COMMUNICATING FUNCTIONS AND IMPACTS TO URBAN COMMUNITIES: AN ONTOLOGY FOR THE INFRASTRUCTURE CONSTRUCTION INDUSTRY

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ABSTRACT

Meeting the community's needs requires a focus on communicating project functions as the key to enhancing their participation in infrastructure planning and design. Earlier work has established that the representation of knowledge through ontologies can be an effective means of employing social and semantic web technologies as a support platform for community engagement. This research builds on the aforementioned proposal for a semantic community empowerment framework.

The current research revisits the representation of product function in the context of construction projects. The resulting representation aims to overcome the limitations of the traditional representation by augmenting economic, cultural, environmental and political dimensions to functions and impacts which are portrayed as complex entities. These dimensions involve a representation of non-tangible and often non-measurable components of utility to which members of the public can relate; hence enhancing three-way communication as part of the participation process.

In this paper, the ontology design is documented through a demonstration of a number of concepts: construction products, their functions and impacts, and communication channels. Furthermore, the main services of the Application Programming Interface (API) are discussed as a standard method for exposing the ontology to third-party software developers. Finally, a sample application is proposed as a validation of this semantic framework.

Keywords: Knowledge Management Ontologies, Community Empowerment, E-society Apps, Construction Functions, Effective Communication

1. INTRODUCTION

Sustainable design and construction have evolved to a user-centric stage at which an integral element of project success depends on meeting the community's needs (Jankowski, 2009; Hoernig et al., 2005), occasionally expressed in terms of goals that can be intangible and difficult to further express in solid engineering design terms. Attaining this community-based level of infrastructure planning requires a focus on communicating project functions as the key to enhancing community participation in the planning and design process. In earlier work, it has been established that the representation of knowledge through ontologies can be an effective means of employing social and semantic web technologies as a support platform for community engagement (CE) in the e-society era (Kinawy and El-Diraby, 2010). This research builds on the aforementioned proposal for a semantic community engagement framework.

The current research revisits the representation of the role played by infrastructure projects and their components, particularly what is referred to in this paper as the *function*. The function of an infrastructure project component is exposed as an important element in determining the *value* of a product and its contribution to the sustainability of a project in the context of planning, design and construction. The resulting representation of design alternatives overcomes the limitations of the traditional representation of functions in manufacturing and information systems through augmenting economic, cultural, environmental and political dimensions to the concepts of functions and impacts. These dimensions facilitate a representation of non-tangible and often non-measurable components of utility with which members of the public can relate in different contexts; hence enhancing three-way communication and the overall participation process. Furthermore, this design follows the mandate of context-sensitive design by considering social, cultural, environmental and economic aspects as design objectives rather than constraints. Construction practitioners should find the eSociety framework fairly familiar as it incorporates many of the main concepts and associated hierarchies encountered in Environmental Assessments and during the formulation of FAST diagrams for value analysis.

In this paper, the definition of a function (role) is presented along with its representation in an ontology. The ontology design is documented through a formal taxonomy of construction products, their functions and impacts, and relevant communication channels. The implementation of the ontology is formalized in OWL (Web Ontology Language) as a collection of entities, relationships and axioms. The application of this ontology can be demonstrated through a number of methods including a standalone or web-based software application. However, this paper proposes a prototype design to aid in integrating the ontology into an App Store to facilitate application vending. This process is facilitated through a number of services that form the Application Programming Interface (API) as a standard method for exposing the ontology to third-party software developers in an extensible manner. Finally, a sample application is proposed as a validation of the framework as well as opportunities for expansion.

2. BRIDGING THE GAP

The academic and industrial literature clearly points to some deficiencies in the process of community engagement (CE) and the perception of its effectiveness (Li et al., 2012; Besley, 2012). Such shortfalls can also manifest themselves in encompassing processes such as Environmental Assessments (EA). Reports from the field cite a number of shortfalls such as the Residential and Civil Construction Alliance of Ontario (RCCAO) report which refers to an average delay of almost 20 months and reveals a lack of effective change as a result of implementing the mandatory CE process (Zechner, 2010). Supplementary evidence also suggests that a focus on communication, representation and relevant technologies can address this gap (Bugs et al., 2010; Roth et al., 2004). This section begins with an emphasis on the need for an integrated communication framework. The discussion builds on the premise that the role of modern public engagement tools in the move from unengaged consultation in planning and design to public empowerment is essential but not sufficient. In addition to independent tools, integration is needed through a platform that focuses on content and the perception of this content by users under a variety of contexts. On the theoretical level, CE is perceived as a standardized spectrum of means for empowerment, yet several solutions are offered on the practical level.

