique that allows for assessment of urban and regional change, and supports decision-making without having the usual concerns of locational data availability. It is this sense, that we present a spatial-retrofitting model, with the objective of (i) retrofitting spatial land use based on current land use and land cover, and assessing proportional change in the past, leading to four spatial timestamps of the Golden Horseshoe's land use, while (ii) integrating this in a multi-user open source web environment to facilitate synergies for decision-making. This combined approach is referred to as a regional-spatial-retrofitting approach (RSRA), where the conclusions permit accurate assessment of land use in past time frames based on Landsat imagery. The RSRA also allows for a collective vision of regional urban growth supporting local governance through a decision-making process adhering to Volunteered Geographic Information Systems. Urban land use change can be refined by means of contribution from end-users through a web environment, leading to a constant understanding and monitoring of urban land use and urban land use change.

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1. Introduction

Canada, one of the most diverse countries on Earth, has a unique abundance of natural landscapes, mineral resources, wetland and forest systems as well as the largest freshwater resources in the planet. However, Canada is quite concentrated concerning anthropogenic activity, with certain regions in Northern Canada, for example, remaining largely uninhabited. While governance is increasingly investing in the peripheral regions of the country, population concentration is still predominant in the regions where climatic conditions are suitable for anthropogenic activity. This anthropogenic activity has led to a series of concerns relating to the consequences on the acidification of aquatic ecosystems, mostly resulting from human pressure (Dillon et al., 1987). The massive increase in population dynamics and the resulting patterns in the rapid urban expansion (Brueckner, 2000), has been linked directly to the growing Canadian economy, leading to new migration patterns, and economic growth around the major metropolitan areas of Canada (Moore and Rosenberg, 1995). One of these regions is Ontario, in particular southern Ontario, where within a rather small area a total of 26 per cent of the Canadian population is present, and is strongly linked to commuting infrastructures between cities (Axisa et al., 2012). This region is growing and changing dramatically, and holds as of 2011, a total of 8.67 million people. This number is rapidly on the rise, and while it entails a unique opportunity of continued economic growth for Canada (Leung et al., 2012), it also deems the first signs of what can be defined as a megacity. Megacities bring excessive urbanised regions, and have unforeseen impacts on the geomorphology of the landscape and ecosystems (Zipperer and Pickett, 2012), that must be carefully managed (Li et al., 2010). Planning and offering diversity of ecosystems and land use types is, therefore, paramount to increase sustainable development, health and well-being (Tzoulas et al., 2007). It is also important to efficiently explore available resources without jeopardizing the carrying capacity of the region, while offering a sound understanding of land use change simulation (BenDor et al., 2013) to avoid the negative consequences of regional urban sprawl. In this sense, remotely sensed imagery (Bhatta, et al., 2010) and Geographic Information Systems through combined landscape and spatial methodologies (Kiran and Joshi, 2013) bring fundamental tools for regional support systems of urban areas (White and Engelen, 2000). This is additionally fostered by the need of integrated modelling approaches that take advantage of spatial data availability and remotely sensed imagery and design systems that evaluate and visualize the effects on the natural and urban environment (Williams et al., 2012). These systems should be open to the public, and through geovisualization techniques should assist in the implementation of integrated knowledge systems (Cash et al., 2003) concerning land use over time. In North America, priority is driven by the abundance of available land and economic demand of population growth in a country like Canada. The market conditions have been favourable for urban sprawl, and only recently have become part of the larger framework of land use change that should be formally understood and quantified to generate more sustainable urban regional and peri-urban environments. Understanding the impacts of urbanisation on natural and cultural heritage are essential as it sets out opportunities for future economic growth, without jeopardizing the environment (Vaz, et al., 2012a). Regions are expected to change dramatically and should, therefore, be monitored adequately by means of geoinformation technologies (Stellmes et al. 2013). A tension has formed between future anthropogenic activity and preserving environmental sustainability (Lyle, 1994) rendering the natural capital of the land in expanding regions through growing understanding of the existing ecological changes in face of change (Haines-Young, 2000). As sustainable development is derived from the regional understanding of the harmony of landscapes, biodiversity and ecology over space, Geographic Information Systems have shown to be the ideal fit to measure spatio-temporal dynamics, provided the incorporation of land use data and remotely sensed imagery to better understand the consequences of the impacts of land (Vaz et al., 2011). It is especially ideal when these systems entail the possibility to be used, shared and assessed by a wider community, as well as when they include the integration of spatial decision support in a regional framework. This understanding is often limited to restrictive regional policy visions. However, it must be rearranged from a bottom-up approach, where the myopic local analysis opens up to the needs of regional demands and brings a deeper understanding of spatio-temporal dynamics. This becomes offered through the contribution of researchers, planners and volunteered geographic information contributors, leading to more efficient policies. This is the role of the regional spatial-retrofitting approach (Figure 1).

