Goal-Oriented System Modelling for Managing Environmental Sustainability

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Abstract- Large organizations play an important role in helping to mitigate and adapt to the consequences of climate change. As a result, they face increasing pressure from Governments and non-governmental organizations to report on the sustainability of their operations. Beyond simple reporting, however, it is difficult for them to identify the most effective actions to take to address the risks associated with climate change and rising energy costs. The problem is hard because it involves tradeoffs between multiple long-term and short-term objectives that must be made under strong budgetary constraints, uncertainties about the future evolution of many system variables, and sometimes simply a lack of shared understanding of what the real objectives are and the potential impacts of various decisions on such objectives. The overall aim of our research is to develop fundamental techniques to help organizations make decisions in this context. As a first step, we are currently applying quantitative goal-oriented requirements engineering technique to model and reason about the sustainability goals of UCL, a large university in central London. The paper also discusses important software systems engineering research challenges in this domain. These are related to the elaboration and evolution of large-scale models, the ability to reason about the timing of system transformations and the delayed impacts of these transformations on goals, and the need to include in the system model funding mechanisms and system governance structures as explicit components that are themselves subject to changes.

I. INTRODUCTION

Sustainability management systems are important enabling technologies to help mitigating and adapting to the consequences of climate change. These systems help organizations collect and make sense of large volume of data concerning a range of sustainability indicators related notably to energy, travel, waste and water. The information provided by these systems can be used by organisations to inform strategic policy and engineering decisions for sustainability and to monitor the impact of such decisions.

The design of the current, fist generation of sustainability management system is largely *data-centric*: it focuses on data collection and reporting, mostly to satisfy new regulations concerning the reporting and trading of carbon emissions. Deploying these systems allows organizations to make significant reductions in energy use and carbon emissions in the first few years. Further improvements, however, are much harder to achieve once the first quick wins have been obtained. A limitation of these systems is that little attention has been given to the decision-making process and to the information needs of decision makers for making sustainability related decisions (Melville 2010).

Our research objective is to develop fundamental techniques to help organizations make more effective and better-informed decisions for achieving their sustainability objectives. Our approach is to design such systems using a *goal-oriented* and *decision-centric* perspective issued from research in systems requirements engineering (van Lamsweerde 2009) (Letier & van Lamsweerde 2004). Instead of starting from data, our design process starts by considering the system's stakeholders, their goals, and the organization-specific sustainability objectives they wish to achieve. Goal-oriented requirements elaboration method provides systematic techniques to refine goals into subgoals, manage conflicts between goals, identify and resolve obstacles to the satisfaction of goals, and explore and evaluate alternative options for goal satisfaction. The information needs of decision makers and the requirements on the data collection processes would therefore be derived from the organization sustainability goals and the context in which sustainability decisions are taken. The method would also support reasoning about obstacles to sustainability goals and conflicts between sustainability goals and other organization goals. Managing changes is another important concern for these systems. These include changes in legislations, changing objectives and evolving definitions of sustainability indicators, continuous changes in the organization's structure, processes and data formats, and changing attitudes of people towards the system. By making

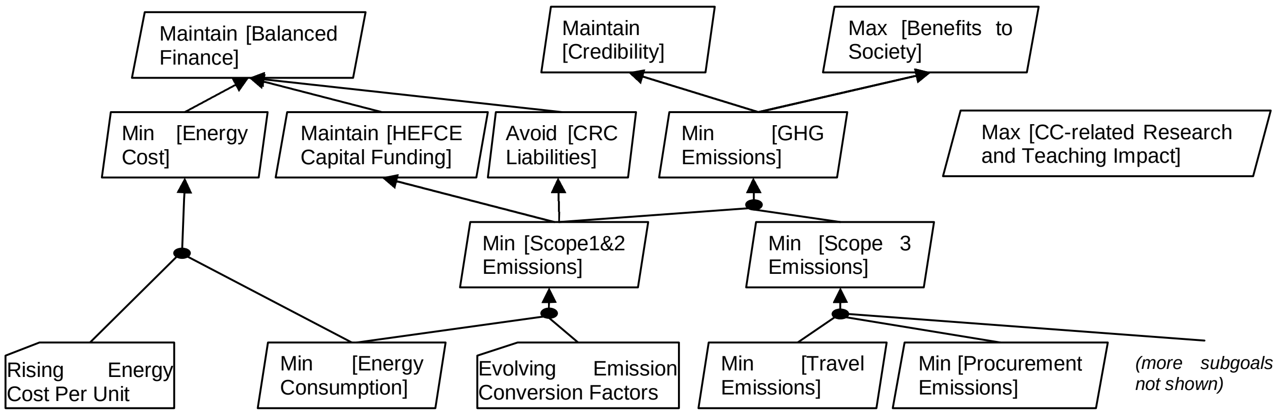

Figure 1. UCL Top-level Sustainability Goals

sustainability goals central abstractions from which other lower-level concerns are derived, we hope to facilitate the system adaptations and evolutions so that it remains fit for purpose as the context changes.