While earlier literature outlined deficiencies in the technology used for communication and during consultations in general (Al-Kodmany, 2002; Al-Kodmany, 1999; Sanoff, 1990), more recent studies show that there is a high proliferation of new technologies in CE (Brabham, 2009; Nash, 2009), ultimately providing evidence that these tools are, to an extent, readily available. An examination of these tools revealed three main categories of features:

- **Visualization**
  Tools that enable the viewing and editing of 2D and 3D images and other media such as videos. More advanced visualization tools also integrate virtual reality and spatial maps which offer a more realistic experience. In addition, maps and lightweight GIS applications can add rich spatial data as layers.
  Examples: CommunityViz, Google Earth, Second Life
- **Interactive simulation**

A collection of interactive tools that provide users with an opportunity to test scenarios and validate their outcomes. These tools often use economic models, role play and gaming platforms to model planning scenarios. The models are useful in facilitating the understanding of tradeoffs necessary in the allocation of funds and resources. Users are able to employ their particular learning styles at their own pace.
Examples: UrbanSim, Urban EcoMap

- **Collaboration, social media and crowdsourcing**
  Dynamic platforms that easily coexist with other tools. They provide users with channels to connect with other users and build their social network that help them navigate the information space. Social media often employ prediction algorithms to make recommendations for content and potential network contacts. Together with crowdsourcing platforms, social media provides a way for collective feedback taking into consideration that people tend to seek indicators of where their opinions stand with respect to others.
  Examples: Engagement HQ, Facebook, Twitter

Scholars in the field often face the daunting task of classifying a commercial tool under one of the aforementioned categories. This stems from the nature of these tools that commonly incorporate more than one category of features. For instance, maps and street views are very popular due to their proved effectiveness in tapping into the spatial cognitive nature most people possess (Bugs et al., 2010; Al-Kodmany, 2002). While early GIS applications were heavy in processing and difficult to learn, current web-based maps are simple, lightweight and easier to use. Nevertheless, most commercial toolkits will rely on one of the categories more heavily. Following this method, products will rather be classified by the features they focus on: the tools that comprise the primary part of the product (Table 1).

Table 1: An outline of current tools and their primary features

Tool Category	**Examples**	**Benefits**	**Limitations**
Visualization	CommunityViz, Google Earth, Second Life	Utilizes the public's preference for using visual references	Complexity of operation and data intensity
Interactive simulation	UrbanSim, Urban EcoMap	Provides an opportunity to test various scenarios and understand tradeoffs	Quality of feedback is limited by an understanding of the simulation
Continuous collaboration	Engagement HQ	Enables 24-hour feedback and collective deliberation between members of the public	The generated feedback can create an overwhelming amount of unstructured information
Social media and crowdsourcing	Open311 API, Facebook, Twitter	Utilizes successful elements such as peer ranking and user profiling	May bias feedback towards tech-savvy participants

The emergence of these tools raises an important question as part of a quest to enhance the effectiveness of CE: what is the best combination of existing tools or new features that would nurture a more effective process? As established earlier, any bridging effort in CE would have to address communication (Kinawy and El-Diraby, 2010). This aspect of communication is not only limited to how communication happens but also what is communicated and the context of interaction. The means of communication are an important factor that involves a move towards three-directional duplex communication. Another aspect is increasing the diversity of the forms of media involved in communication with the public and between members of the public. However, these two aspects cover how communication is achieved and not the more important element of selective communication ov relevant content and how the level of understanding is enhanced through meaningful communication. Cognition and understanding within communication can be affected by noise, and necessitate the consideration of background context as a primary factor that influences communication. Information is perceived differently by different people based on their previous experiences and knowledge, and the context of interaction (for example, a municipal election year on which certain decision aspects are more sensitive). Such benefits are highlighted in the context of role and impacts in the following section.

