Supporting Sustainable Service-System Design: A Case Study on Green-Roof Design with InDeaTe Template and Tool at Syracuse, New York

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Abstract InDeaTe Tool and Template is a sustainable design support, aimed at imbibing and improving the sustainability considerations in any design. This paper presents a case-study on 'design of green roof', a type of green infrastructure, to combat the existing issues of Stormwater Management in Syracuse. The primary objective of the design project is to design (or re-design) a green roof that will store stormwater for enough time during a reasonably strong storm so that the capacity of the Syracuse Metro treatment plant would not be exceeded. A second objective is to incorporate low environmental impact materials when designing the green roof so that the final design is more sustainable. The case study discussed in this paper, illustrates how the use of InDeaTe Tool not only improved sustainability considerations and led to many creative solutions, but could be used for design of more sustainable service systems.

Keywords Eco-Design · Design for sustainability · Enabling technologies and tools · Indeate tool and template

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1 Introduction

The city of Syracuse, located in the Onondaga County, also known as "The City that Salt built", succumbed to rapid industrialisation that eventually led to the contamination of Onondaga Lake making it America's most polluted lake. It was designated a federal Superfund site in 1994. The New York State Department of Environmental Conservation has identified that currently the two main sources of pollutants for the Lake are; (i) combined sewage overflow and (ii) stormwater run-off. The EPA (Environmental Protection Agency) defines green infrastructure as "a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits". Green Infrastructure can help solve urban stormwater challenges and includes rainwater harvesting barrels, rain gardens, planter boxes, urban trees, bio-swales, constructed wetlands, permeable pavements, green streets and alleys, green parking lots and green roofs. A Green roof is essentially a Sustainable Service-system designed for the benefit of society, environment and economy; and is already widely in place at Syracuse.

This case study illustrates the re-design of an existing green roof, to improve its sustainability considerations and address issues by using the InDeaTe Tool and Template. The resultant design is evaluated against the existing solution, to assess the improvement in sustainability considerations with the use of Tool.

2 Case Study: Overview

The goal is to assess the improvement in the sustainability consideration of the re-designed green roof and in turn, the effectiveness of the InDeaTe Tool.

This is an exploratory Case Study and key questions studied are;

(i) Does the sustainability consideration improve with the use of the InDeaTe Tool and Template?
(ii) How effective is the InDeaTe Tool and Template in supporting designer?

The underlying **proposition of this case study** is that the use of the InDeaTe Template and Tool improves the sustainability consideration of a system by supporting designers in formulating, iteratively improved List of Requirements with sustainability-focus.

2.1 Problem Brief

In Syracuse, the sewers carry both sewage and stormwater to the Metro treatment plant. When it rains, more than a light drizzle, the capacity of Metro treatment plant is exceeded. The mixture of sewage and stormwater which is in excess of the capacity must be released to Onondaga Lake without any treatment, which causes damage to the ecosystem. To avoid this problem, more places to store the stormwater over short periods of time are needed. Many kinds of green infrastructure can provide the storage.

The **objectives** of this design exercise are;

(i) to design a green roof that will store stormwater for enough time during a reasonably strong storm so that the capacity of Metro would not be exceeded,
(ii) to incorporate low environmental impact materials when designing the green roof so that the final design is more sustainable.

2.2 Design Methodology

The Design team followed the InDeaTe design process Template, where iterative GEMS activities of design are performed in each design stage while considering each life cycle phases of design.

This design exercise involved the first two design stages due to time constrain; and followed the InDeate Template's proposed design process steps to produce the following set of Deliverables; summarised in Table 1.

2.2.1 Exercise Duration

Approximately 40 h, Five days

Day 1—Introduction of team members, Design problem and Literature review
Day 2—Design Exercise with Tool—Problem Definition and Task Clarification, Site visit
Day 3—Continuation of Task Clarification
Day 4—Conceptual Design and Presentation of concept for discussions
Day 5—Design Analysis and Feedback on InDeaTe tool.

2.2.2 Participants

The Team composed of six PhD students—three of whom performed the re-design task having mechanical engineering, architecture and design backgrounds; while the other three students had prior knowledge and expertise in different aspects of green roof design. The latter three members were involved with the design of the green roof being used as benchmark.