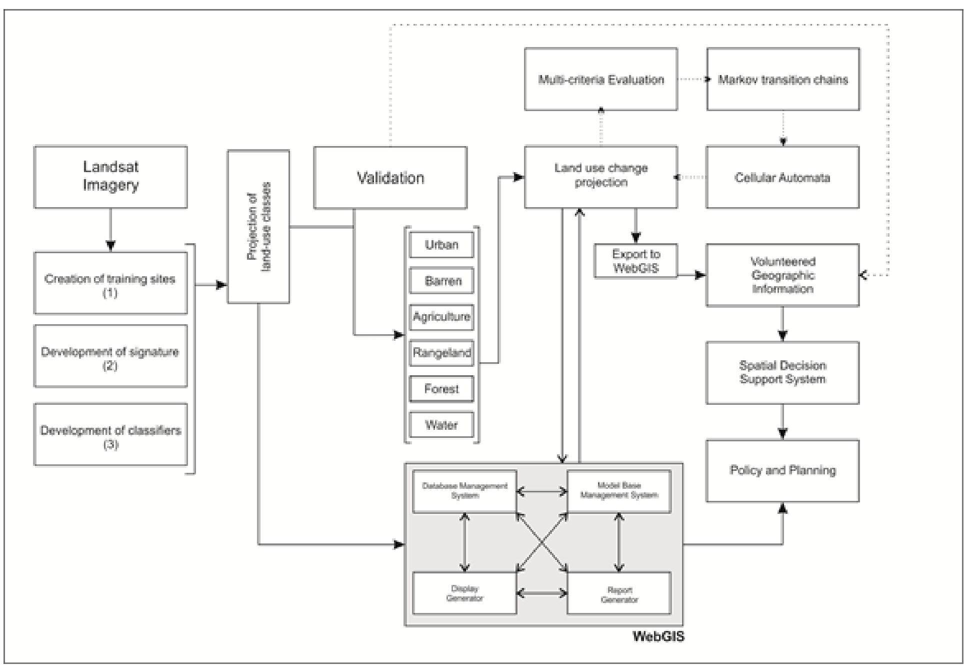

Figure 1 – Integration of the RSRA Framework

The model takes advantage of local governance and spatial decision support systems that envision regional land use dynamics based on available satellite imagery on ubiquitous models of scenario generation, that monitor and present future land use dynamics allowing for spatio-temporal conclusions. There is an integration of non-linear stochastic models in the predictive modelling output to support spatial decision making via Spatial Decision Support Systems (SDSS) for policy and planning. This is achieved by a natural evolution of Armstrong and other's (1986) SDSS proposed model, but brings to light the possibilities of using Volunteered Geographic Information (VGI) and WebGIS. The microcomputer solution proposed by the authors in the 1980's allows the integration of a web 2.0 platform. This brings the RSRA framework to a larger audience and provides a community driven solution and therefore, making it more complex. This allows for adaptation and readjustments to be made on the fly for spatial data and land use information. But most importantly, it allows for a collectively integrated support system from a planning and regional development perspective that considers regional scale, rather than local policies leading to spatial exploratory analysis (Dragicevic and Balram, 2004). This allows us to take advantage of available non-linear spatial techniques, and contributes to regional decision making (Vaz et al., 2012b). In regions such as the Golden Horseshoe, the unique opportunity at the provincial level to foster emigration, tourism and preservation of its rich and abundant heritage justifies a spatio-temporal understanding of the dynamics of change and exportation of them to a collective regional vision. The regional sustainability dimension explored by Gadal (2006) shows the applicability of taking regions such as the Golden Horseshoe and applying an empirical perspective to land use modelling to enable decision-makers to better understand methods for a sustainable future. .The objective of this paper is to contribute to (i) a multi-temporal understanding at regional level of the land use / land cover in the Golden Horseshoe in Canada, (ii) foment the usage of freely available remotely sensed imagery to define land use cover for different regions throughout the world, while showing that integration of support systems such as WebGIS can help decision-making and (iii) foster the notion that landscape metrics aid in the design of more sustainable futures, bringing quantified tools to the context of regional strategies and urban planning, besides the traditional applications in ecology, and finally (iv) offer a scientific outlook of applied research for the Canadian regional agenda, concerning land use and land cover change systems and their applicability at regional level.