3. COMMUNICATING ROLES AND FUNCTIONS

Infrastructure construction as an industry has traditionally emphasized the technical dimensions of planning and form, widening the scope to the function of a product provides the public and planners alike with an opportunity to look at the bigger picture that extends beyond physical dimensions, demand forecasting and costs. The role played by a product naturally explains the need for this product, some of its dependencies and its overall value to the project and society. This sort of analysis is common in projects that involve Function Specification; a technical activity with an output that is seldom exposed to the user's side. On the other hand, products are often perceived by users through their impact: effects during and post construction which are represented as a cost that should be minimized. Thus, communicating the role of a product within a project enables the formulation of value for various alternatives while considering the tradeoffs. Nevertheless, the consideration of tradeoffs is also heavily dependent on impacts which often carry a negative connotation as evident in the case of high noise levels, traffic blockage and harmful air emissions. Considering the role and impact collectively as the product's *influence* can provide a powerful tool for sustaining the design of alternatives and supporting decision-making.

1.1 The Knowledge Component

Aiding encoding and decoding within the web-based communication process requires the formal representation of knowledge that is inherent to the process. One of the standard methods of representing knowledge is an ontology. The ontology presented in this work, eSocOnto, is one which represents the main entities in CE and their relationships as well as the rules that govern them. In this paper, a number of concepts, relationships and axioms will be highlighted.

1.1.1 Formulation Method

This research primarily but not exclusively follows the methodology outlined by Gruninger and Fox (1995). This methodology focuses on extracting requirements from the application perspective. A set of competency questions outline the necessary concepts and dictate the relationships and axioms. Together, these required entities ensure the ontology provides the proper knowledge representation in its field. While competency questions do not appear in the formalization or coding, they are a central component of ontology formulation and a primary ingredient for validation in the later phases of ontology development. The formulation of eSocOnto also incorporated a bottom-up approach based on the content of public meetings, design documents and official guidelines, after the competency questions were formulated.

1.1.2 Competency Questions

The ontology should satisfy two basic application scenarios: 1) every function and impact can be linked to a product, actor and/or communication channel; and 2) actors can adhere to different profiles based on their attributes, and the type of project they are engaged in. Based on these requirements, the following competency questions will be among those used to generate the entities and ultimately validate the ontology:

1. What are the best communication channels and techniques for each function?
2. What are the suitable communication channels for each profile of communicating parties?
3. What contexts, such as culture, affect the perception of function?
4. How do these functions relate to various profiles, product attributes and communication channels?

5. How can concepts like vitality, constructability and livability be supported and verified through the social web and user profiles?
6. How can a different set of product elements produce a specific function?

1.1.3 Entities

The primary block of eSocOnto is the taxonomy of concepts. This taxonomy provides a hierarchy of entities and their classification which highlights common attributes and also properties that differentiate entities. Each entity must correspond to a concept. The concepts in this ontology are divided into two main levels: core IFAP (Impact, Function, Actor, Profile) concepts and supplementary relational concepts. Additionally, a number of external but essential fields are included as sources of secondary concepts. These are represented in orange on the outskirts of Figure 1. The figure presents a two-dimensional snapshot of a sphere in which each concept is connected to the other concepts with varying degrees of relational strengths. As shown in Figure 1, the concepts are also divided along two axes. The horizontal axis divides the concepts into a lower product side and an upper community side. The technical product side encompasses a product's attributes, functions, impacts and constraints. The community side represents the social concepts such as a citizen's profile, community's culture and relevant communication channels. The second axis divides the map vertically into a function-based and an impact-centric hemisphere; the two perception dimensions of a product's value. The function hemisphere stresses the relationship between a product's attributes and its function. This layout also emphasizes the relationship between an actor's needs and the perception of a function. The second hemisphere focuses on a product's impact on an actor based on an actor's experiences, activities, goals and interests.

