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Article

An expert system approach to green stormwater infrastructure selection for urban area

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Abstract

The green stormwater infrastructure for urban area is an important, complicate and time-consuming task that relates to huge amount of information, data, domain law, expert knowledge and experience in terms of environmental protection. An expert system has been successfully applied in environmental studies. This paper presents an expert system “ES-GSI” developed by using Microsoft Visual Basic that is used to manage urban area stormwater. To acquire expert experience and knowledge, decision trees and tables are used. For measuring the expert opinion about system rules, certainty factor is used. By using Expert Choice software, multiple experts’ opinion is integrated where various alternatives are available. Forward chaining inference mechanism is utilized for results assessment. The proposed ES-GSI are tested and evaluated during all stages of system development for its performance accuracy. System recommendation is displayed in report form. By ES-GSI application, having more accurate decisions will be its benefit.

Keywords expert system; stormwater; management plan; urban area; green stormwater infrastructure.

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1 Introduction

Urbanization has reduced vegetative cover which can affect the quality and quantity of urban runoff. In impervious urban area, precipitation cannot fully infiltrate in to the soil that become runoff with the potential to wash pollutants (Hsieh and Davis, 2005; Raeiet al., 2019). The water pollution and urban flooding caused by surface runoff increase have been recorded worldwide due to land use and land cover change by urbanization (Lee et al., 2012; Behroozi et al., 2015; Liu et al., 2015; Luan et al., 2019). To mitigate the problems induced by increasing runoff in urban areas, various stormwater management approaches have been proposed and adopted in the developed countries (Luan et al., 2019). The management of urban surface runoff is a matter of considerable environmental concern because pollutants in urban surface runoff can substantially impact the receiving waters quality (Behera et al., 2006; Raeiet al., 2019). One aspect of urban sustainability is managing stormwater runoff with the rising amount of impervious area in dense urban environments

(Christopher et al., 2017). The urban environment greening with vegetation, in the form of green infrastructure; can provide improving urban runoff quality and reducing its volume (Christopher et al., 2017). Green infrastructure is a sustainable approach to water management that can mitigate the wet weather impacts by capturing and managing rainfall on site. Effective green infrastructures divert excess stormwater and prevent it from entering rivers, streams and the sewer system (Washburn, 2015).

In recent years, green infrastructure has become widespread (Simíc et al., 2017; Jan et al., 2018). Green stormwater infrastructure (GSI) includes a series of green technologies which has more advantageous than traditional gray technologies (Lucas and Sample, 2015; Tao et al., 2017; Luan et al., 2019). It uses vegetation, soils and natural processes to manage surface water and create healthier urban environments (Bicknell et al., 2019). It has the merits in environmental, ecological, hydrological and social aspects (Tzoulas et al., 2007; Luan et al., 2019). The commonly known GSI strategies are the basic technologies for sustainable stormwater management practices including green roofs, bioretention, porous pavements, wetland, vegetated swale and detention/retention basin (Luan et al., 2019). It provides an approach to managing stormwater runoff. It aims to restore, protect and mimic the natural water cycle with methods that would occur naturally. GSI places an emphasis on low impact development with nature based practices to increase infiltration, transpiration, evapotranspiration and enhance water quality (Stantec). GSI as a more sustainable alternative approach and differing from the conventional ones focuses on decentralized units and the control of runoff near the source by imitating the natural hydrology and promoting the evaporation, infiltration and retention of urban area (Eckart et al., 2017; Lu and Wang, 2021). Hydrological conditions after development remain close to natural conditions before development by application of GSI (Ahiablame et al., 2012), which is useful to returning runoff to the natural water cycle, improving water quality, reducing stormwater runoff, groundwater recharge and reducing implementation and maintenance costs (Eckart et al., 2017; Son et al., 2017; Lu and Wang, 2021). In addition green infrastructure provides other multiple benefits. GSI provides social benefits to promote community sense, public and mental health through increased green spaces (Tzoulas et al., 2007; Schilling and Logan, 2008, Dunn, 2010; Lee and Maheswaran, 2011; Roe et al., 2013; Christopher et al., 2017). The economic benefits include lower costs and increased property values compared to gray infrastructure (Christopher et al., 2017). Environmental and ecological benefits include reduced urban heat island effects and improved air quality (Oberndorfer et al., 2007; Baik et al., 2012; Santamouris, 2015; Christopher et al., 2017). Additionally, there is a link between energy savings and various forms of green infrastructure (Malinowski, 2015; William, et al., 2016; Christopher et al., 2017). It is important to consider both the quantitative and qualitative aspects of these spaces in any green infrastructure assessment (Tzoulas et al., 2007; Christopher et al., 2017). The combination of the environmental, social, and economic benefits of green infrastructure requires an integrative approach to planning, implementation, and evaluation (Christopher et al., 2017).