Table 1 Case study: design methodology

Design stage	InDeaTe template: design process steps	Deliverables
Task clarification	Select system boundary	1. Preliminary list of requirements often qualitative with some understanding of their relative importance, often qualitative
	Analyse current situation to identify issues (generate requirement)	
	Using the tool/database select sustainability definitions and Indicators to be used in the process	2. Some ideas of how to solve the design problem, noted down for further use
	Evaluate the issues to find the important ones to address (evaluate/modify requirements)	
	Decide on a list of requirements and their relative importance for use the subsequent stages (select requirement)	
Conceptual design	Generate alternative ideas to satisfy each major requirement (generate solution)	1. A more concrete list of requirements
	Evaluate these ideas to select the most promising ones (evaluate/modify solution)	2. A list of possible solution-variants that could be used to solve the problem (i.e. satisfy these requirements)
	Integrate these ideas to generate alternative solution principles (generate/modify solution)	3. An evaluation of these variants for their suitability to satisfy these requirements
	Evaluate these alternatives to select the most promising solution principle (evaluate/select solution)	4. The solution-principle selected as the most promising for further development

2.3 Analysis Methodology

For the analysis of the effectiveness of the InDeaTe Tool and Template, first the design solution conceptualised was assessed following which participants analysed the effectiveness of the Tool from their experience in the design exercise.

2.3.1 Assessment of Design with Respect to Benchmark

The final design selected as concept was assessed by subject-matter expert for the following;

(i) The **Criteria for the assessment** of the design and in turn the Tool are;

- Satisfaction of Requirement
- Improvement of Sustainability consideration

(ii) **Data for analysis**: The resulting design is analysed with respect to the existing design, as benchmark, and data is in the form of List of Requirements, design sketches, design specifications and other documents.
(iii) **Units of analysis**: Qualitative analysis was performed by subject-matter experts to assess two aspects of the design;

- *High, medium, low, zero* satisfaction of requirements
- *Significantly improved, improved, not improved* Sustainability consideration.

2.3.2 Analysis of Effectiveness of Tool:

A retrospective analysis of the effectiveness of the InDeaTe Tool and Template was conducted via a Questionnaire to participants.

2.4 Limitations of the Study

- The design exercise is conducted with one team performing a single-instance of design with use of InDeaTe Tool and Template. However, multiple case studies have been performed across domains to assess the same and the analysis results were found positive and corroborative.
- Due to the dearth of a parallel exercise as control, the original design has been used as benchmark to asses the sustainability improvement of the new design. And though it may be argued that there is always scope for improvement upon an existing design, the improvement proves that the Tool can be used to re-design existing issues effectively.

2.5 Key Findings of the Study

1. The InDeaTe Template and Tool is effective for improving sustainability considerations in designs. Design assessments were conducted to determine the same and is presented in this paper.
2. The InDeaTe Template and Tool is effective in supporting the designer during the design process, this was carried out with a questionnaire, however the details are not presented in this paper.

3 Literature Review

3.1 Relevance and Need for a Holistic Support

Literature presents a number of sustainability focussed design support are available but most of them are for assessment and evaluation; such as the Swiss Ecoscarcity methods (Ecopoints). While certain tools such as DFE Workbench though well integrated with Solidworks CAD tools, is able to support designers only with respect to the a specific, in this case environmental, aspects of a design. There are also design methods that are developed that support only a specific Life Cycle Phase such as the Use-phase [1].

Literature also notes the existing "interaction of methods and tools at various steps in the process" of design and further stresses on the need for interaction between design methods and computer-aided tools to support decision-making [2]. Lopez-Mesa [3] enumerated potent findings about the knowledge and use of design methods in practice and highlighted that only a few methods are 'widely and systematically used' while most are unaware of the availability of other methods and believe that abundance of time is required. However, she notes that implementation of methods provides support to an array of tasks during the design process and leads to consideration of a large number of ideas. Lopez-Mesa further stresses on the increased positive contribution by a method upon the design when it is in a computer based system [3]. Thus, there is need of a computer-based support that encompasses all three dimensions of sustainability across the entirety of the Life cycle of the design.

3.2 InDeaTe Tool and Template: A Novel, Holistic Design Support

InDeaTe Template and Tool, is a knowledge-driven Sustainable Design process support, aimed at imbibing and improving the sustainability considerations in a design. It comprises of two elements—a sustainable design process Template, and a sustainable Design Database—that work synergistically to support the designer on a user-friendly, computer interface. The Template and the Design Database ontology is based on the ACLODS holistic framework [4] which proposes dimensions—Activities, Criteria, Life cycle phase, Outcome, Design Stage and Structure—essential for life cycle development of a design.