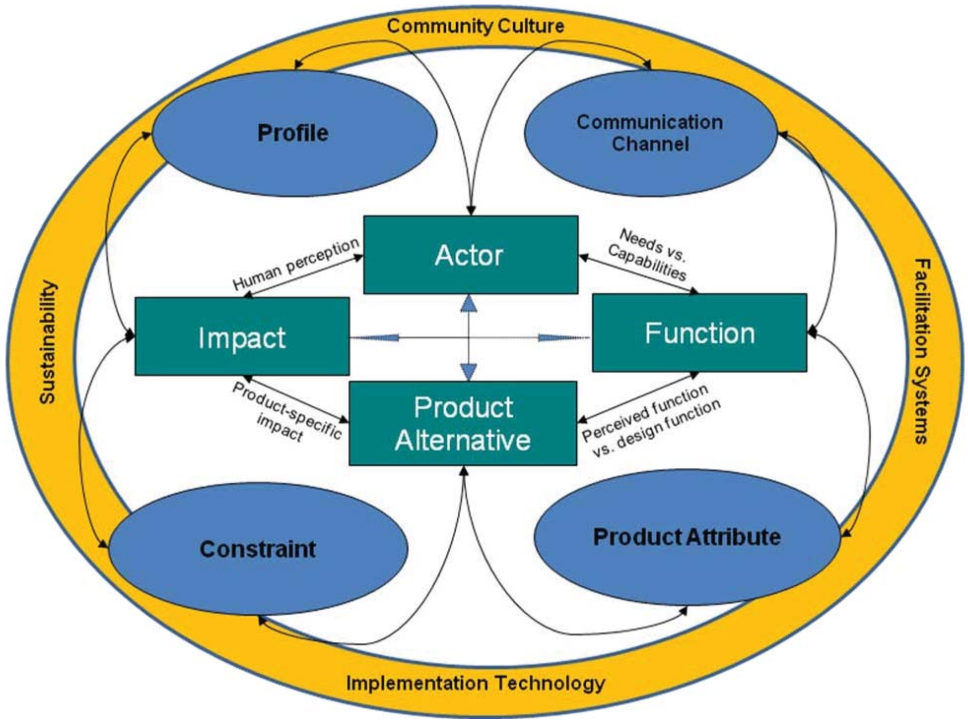

Figure 1: eSocOnto Conceptual Framework

As evident, this ontology is focused on linking all products (infrastructure components) to their role in the project, simply represented through the Function concept at this stage. Functions add the necessary context that enables public input into the infrastructure planning and design process. The structure of this ontology intrinsically includes the Function as a core concept that spawns several modalities. Furthermore, the primary significance of the ontology is manifested in two main themes: 1) carefully selected aspects of product functions should be communicated to different actors to match their interests and knowledge; 2) actors with different profiles will be impacted in unique ways. To address these two themes, the ontology deeply enumerates entities that represent the Communication Channel and Profile concepts respectively. The relationships and axioms forming this ontology also reflect this notion.

1.2 Relationships and Axioms

eSocOnto depends on two basic types of relationships: hierarchical (is-a) and compositional (is-part-of), in addition to more specific relationships that connect the various entities. For instance, Professional Engineer and Resident are both children of the Actor entity through two separate *is-a* relationships. In a different manner, a Dry Well *is-part-of* a Wastewater Pumping Station in a compositional relationship. For the scope of this paper, only a limited number of concepts, subconcepts and rules are included:

- An Actor has one or more Profiles (Inversely, a Profile can belong to more than one Actor)
- Professional Engineer is a child of Actor
- NIMBY (Not-In-My-Back-Yard) is a child of Profile
- Impact is a child of Product Influence
- Function is a child of Product Influence

The relationships that connect the entities are governed by rules that maintain the integrity of the knowledge model. The following set of axioms presents an example of some of the rules that govern eSocOnto.

- An Actor can have more than one Profile but must have at least one default Profile
- Every instance of Product must be related to an instance of Function
- Every instance of Function must be related to an instance of default Communication Channel
- For every instance of Product that has Impact:Noise, Impact_perceived_value is High for Non-Resident with Profile:Rural_Resident

4. IMPLEMENTATION

The ontological concepts and rules described earlier along with the full representation were formalized using OWL which facilitates knowledge representation, inference, and translation to Java classes or alternative classes. OWL was the language of choice for several existing ontologies such as Towntology (Teller et al., 2005), Syndromic Surveillance Ontology (Okhmatovskaia et al., 2009), and 4CitySemantics (Montenegro et al., 2011). The proposed implementation involves integrating the ontology into a software platform on which the ontology constitutes the reasoning unit.