2. Study Area

The Golden Horseshoe is located at 43.6°N 79.73°W, and is one of the most dynamic socio-economic regions of Canada. It is located in Southern Ontario, and it stretches its boundaries south to Lake Ontario and Lake Erie. It is thus, a particularly interesting area because it is surrounded by fresh water. It has been found that freshwater shore zones are amongst the most ecologically valuable places on the planet, and the complex interactions that exist within their biodiversity have been heavily damaged by anthropogenic activity (Strayer and Findlay, 2010). It cradled over 8.1 million people in 2006, meaning it is home to two thirds of Ontarians and to one quarter Canada's total population (Statistics Canada, 2006) (Figure 2). One of its key characteristics is the urban concentration, (Edmonston et al., 1985) counting as one of the most concentrated economic regions in North America, with one of the largest growth rates alone being in the Greater Toronto Area (GTA) (Yeates et al., 2011). The population of the Golden Horseshoe is rapidly increasing with a growth rate of 8.4% per annum, and some of the fastest growing municipalities include Vaughan, Brampton and Milton. Milton had a growth rate of

71.4% in 2006 (Statistics Canada, 2006). Integration of Landsat satellite imagery from the United States Geological Survey (USGS), allowed for a supervised classification of the different land use/cover classes based on Landsat and TM data with some interesting results for

Figure 2 – Study area – The Golden Horseshoe Core Area

classification purposes, as discussed by (FitzGibbon and Chen, 2008). The land use classes were classified into (i) urban/built-up, (ii) agriculture, (iii) forest, (iv) rangeland and (v) waterbodies. These classes were taken into account as to keep spatio-temporal consistency and diversity in regional applications. This diversity, was especially welcome in a context of the collective WebGIS, where the depiction of the continuous flow of the changing land use patterns within the

Golden Horseshoe is of interest concerning different sets of land use. The available land use classification for 2006 was used as an ex-ante classifier to provide ancillery information on the accuracy and generalization procedures of our land use classification and to guarantee accurate classification. An overall accuracy of 80% was accomplished in the land cover classification. From a regional perspective, the multi-temporal analysis of land use poses interesting challenges not only to planning, but also to understand the aggregate of land use change function closer to previously existent urban areas, and regions which are in the suburban location of the rural fringe.

3. Methodology

3.1. Land use and Land cover in the Golden Horseshoe

Land use classes were developed by different categories based on composite mosaic of Landsat imagery. A nomenclature for land use was defined by the extraction of land use classes for Ontario in 2006, and correlating land use classes available for Toronto in 2010. The nomenclature was standardized as to have a consistent description for all the timestamps, corresponding to 1980, 1990, 2000 and 2010. The choice of a 10 year interval, resulted from available Landsat imagery within a three to four year span, where the paths and rows for the Golden Horseshoe were available. The merged spatio-temporal tiles, allowed extracting a polygonal shape mask which was kept constant during the entire thirty years span (Figure 3)