The InDeaTe design process Template offers an overview of the design process and provides a generic guideline to follow as the design process is carried out. There are four stages of design—Task Clarification, Conceptual Design, Embodiment Design and Detail Design [5]. And every design has five Life cycle phase, which are; Material, Production, Distribution and Transportation, Use and

After Use. The Template encourages designing for the entire lifecycle of the system, with the aim of making it more sustainable. It guides the designer to perform suitable Activities of design, i.e., generate-evaluate-modify-select (GEMS) in each Design stage, at the intersection of every Life Cycle Phase.

3.3 Green Roofs: A Literature Survey

A green roof is a green infrastructure being promoted through incentive programs for construction for being a sustainable solution to the plaguing issue of combined sewage overflows across cities in America. Green roofs have the ability to store a portion of storm water, attenuate stormwater run-off into the sewage system and allow evapotranspiration, thereby reducing the load on the common sewage system and deterring sewage overflow, and eventually protecting ecosystem damage. Green roofs also reduce energy usage for cooling and urban heat island effects, and provide wildlife habitat.

A typical green roof comprises of layers of drainage course, growing substrate and drought resistant vegetation atop a waterproof membrane of the roof floor, and may have geo-synthetic layers interspersed to limit sediment intrusion into drainage layer and the plant rooting. They maybe extensive or intensive, depending on the thickness of the substrate layer. Extensive green roofs are more common as they are cheaper to install, require less maintenance and are lighter, with approximately 15 cm of substrate and short rooting vegetation. The hydrological behaviour of a green roof is affected by construction type, growing substrate depth, vegetation type, areal coverage, as well as the local climate which determines the precipitation pattern and the rate of evapotranspiration [6]. Owing to the substrate layer with low thermal conductivity and high thermal mass, green roofs behave as natural insulation and reduce energy consumption of buildings. They can further be used to reduce the urban heat island (UHI) effect of big cities as the vegetation reduces solar heat gains due to its high albedo and evapotranspiration. However, their efficacy reduces with high insulation of the building roof and requires adequate calculations for improving performance [7].

As green roofs emulate natural habitats, Dvorak and Volder [8] published a 'Chronological summary of green roof vegetation findings' for North America based on the eco-region of the location and further enumerated effective plant species by type and location. They further stated that "succulent-dominated green roofs are well-suited to survive the extreme conditions found on rooftops and prefer shallow substrates from 7 to 10 cm thick for many of the eco-regions investigated" [8].

The green roof for the re-design exercise was an extensive, built-in-place roof with sedum as the primary vegetation though certain other sporadic species were also found to have grown. It had slopes designed perpendicularly to its length along the centre and were fitted with french drains as would be the norm for a regular roof. Also, the roof was capable of withstanding the additional load of the green roof and more importantly the expected storm-water to be retained, being heavily insulated for snow-load. Thus from site conditions and literature review, it was concluded that the existing Sedum vegetation was ideal for the given conditions.

4 Design Exercise

4.1 Task Clarification Stage

In this stage, the design team well defined the problem statement with the intent to identify a preliminary list of requirements.

Step 1: The team **Selected a System Boundary** as prescribed by the InDeaTe Template. Due to the propensity of time and complexity of the issues, certain aspects of green roof were identified to be outside the system boundary, such as—Composition of growth medium, Species of vegetation and Methods of planting the vegetation, and were taken as is for the re-design exercise.

The teams together identified certain other constraints, as listed below;

- usable flat, surface area for installation and thus the volume for water retention
- snow-load capacity of the roof to bear the volume of retained storm water
- existing slope and drainage system on the roof
- the location of the green roof (physical and visual access)

The areas of intervention identified were;

- means to retain storm water
- type of irrigation to get water for the plants for the first few months
- methods of laying down the growth medium
- maintenance of green roof after the vegetation is planted
- increase social acceptance of green roofs

Step 2: The team **analysed the current situation to identify issues** and generated (G) requirements.