1.3 Software

The proposed software system follows the model of semantic application vending, more widely known as an App Store. Given the pervasiveness of mobile apps, they present themselves as an ideal solution to many urban data needs and a valuable tool for community empowerment. The City of Boston launched an app labeled as Citizens Connect. The apps are an interface for an empowerment framework through mobile apps which engages citizens in various issues around the city, from reporting issues in their neighborhood such as those offered by open311 to more empowering citizens to follow and become more involved in policy decisions (City of Boston, 2012). The emergence of such apps points to their potential in tackling issues in the planning and management of infrastructure. Through these apps, citizens can become better informed and consequently engage in creating solutions. In the age of open data, the success of such apps depends on the availability of reliable data to the public. However, this abundance of data can offer an overwhelming amount of information which needs to be validated and enhanced through a knowledge model.

As shown in Figure 2, the Semantic App Store would aid non-professional app developers in realizing public needs and vending their software to the right users. Thus, the software platform contains two main components: 1) ontological reasoning unit, and 2) App Store (vending software as a service).

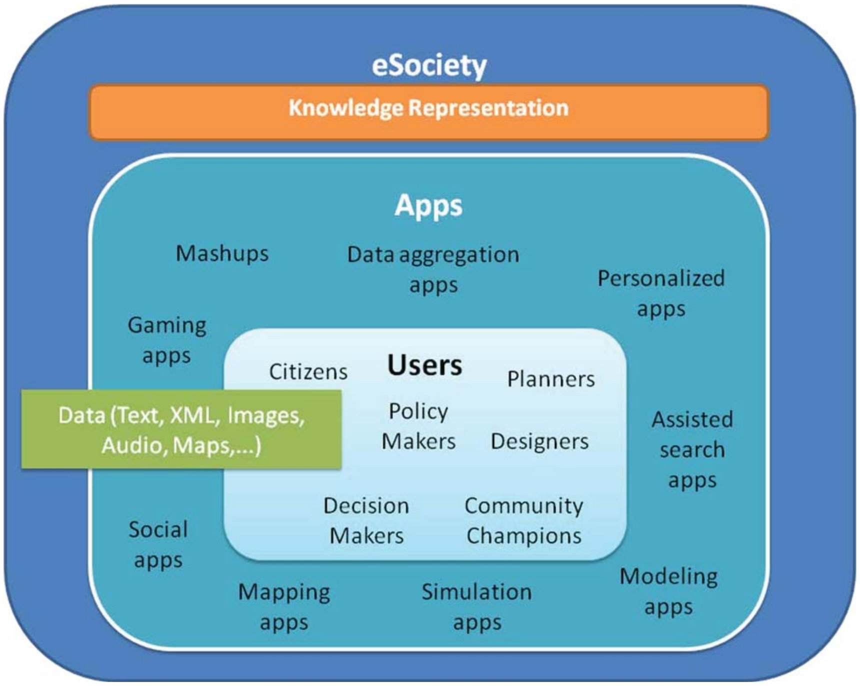

Figure 2: An illustration of the added value of apps and ontologies in eSociety

1.3.1 Reasoner

A designer or planner can distill a variety of information through the reasoning unit supported by the ontology. For instance, a user comment coupled with a user's profile can reveal some context around the functions and impacts referenced in the comment. Consider a hypothetical case, albeit an increasingly common one, in which the City of Toronto is installing bicycle lanes on an arterial road. This case is used to showcase some of the difficulties faced by the public in understanding the complexities of the alternatives and the factfinding process decision-making. The public can also find it challenging to collaborate with others and generate viable alternatives or analyze them without these tools.