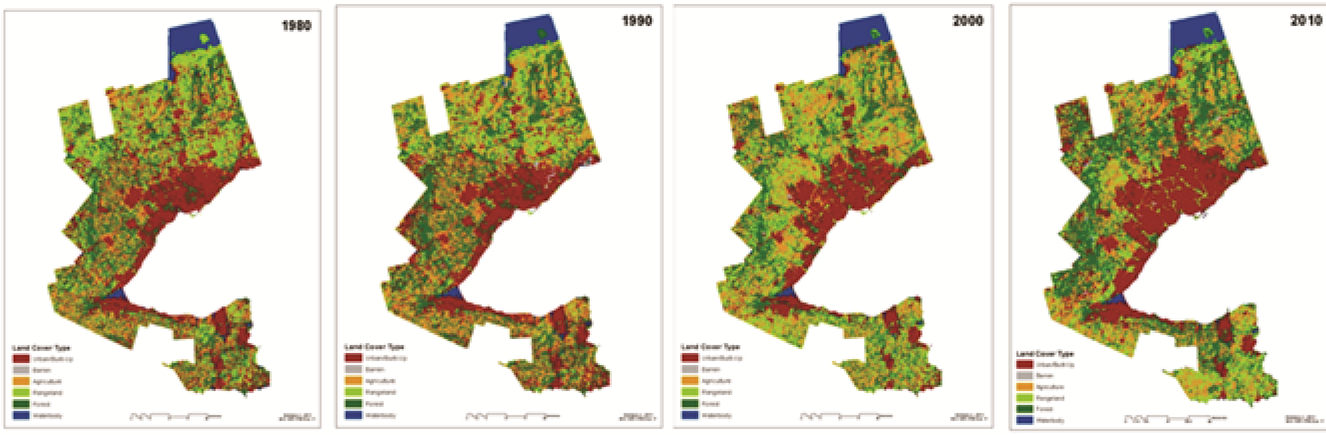

Figure 3 - Supervised land cover classification of the Golden Horseshoe from 1980 to 2010.

This technique of filtering, concentrating and generating a nomenclature over a series of different time stamps for land use was widely applied in the CORINE Land Cover project in the beginning of the eighties and is currently in its third edition. The availability of four timestamps for any land use classification, as discussed in Vaz and others (2012b), allows the generation of a better statistical validation on the accuracy of both classification and prediction. In this sense, it is also important to mention that Landsat satellite imagery is an accurate source to measure spatio-temporal change at the regional level, as explored by Bedard and others (2007). This is particularly the case when focusing not only on a multi-temporal assessment, but also when assessing the regional dynamics of land use change, benefiting from a more global vision of geographical change dynamics at the regional level. An supervised classification was conducted based on a set of samples generating a significant amount of land use classes. Six classes were considered as main classes of land use, and reflect both the most relevant environmental characteristics of the topology of land use in the Golden Horseshoe. The unsupervised classification algorithm was constructed for all timestamps, namely for 1980, 1990, 2000 and 2010, and for each individual time stamp, the following steps were taken carefully into account:

(i) identification of training sites resulting from similar values in the electromagnetic spectrum and their reflectance attributes, (ii) classification at a pixel level of each land cover class, and finally, the production of a thematic map (Lilesand et al., 2004), consistently identifying land use and land cover for the regional of the Golden Horseshoe in Canada. Although Canada is quite advanced in spatial data availability, some concerns exist in the usage and organization of land use data, where no generalised repository exists that contains and allows analysis of the land cover data for the Golden Horseshoe. At the regional level, such data availability would be of utmost importance to permit the execution of advanced spatio-temporal studies both in line with research as well as policy makers. There is an intrinsic need for the sharing of spatio-temporal land use information among the community and there is a demand for integrating a WebGIS interface, which we have successfully explored by offering the different land use covers available for free download. This again, was inspired in the CORINE Land Cover project, as well as in the fact that our approach, of building 1:100,000 maps does allow low-budget assessments of land use change and delivers up to date information for scientific purposes. The satellite imagery used were downloaded from the USGS Earth Explorer (http://earthexplorer.usgs.gov/), and Landsat TM data was converged and mosaics were built for each temporal land cover.

3.2. Geovisualization of Urban change

Urban growth geovisualization allows for an accurate understanding of the spatial changes and morphology by interpreting possible future outcomes from an empirical standpoint (Clarke, 2003). In this sense, Landsat imagery allows a composition of generating timestamps to depict urban change, but it is up to non-linear modelling techniques to allow the assessment of land change (Pontius et al., 2008) enabling the possibility to construct possible future outcomes at the regional level of urbanisation processes (Jantz et al., 2010). Thus, while satellite imagery allows detection of change patterns for large regions and classification of urban land use types (Xiao et al., 2006), it is the urban growth modelling framework that assesses the dynamics of change, by means of comparing in a WebGIS environment the different land use covers for urban land.