The existing system had **three primary issues** and each of these in turn had the following **lifecycle issues** to be addressed;

- **The lack of adequate retention of storm water** resulted from a Production phase issue. During the installation of the green roof, the existing french drains common to other flat roofs, were not removed, which leads to the issue of rapid drainage of the precipitated water into the main sewer line and defeats the purpose of the green roof as a retention unit
- **The poor visibility and access to the roof**, inspite of being on a public building, results in low social impact. Also, the diverse eco-system on the roof

attracts a large number of insect, bird and small animal species causing social nuisance. Together these adversely effects the Use phase and has lead to low social acceptance
- **The high cost of installation** causes socio-economic dissent and hinders the overall lifecycle of the system and in turn negatively impacts the environment
- Also, due to the use of fine plastic mesh atop of plantation as wind-cover, small bird get caught and lose their lives. This is displeasing and is a Use-phase issue.

In order to well-define the problem, the designers formulated a **Solution Neutral Problem Statement (SNPS)**—*To re-design the green roof system having high stormwater retention, controlled run-off and increase social acceptance towards its installation in Syracuse.*

The design team then turned to the Tool and **chose the TBL scope** as—environment, society and economy, for the issues already described above. The Tool provided a list of Sustainability Definitions from which the designers **selected Sustainability Definitions, Principles and Indicators** for their design process.

The team found the following definitions to be appropriate: **World Bank** [9], **IISD** (International Institute for Sustainable Development) [10], **Sustainable Seattle** [11], **Sustainable Arizona** [12], and **Dillard et al**. [13].

Upon selecting the definitions, the Tool further provided a set of **Sustainability Indicators** that would be used to operationalise the selected definitions. These were;

- Land (Environmental Indicator): Fertiliser use efficiency, Use of agricultural pesticides [14];
- Water (Environmental Indicator): Presence of faecal coliform in freshwater, Wastewater treatment [14]; Urban wastewater treatment [15]; Index of heavy metal emissions to water, Eutrophication [16];
- Waste (Environmental Indicator): Waste treatment and disposal (as per sectors) [14]; Initiatives to mitigate environmental impacts of products and services, and extent of impact mitigation [17]; Eco-toxic substance effluent [18];
- Health and Safety (Social Indicator): Life cycle stages in which health and safety impacts of products and services are assessed for improvement, and percentage of significant products and services categories subject to such procedures [19];
- Investments, costs (expenditures) and consumption (Economic Indicator): Environmental expenditure [20]; Waste treatment costs [18].

Step 3: These Indicators prompted the generation of preliminary requirements and the teams together conducted an e**valuation of issues** to find the important ones to address.

To prioritise these requirements, the design team selected **Quality Function Deployment (QFD) Method** from the Design Database and calculated the relative importance of the requirements by Weighing factors on a 5-pt scale to determine the priorities of the Requirement, as shown in Table 2.

Table 2 Task clarification: weighting factors to develop prioritised LoR

Weighing factors	High retention capacity	Reduce pollution of run-off water	Control over run-off rate	Cause no harm to the fauna	Prevent substrate material from blowing away	Better visibility and marketability	Easy maintenance	Sum
High retention capacity		1	0.5	1	0.5	1	0.5	4.5
Reduce pollution of run-off water	0		0.5	1	0.5	1	0.5	3.5
Control over run-off rate	0.5	0.5		1	0.5	1	0.5	4
Harmless to the fauna	0	0	0		0.5	0.5	0	1
Prevent substrate material from blowing away	0.5	0.5	0.5	0.5		1	0.5	3.5
Better visibility and marketability	0	0	0	0.5	0		0.5	1
Easy maintenance	0.5	0.5	0.5	1	0.5	0.5		3.5

Step 4: Thus, the team fulfilled the **Task Clarification Deliverable** of formulating a **Preliminary List of Requirements,** as given below;

(i) Increase storm water retention capacity
(ii) Control stormwater run-off rate into sewers
(iii) Reduce pollution of run-off water
(iv) Prevent substrate material from blowing away
(v) Easy maintenance
(vi) Cause no harm to fauna
(vii) Better visibility and marketability

4.2 Conceptual Design Stage

In this stage, the design team explored a number of solution-variants and worked towards selecting the solution-principle or "concept".

Step 5: The team **generated (G) alternative ideas to satisfy each major requirement** and to do so selected the Brainstorming Method from the Database. The result was a number of ideas for each of the requirements, as given below in Table 3.