Through the user's registration parameters, their interaction on the system, and social network rankings, the reasoner can assign several profiles to each user. For instance, one user can be tagged as a non-resident who only commutes in to the project area during working hours. Another user can be tagged as a NIMBY, a term reserved for citizens who may support the idea of bicycle lanes as long as they are not on the street where they reside. In this case, the reasoner would suggest that similar projects would be presented to the latter through videos and interviews with residents, while the former would be presented with an interactive model to indicate the availability of parking on the street. *Parking* can be discussed as a more abstract concept to refer to surface parking on the street, or the parking capacity of a neighborhood of street. This is another useful feature of the reasoner as it enables the App Store to differentiate such concepts. The aforementioned profiles can be used to group citizens of similar opinion in order to help them collaborate, present them with relevant functions through proper communication channels, and subscribe them to specific apps for further engagement.

1.3.2 App Store

Commercial software vending is an emerging field although its theoretical and practical foundations have existed for decades. The use of APIs can be traced as far back as distributed systems have existed but combining APIs and distributed online service discovery was an innovation that changed the nature of selling and distributing software as a service. For example, the introduction of the Open311 initiative was welcomed as an alternative to traditional 311 services for nonemergency repairs. The associated GeoReport v2 API is now used in applications by more than 30 cities around North America and the world (Open311, 2012). Furthermore, the introduction of App stores, as they have become commonly known, allowed non-professional developers to program with the aim of serving their needs or the needs of their customers, and further market their apps through these stores. Nevertheless, it is a tool that is defined by the limitations of its content, and can benefit from the support of a knowledge base and the social web. The field of mobile commerce investigates the wider range of app store features which fall outside the scope of this paper.

An important component of the proposed App Store is the eSoc API which exposes a number of features to third-party app developers. Rather than simply expose the ontology, the API will expose the following functions:

- List available services
- Provide a semantic vector on demand
- Extract parts of the ontological implementation for sandboxing and eventual update

The functions of the eSoc API can be further broken down into App services, social services and ontological services as outlined below. While App services exhibit common features in current app stores, social and ontological services cover a sector of services less featured in app stores.

- App services
  - Publish a new app
  - Link to existing external app
  - Remove an app
  - List apps by category
  - App discovery
    - Search for an app
    - Automated app recommendation
  - Request an app (provide specifications)
- Social services
  - Comment on an app
  - Tag an app
  - Rank an app
  - Subscribe to an app
  - Unsubscribe from an app
  - Recommend an app to a contact or group
  - Recommend an app for a project
- Ontological services
  - Generate a list of classes
  - Provide a pointer to a class
  - Add new entity, edit entity or remove entity
  - Add new relationship, edit relationship or remove relationship
  - Add new axiom, edit axiom or remove axiom
  - Generate a list of impacts associated with a given product
  - Generate a list of impacts associated with a given profile
  - Generate a list of functions associated with a given product
  - Generate a list of functions associated with a given profile

5. CONCLUSIONS AND FUTURE WORK

This research addresses the communication gap in involving members of the public as important stakeholders in infrastructure construction projects. It is also an attempt at following a trend in which members of the public are engaged as collaborators rather than opposing proponents; consequently, leading a similar trend in infrastructure planning and construction. The eSociety framework incorporates an ontology, eSocOnto, which aligns public needs and their perspective of infrastructure products and services with the functions considered by planners and designers in the early stages of a construction project. Clearly, the eSocOnto is not a decision-making. It rather supports the underlying communication processes that eventually lead to the collaborative generation of planning alternatives and ultimately decision-support. Consequently, the competency questions for this ontology focus on communication channels, profiles and function. In addition to the ontology, the framework includes a proposed App Store. The paper presented a skeleton for an API to support an App Store through providing methods for developers to create apps, distribute them and interact with the ontology.

The benefits of this framework should be realized by various stakeholders including the public as well as developers. In a similar manner, planners and designers can effectively use this framework to help them translate public feedback into planning and design parameters to inform their plans. For instance, it can help them determine the best communication channel to use for each type of participant or group of participants.

Future work includes developing the eSoc App Store as a validation platform for the ontology. Essentially, an extended framework can satisfy a role in bridging the communication gap in infrastructure planning and construction. Consequently, it can have significant positive implications on the sustainability of infrastructure construction projects in urban communities as it aids in guiding project planning and design to meeting the needs of the public.

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