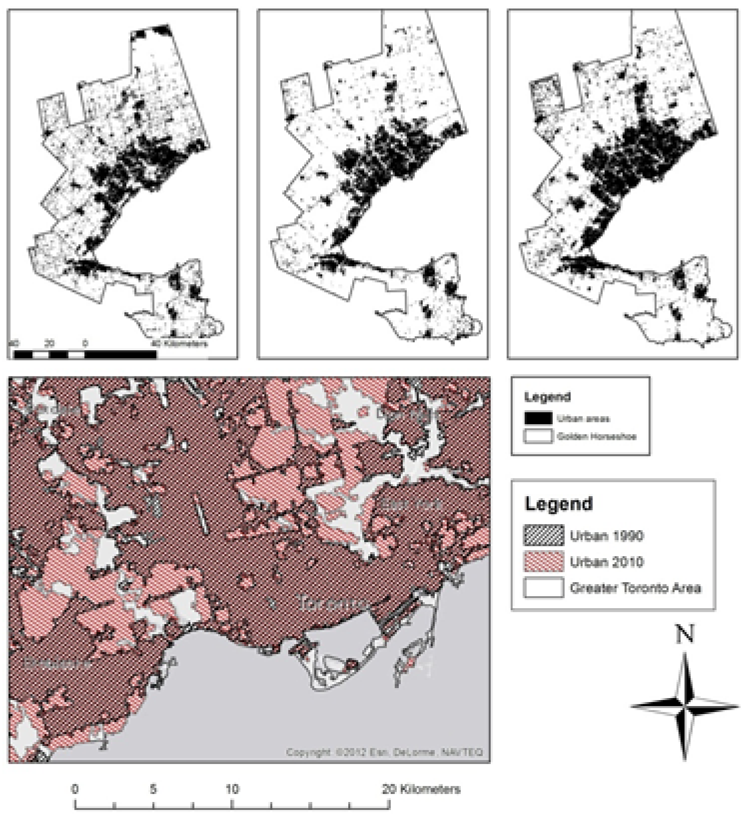

Figure 4 – Visualization of urban change in the Golden Horseshoe (1990-2010)

3.3. WebGIS

By incorporating a WebGIS as part of the urban land-use analysis we will enable open access to information, promote community participation and support decision making processes. The ability to access information for free 24 hours a day, 7 days a week using a standard computer and web browser has become the status-quo. End-users expectations have been furthered as modern technology enables more visually compelling and interactive online presentations without the need to install additional software. Web-based mapping applications are a product of this innovation and web users are becoming more savvy to them. These applications promote interactivity and create a sense of relation for end-users due to their geographic nature and geo-location. To satisfy the needs of this project the open-source Web Mapping Platform Leaflet has been chosen. As modern web technology is able to display content dynamically using a map-based web applications, so too can it allow end-users to update this information if they deem necessary. By facilitating the ability for end-users who have a local knowledge to update information, content is able to more accurately represented. Editors of online content will be able to track their changes by creating an online account. Information will be immediately displayed on the map for other viewers to see. Historical information will also be maintained showing the evolution of changes made. In addition, the ability to revert changes back to a previous points in time will also be possible in case an error is made. Supporting decision making processes will be achieved through the WebGIS using a combination of features. Firstly, the ability to interactive with the map by targeting a specific area of interest and zooming-in allows them see more granular data. By adjusting controls such as filters, displayed information is able to be customized to satisfy their specific needs. And once the desired data is displayed on the screen, it can be downloaded in a usable fashion for further research and analysis.