In this paper, we present our ongoing work in developing a goal model for the sustainability management programme currently taking place at University College London (UCL) and briefly discuss some of the research challenges we've encountered during this exercise.

II. RELATED WORK

Previous work on applying goal-oriented requirements engineering techniques to sustainability management systems (Cabot et al. 2009) (Mahaux et al. 2011) has taken a qualitative approach based in i* (Yu 1997). In these approaches, a single generic "Sustainability" goal is refined into subgoals that contribute to it. The qualitative nature of the model offers only very limited support for decision making. In contrast, we aim to use a quantitative approach based on the KAOS method where goals are given formal, measurable definitions (van Lamsweerde 2009). Our models will therefore include multiple, organization-specific sustainability goals defined in terms of domain-specific variables that are related to each other through refinement equations (Letier & van Lamsweerde 2004). Such models allow one to reason quantitatively about the impacts of alternative options on the levels of goal attainment and make tradeoffs among them.

III. CASE STUDY: SUSTAINABILITY MANAGEMENT AT UCL

University College London (UCL) is a large university in the centre of London with more than 20,000 students and close to 8,000 staffs. Its estate is a large, heterogeneous, and complex system composed of around 200 buildings with a mixture of new and heritage buildings that must serve a wide variety of functions (student residences, teaching spaces, offices, research laboratories, etc.). The university is currently engaged in a sustainability management programme with the aim of reducing its carbon emission by 34% from its 2005/06 baseline by 2020. This programme, described in a recent carbon management plan (UCL 2011), follows the EcoCampus scheme, which is a generic sustainability management framework for higher education institutions in the UK.

We have started to elaborate a goal-oriented model of UCL sustainability goals from information contained in the last two UCL carbon management plans from February 2008 and March 2011, information collected from the programme managers, and available data about UCL estates and organization. Figure 1 shows a portion of this model including the high-level goals related to energy consumption and carbon emissions. Three important goals are to minimize utility costs, minimize scope 1 and 2 carbon emissions, and minimize scope 3 carbon emissions. Scope 1 and 2 emissions are produced either directly on campus (e.g. by the on-site Combined Heat and Power plant) or resulting from the external production of electricity consumed in buildings under UCL control. Scope 3 emissions are all the other indirect emissions that result from the activities of the institution such as those related to travel, procurement, water usage, waste disposal, and energy use in leased buildings and facilities. UCL's objective of reducing its emissions by 34% by 2020 concerns scope 1 and 2 emissions only. This target is related to a condition set by the Higher Education Funding Council for England (HEFCE) for universities to keep their full level of capital funding. Achieving this goal will also reduce UCL's financial liability to purchase emissions allowances under the Carbon Reduction Commitment (CRC) which is a mandatory cap-and-trade scheme that will apply to large organizations in the UK. The goal of reducing all green house gas emissions (scope 1, 2, and 3) contributes to the goal of maintaining UCL's credibility as a world-leading research and teaching institution, notably in areas related to energy, climate change, and environmental sustainability, and to its goal of achieving benefits to society by contributing to the effort of mitigating and adapting to the consequences of climate change. Another goal, which contributes to the two high-level goals, is to maximize the university research and teaching impact in areas related to climate change.

In this model, goals' objective functions are defined in terms of domain-dependent quality variables and the quality variables attached to a goal are related by refinement equations to quality variables associated to subgoals, domain assumptions, or obstacles. For example, in our simplified model, the goal **Min [Energy Cost]** has a quality variable $YearlyEnergyCost: Year \rightarrow Nat$ that denotes the total energy cost for each year. The value for this variable can be defined by the equation $YearlyEnergyCost = YearlyEnergyConsumption * YearlyEnergyPrice$ which refers to the quality variables attached to the domain assumption **Rising Energy Cost** and the subgoal **Min [Energy Consumption]**, respectively.