Assessing and preparing the GSI are the most important and time-consuming task that relates to huge amount of information, data, domain law, and expert knowledge and experience in terms of environmental protection. The environmental study is a time-consuming process due to more variables for considering. For collecting, analyzing and reporting data and information there needs to be a support system (Say et al., 2008; Muthusamy and Ramalingam, 2003). Expert system can manage data and information for giving the suitable expertise. Therefore it is useful tool for environmental study (Say et al., 2008). An expert system is used to extract the human expert information within a specific domain and makes knowledge available to less experienced users through a computer program (Dogantekin et al., 2010; Akram et al., 2014). Expert system is a technology that manages information and data, diagnosis the problem, provides the advice and expertise for solution the problem (Raza, 2009; Akram et al., 2014). Therefore it is an efficient computer program which provides the solution of problems based on task specific knowledge and inference techniques at the level of a human expert (Bolloju et al., 2001; Akram et al., 2014).

Expert system consists of components which are knowledge base, inference engine, knowledge acquisition, explanation facility and user interface (Akram et al., 2014).

A knowledge base consists of rules and facts which provides all the information and knowledge about the problem domain (Shen, et al., 2010; Akram et al., 2014). The role of an inference engine is to work with the available data from the user and system to derive a solution (Kendal and Creen, 2007; Akram et al., 2014). The knowledge acquisition provides the knowledge to the database that operates an editor for entering the knowledge directly to the expert system (Raza, 2009; Akram et al., 2014). The explanation facility provides a solution by showing a path to the user to reach a certain conclusion (Reffat and Harkness, 2001; Akram et al., 2014). The user interface manages the dialog between the user and the system that allows communication between them (Akram et al., 2014). The expert system has been successfully applied in various domains such as engineering, environmental protection, urban design, agricultural management, waste management, wastewater treatment, and medical treatment (Liao, 2005). Jin presented GIS-based expert system for onsite stormwater management (Jin et al., 2006). Say developed an expert system for Environment Impact Assessment (EIA) on energy power station (Say et al., 2007). Lee proposed GIS-Knowledge-based System (KBS) application in river land use assessment (Lee et al., 2008). Oprea suggested an expert system to analyze water, soil and air pollution (Oprea and Dunea, 2009).

There are several tasks to be completed in developing the ES-GSI: (1) knowledge base, (2) user interface, (3) inference engine, and (4) explanation facility. The user interface helps entering inputs data, and visualizing results in the reports form. The knowledge base acquires domain knowledge, experience, and regulations from experts by applying knowledge acquisition and representation techniques. The inference engine has forward chaining mechanism regarding to the experts experience presentation. The explanation facilities consider the structure of inference mechanism and knowledge base.

2 ES-GSI Framework

Decision trees and tables are used for the knowledge acquisition to acquiring expert knowledge in the ES-GSI development phase (Lee et al., 2008). Experts diagnose factors that affect green stormwater infrastructure in urban area by their experience and guidelines on urban storm water management. These factors formalized into assessment trees and tables to derive the control measures for urban stormwater management. The experts' evaluation processes and law regarding urban stormwater management are considered to construct the expert decision model and develop the inference engine. ES-GSI is developed by using Microsoft Visual Basic 6.