Step 6 and 7: These **ideas were then evaluated** to see which were feasible and which ones would have greater effect. The design team used the **Morphological Chart Tool** from the Database. It was further used to **combine solutions and generate** five distinct solution-variants, namely #1, #2, #3, #4, #5, as given below. These variants were sketched as part of the generation/modification of solutions.

Step 8: The design team further **evaluated the solution-variants** by using the **Quality Function Deployment (QFD)** Method from the Design Database, where the solution-variant attributes, developed from the previous list of requirements, were ranked based on their satisfaction of requirement and compared. The selected concept was Solution-variant 1 to be embodied.

5 Key Findings

5.1 Design Assessment

A number of design solution variants were presented to subject-matter expert to assess the final concept design with respect to the benchmark for requirement satisfaction and improvement of sustainability consideration of the Service system designed. This is presented in Table 3.

Table 3 Conceptual design using brainstorming method

Requirements	Ideas generated during brainstorming					
High retention capacity	Solution-principle: Conceptual sketch Alternative absorbent (foam) materials	Increase the thickness of substrate/drain layer	Vertical green roofing	Reservoir	Water absorbing silicone balls	Arduous drainage path
Control run-off rate	Flow rate sensors	Automated control valves on drains	Compartmental storage tanks	Timed water release mechanism (coordinating with urban flow, post-storm)	Drip irrigation from reservoir	Pass it into ground water reservoir
Reduce pollution of run-off water	Install filtration system (activated carbon)	Organic fertiliser/manure	Run-off water quality monitoring	Plant Ryegrass, Lolium multiflorum- absorb relatively large quantities of certain types of toxics such as PAH (polycyclic aromatic hydrocarbons)	Phytoremediation - Plants that absorb pollutants from water in drainage sump (hyperaccumulators)	Increase thickness of the substrate
Prevent substrate material from blowing away	Resinated pieces that stick together	*Mulch as a top layer	Moss			
Easy maintenance	Improve the access	Maintainance Drones		*Note: Green roofs overall, and especially extensive ones, do not require high maintenance*		
Cause no harm to the fauna	Lighter wind blanket material	Easily breakable wind blanket material	Eliminate wind blanket	Wider modular plastic frames for tacking + decomposable blankets sheets in between		
Better visibility and marketability	Locating green roofs on medium height bldgs.	Providing public access (consider dynamic load)	Smaller green roofs on tiled sloping roofs (affordable & appealing to residents)			
Vegetation	Sedum *Note: as in existing, good choice supported by Literature*	Aloe, Delosperma, Euphorbia (Desirable for Hot and humid)	*Mulch—increase water retention and as it decomposes enriches the soil			

Table 4 Assessment of design—proposed solution benchmarked to existing solution

List of requirements	Existing solutions (Benchmark)	Proposed solution concept	Requirement satisfaction	Sustainability consideration
High retention capacity	– Single layers of plastic profiled element and media	– Increased thickness of substrate/drain layer and varying layer grain	High	Improved significantly
Control run-off rate	– Presence of french drains, increase the rate of run off	Timed water release mechanism (coordinating with urban flow, post-storm)	High	Improved significantly
Reduce pollution of run-off water		Phytoremediation—plants that absorb pollutants from water in drainage sump (hyper-accumulators)	Medium	Improved
Prevent substrate material from blowing away		– Easily breakable wind blanket material of thicker borders and thin, perpendicular strands of organic fibre	Medium	Improved
Cause no harm to the fauna			High	Improved significantly
Easy maintenance		– Improve the access	Medium	Improved
Better visibility and Marketability		– Locating green roofs on medium height buildings, and along the facade	Medium	Improved
Assessment			Satisfied	Sustainability improved

The results of the two criteria were in consensus which may be viewed as a validation of the InDeaTe Tool and Template as an effective support to improve sustainability of a service system (Table 4).

5.2 Analysis of Tool

The results of the Questionnaire were overall positive with designers stating that they found the Tool useful

InDeaTe effectively supported the design team to;

– Identify many, new or otherwise neglected, requirements across social, economic and environmental aspects
– Conceptualise a large number of design solution-variants
– Select a “good” concept hich satisfies the requirement and achieves improved sustainability considerations.

6 Conclusions

It is concluded that InDeaTe Tool and Template is an effective sustainability design support as it improved sustainability considerations of the green roof Service-system and in turn was found useful by the designers. Thus, the InDeaTe Tool and Template is recommended for design of more sustainable service systems.

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