To identify potential opportunities for carbon emission savings and sustainability practices (i.e. to identify subgoals to the leaf goals in Figure 1), the team responsible for the carbon management programme organized three brainstorming sessions, one involving students, one involving academics, and one involving staff from the Estate and Facilities Division. These sessions produced more than 70 suggestions that were then analysed and assessed at a coarse grained level (on a 5 point scale) for their potential carbon saving, utility cost saving, implementation cost, and ease of implementation. Some of these projects were then selected for implementation. The current plan consists of a list of 12 projects – e.g. installing wrap-up valve insulation jackets, and extending the capacity of the existing on-site Combined Heat and Power plant – for which funding has been obtained or is currently being sought. For each of these projects there's a quantitative assessment of its yearly budget and carbon savings, its cost, and its payback time.

Estimations about the cost and impact of the 12 retained projects, as well as other future propositions, can be included in the goal model and standard multi-objective decision techniques, such as the ones used in software engineering for release planning (Zhang et al. 2007), could then be used to analyse the cost/benefit tradeoffs for alternative sets of projects and guide their staged deployments. Obtaining accurate and justifiable estimates for the cost and impacts of sustainability enhancing measures however remains a difficult step in such approach. With weak justifications for these estimates, the business cases for deploying these measures stay difficult to make.

We are therefore currently engaged in refining our first-sketch models to obtain a more detailed quantitative model of UCL energy consumption that would provide a more detailed assessment of projects on the university sustainability goals.

IV. Research Challenges

Our initial application of goal-oriented system modelling techniques led us to identify the following research challenges for the use of software system modelling techniques in the area of sustainability management.

A. Elaborating and evoluting large-scale models

A lot of research has been done on providing systematic support to guide the refinement of goals into subgoals through the use of goal refinement patterns and heuristics (Darimont & van Lamsweerde 1996) (Letier & van Lamsweerde 2002). In practice, however, elaborating good quality goal models for complex, large-scale systems remains difficult, and maintaining the model up to date as the system evolves is even more so.

One promising approach to address these problems is to provide support for the collaborative elaboration, reviewing, and evolution of goal models by all system stakeholders. Steps have recently been made in this direction by providing web-based stakeholders' management and requirements elicitation tools (Lim & Finkelstein 2011) (Castro-Herrera et al. 2009) and web-based tools for editing and sharing quantitative argumentation models (Lung 2011). This is an area we wish to investigate further by providing tool support for the collective editing and reviewing of models (in the spirit of the Wikipedia model for encyclopaedia editing) and for managing the relations multiple views on the system (Finkelstein et al. 1992) (van Lamsweerde et al. 1998).

B. Reasoning about system evolution

Existing requirements engineering techniques have been developed for traditional software development projects where the focus is on making decisions and developing the *system-to-be* (van Lamsweerde 2009). No explicit attention has been given to support the continuous evolution of this system after its development (such activities being considered to be part of the system maintenance rather than traditional requirements engineering). The techniques developed in this context are therefore ill-equipped to deal with projects concerned with the *continuous improvement* of an existing system where the levels of goals satisfaction and the value other model parameters vary over time. For example, it is difficult using current quantitative goal modelling techniques (or other software engineering modelling techniques) to reason about the evolution over time of an organization's green house gas emissions, the potentially delayed impact of system transformations on emissions levels, and take into consideration time-varying variables (such as energy prices and number of students) when assessing alternative system designs.

Extending goal-oriented system modelling approaches with concepts and techniques from system dynamics (Forrester & Wright 1961) (Ford 2010) could be a promising approach to address this limitation.

C. Reasoning about funding mechanisms and system governance

Obtaining funds to finance sustainability projects can be a significant difficulty for sustainability management programme. In principle, the funds invested in most sustainability projects are quickly regained through energy saving cost. A sensible funding mechanism is therefore to have a dedicated “green fund” in which savings obtained by previous initiatives are used to fund further initiatives. UCL is considering introducing such a fund in combination with a carbon offset scheme for air travel to feed it. It would be useful for sustainability management decision support tool to be able to assess the impact of alternative funding mechanisms and include such considerations in the decision making problem. Traditional cost estimations techniques in software engineering are limited to estimating a project cost from its specification. We are not aware of any work in the software engineering literature concerned with the issues of the origins of funds and the question of designing and analysing funding mechanisms for managing the continuous evolution of large-scale systems.