4. Discussion

The RSRA is an applied method of spatial analysis and planning at the regional scale and has provided an integrated approach not only for land use analysis, but for collective geovisualization and information sharing. The model presented serves as a useful tool in planning and development in the Golden Horseshoe, which has been an area of interest to the Government of Ontario in the past decade. Figure 3 shows land cover change in the region in the past 30 years. The urbanization is identifiable and the most recent decade shows much faster growth than the previous three decades. This spatial information would prove useful for the Growth Plan for the Greater Golden Horseshoe, which was approved in 2006, and strives to revitalize downtowns and communities, while reducing urban sprawl and protecting the environment (Ministry of Infrastructure, 2006). The RSRA method allows for analysis of past, current and future trends in anthropogenic activity, and therefore could be used in the planning process. The tool is designed to help planners to understand the geographical relationship between the human and natural environment. Within this, planners can specifically begin to understand the relationship between the region's economic, human and physical resources. Ontario has a combination of quality soil and suitable climate that makes Southern Ontario the best place for agricultural production in the country (Caldwell and Stewart, 2005). Therefore, preservation of farmland in the region is important, and the monitoring of the land cover is one major component. The RSRA can also be used to identify areas with the capacity of economic growth. The town of Milton has undergone rapid population growth over the past 10 years, with a growth rate of 56.5% reported in 2011 (Statistics Canada, 2011). This urban growth is captured in the RSRA model and can be quantified to understand the nature and extent of it to ensure a sustainable economic approach to growth is taken. The infrastructure and services are being outgrown by the rapid population growth, and this is why studying the settlement pattern is so important to ensure development is served equally, effectively and sustainably. The RSRA method also allows planners to analyse the interactions that take place within urban areas as well as between them. Looking at growth patterns over time allows linkages among settlements and the degree of access that they have to one another to become apparent. Analyzing the rural-urban relationship is crucial to understanding regional development in the Golden Horseshoe. Transportation is one of the major focuses of Ontario's Growth Plan, and incorporating models for a long-term solution is needed for decision-support. Despite the attention of models for transportation modeling, there are a large number of jurisdictions within Canada that adopt outdated models or do not rely on integrated land-use or transportation modeling for decision-support (Hatzopoulou and Miller, 2009). Without the spatial dimension of regional planning in the Golden Horseshoe, the process will be costly for the government. A method like the RSRA reduces the uncertainty of future trends in an interdisciplinary way by detecting changes through time. As seen in Figure 3, urban growth in the past 30 years is getting closer to the greenbelt, and monitoring this growth is becoming even more essential. The WebGIS aspect of the RSRA promotes the interdisciplinary of studying land use and land cover change over time. Users can freely enter and access diverse information, which could lead to further enhancement of public involvement in environmental management (Kearns, F. et al., 2003).

5. Conclusions

Spatial equilibrium within regions are linked to the importance of generating urban hubs, that allow for economic and regional growth, and often underlie a monopolic competition, leading to spatial agglomeration (Fujita and Krugman, 1995). This spatial structure found in urban areas is closely linked to the knowledge and skills that urban regions can foster as productive hubs of generating significant contributions to learning and innovation, and where spatial organization of agglomeration may be very useful in an urban context (Cooke and Morgan, 2000). It is especially useful in an age where a collective approach residing on information sharing must be fostered as to plan anthropogenic activity at regional and local level. Innovation and technological advances therefore, allow for the creation of more sustainable regions, while fostering an increase in production, and also inspires investment and a causal relation of immigration patterns in what Wolfe defines as the 'Schumpeterian hubs' of Canadian cities (Wolfe, 2009). This has been particularly the case of Canada, where the changing urban landscape can be measured by means of GIS technology. Also, the regional challenges faced in urban areas given the pressure on the carrying capacity of humankind, have led to some concerns on the sustainability of continued pressure on rural areas, as well as the conversion of natural habitats and ecological sustainability (Hathout, 2002., Vliet et al., 2009). It is however not an issue of reshaping and redesigning the city, but much rather, taking advantage of the different institutions that partake in the collective process, as explored by Sancton (2008) and adopting bottom-up approach for Canada at the provincial level. Sustainable environmental development is also fostered by understanding in a collective sense, the intrinsic urban dynamics in regions as the Golden Horseshoe. From an economic perspective, this allows for a maximization of knowledge flow for potential investors in the region, helping collectively to promote sustainable policies through the adoption of the spatial-retrofitted methodology. The importance of regional preservation and environmental concerns have been outlined in the leadership of the Conservative Prime Minister Stephen Harper, bringing as an example the importance on how

Canada must cope with a changing land and environment, due to unpredictable reasons such as climate change, land use transitions and population increase. The Golden Horseshoe from a spatial economic perspective, represents a polarized space where central place theory plays a unique importance, because Toronto is becoming increasingly one of the major hubs in North America for economic growth, which also spans out to the Greater Toronto Area. From an economic perspective, it is of utmost importance to follow this growth, and use available tools found in the geographical rationale to collect information, and retrieve spatial knowledge for planning purposes. The RSRA approach tackles precisely these relations, by means of implementing and using WebGIS solutions as tools to retrieve land use dynamics over time, and by interpreting remotely sensed information. It has become more evident for planners and governance to reflect on a spatial perception of land use change, while rendering better solutions for sustainable land use changes. This paper has discussed an integrated approach for using WebGIS through remotely sensed imagery to extrapolate land use, and has reflected on the changing land use in the Golden Horseshoe. The implementation of a WebGIS in a decision making context further allows for the understanding and reflection on the future challenges such an active region faces, and that spatial economic rationale can foster a better and more accurate decision process when linked to the correct set of tools, such as advanced spatial information, when interpreted from a spatio-temporal perspective.

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