A related problem is that of the system governance. A difficulty for sustainability management programmes is to ensure that *all* decisions taken across the organization are in line with the sustainability objectives. The benefits of a set of sustainability improvements actions could for example by entirely wiped out by some other factors that result in a significant increase in energy consumption (e.g. due an exponential growth in the use of energy-intensive computing equipments). Achieving sustainability goals will typically also require cooperation of all for not wasting resources. The question therefore is how to design (and evolve) the structure processes, and policies by which the organization is directed and controlled are aligned so that it is aligned with its sustainability objectives. Including the system governance as explicit component of the decision model would allow us to analyse it in order to detect pathological structures, find ways of resolving them, and take the governance mechanisms into explicitly into account in the decision-making process. The importance of the relation between requirements models and software engineering governance has been recognized only recently and little work has been carried out so far in this area (Finkelstein 2009).

V. Conclusion

We have argued that goal-oriented system modelling provides useful abstractions and analysis techniques for designing sustainability management systems. It notably allows one to model and reason about the impacts of sustainability improvement projects on sustainability goals and to reason about interrelations between multiple goals. Our initial modelling and analysis of sustainability goals at UCL confirm these benefits. We also identified a series of research challenges that arise in this context. These challenges are not specific to sustainability management; they arise in many other contexts involving incremental transformations to an existing large-scale socio-technical system. Addressing these challenges will therefore be of benefit to other domains as well. Addressing them in the context of sustainability management has the benefit of providing a very concrete and important area in which to start tackling them.

VI. References

Cabot, J. et al., 2009. Integrating sustainability in decision-making processes: A modelling strategy, *Proc. ICSE’09 - Companion Volume*, pp. 207-210.

Castro-Herrera, C. et al., 2009. A recommender system for requirements elicitation in large-scale software projects, Proc. SAC ’09, p. 1419–1426.

Darimont, Robert & van Lamsweerde, Axel, 1996. Formal refinement patterns for goal-driven requirements elaboration, Proc. FSE’96, p.179–190.

Finkelstein, A. et al., 1992. Viewpoints: A framework for integrating multiple perspectives in system development. *International Journal of Software Engineering and Knowledge Engineering*, 2(1), p.31–58.

Finkelstein, Anthony, 2009. Software Engineering Governance, BCS Computer Journal Lectures 2009. Available at: http://www.bcs.org/content/ConWebDoc/24408.

Ford, A., 2010. *Modeling the Environment, Second Edition* 2nd ed., Island Press.

Forrester, J.W. & Wright, J., 1961. *Industrial dynamics*, MIT press Cambridge.

van Lamsweerde, A., Darimont, R. & Letier, E., 1998. Managing conflicts in goal-driven requirements engineering. *IEEE TSE* 24(11), pp.908-926.

Lamsweerde, A. van, 2009. *Requirements Engineering: From System Goals to UML Models to Software Specifications*, John Wiley & Sons.

Letier, Emmanuel & van Lamsweerde, Axel, 2002. Agent-based tactics for goal-oriented requirements elaboration. *Proc. ICSE ’02.*

Letier, Emmanuel & Lamsweerde, A. van, 2004. Reasoning about partial goal satisfaction for requirements and design engineering, FSE’04.

Lim, S.L. & Finkelstein, Anthony, 2011. StakeRare: Using Social Networks and Collaborative Filtering for Large-Scale Requirements Elicitation, *IEEE TSE*, 99(1).

Lung, J., 2011. Inflo, a collaborative decision-making tool. Available at: https://inflo.cs.toronto.edu/ [Accessed April 13, 2011].

Mahaux, M., Heymans, P. & Saval, G., 2011. Discovering Sustainability Requirements: An Experience Report. *Proc. REFSQ’2011*, p.19–33.

Melville, N., 2010. Information Systems Innovation for Environmental Sustainability. *Management Information Systems Quarterly*, 34(1), pp.1-21.

UCL, 2011. *Carbon Management Plan, version 2*, Available at: http://www.ucl.ac.uk/environment/vision/UCL_CMP_v2_3b.

Yu, E.S.K., 1997. Towards Modeling and Reasoning Support for Early-Phase Requirements Engineering. In *Proc.* RE ’97.

Zhang, Y., Harman, M. & Mansouri, S.A., 2007. The multi-objective next release problem. In *Proc.* GECCO ’07.