The ES-GSI framework is illustrated in Fig. 1 that includes knowledge base, working memory, inference engine, explanation facilities, knowledge acquisition, and user interface. The knowledge base contains information data, facts, rules, and their relationship (Oz, 2009) that is developed by acquiring and analyzing regulation and expert knowledge by IF-THEN rules. The working memory is a database of information and facts relevant to the domain area used by the rules (Shim and Siegel, 2005) that are about the current situation in a rule-based system. The inference engine is built by applying forward chaining control strategy in which rules can be used. The explanation facility allows the system to explain problem solving process and its reasoning to the user (Islam, 2004) to understand how the expert system arrived at certain results (Abraham, 2005). The user interface is responsible for translating the user data to the form used by the expert system (Chau and Albermani, 2002) that is designed friendly to assist the user for interaction with the ES-GSI. The characteristics of the ES-GSI are presented in Table 1 that states domain, knowledge resources, knowledge acquisition technique, knowledge representation technique, inference engine, explanation facility, development method, development tool, user interface, and objectives of the ES-GSI.

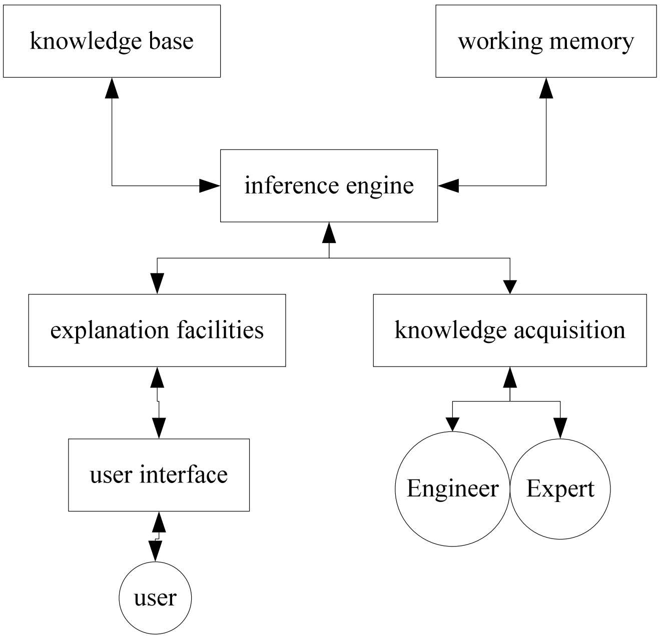

Fig. 1 ES-GSI framework.

Table 1 ES-GSI characteristics.

Items	Characteristics
Domain	Green stormwater infrastructure in urban area
Knowledge resources	Textbooks, manuals, guidelines, expertise
Knowledge acquisition technique	Decision table and tree
Knowledge representation technique	Rules
Inference engine	Forward chaining
Explanation facility	Relation between regulations and expertise analysis
Development method	Prototype
Development tool	Visual basic
User interface	Visual basic
Objectives	To help in managing stormwater in urban area

2.1 Knowledge base development

Development of ES-GSI knowledge base includes interviews with experts, design of decision tables and decision trees, evaluation of expert experience by application of Certainty Factor and Expert Choice software, and knowledge base development in a rule-based form. Ten experts were interviewed whom had professional skills in Green stormwater infrastructure from university and consultant. The Green stormwater infrastructure categories in urban area and assessment items were developed. For the assessment items, the experts defined five main types according to their expertise, including (1) benefits, (2) constraints, (3) suitable for, (4) maintenance, (5) key. Each type has various sub-types that are used for the assessment. These types and their sub-types are presented in Table 2.

Then for each type and sub-type, assessment tables were developed based on their properties and related regulations. Experts classified assessment into seven classes (Office of Sustainability), including (1) rainwater harvesting (I_1), (2) green roofs (I_2), (3) urban tree canopy (I_3), (4) alternative planting methods: tree boxes (I_4), (5) bioretention (I_5), (6) permeable pavement (I_6), and (7) no mow/ low mow areas (I_7). Table 3 lists the regulations of assessment for sub-types of the category of ‘‘Green stormwater infrastructure’’. For example, when suitable for is buildings, then experts make three suggestions, including I_1, I_2, and I_3.

Table 2 Type for green stormwater infrastructure in urban area.

Sub-type	
Constrains	
C_1	Poorly draining soils
C_2	Space limitations
C_3	Steep slopes
C_4	Retrofit use
Benefits	
B_1	Water quality
B_2	Air quality
B_3	Stormwatercapture
B_4	Habitat creation
B_5	Heat island effect
B_6	Water supply
B_7	Energy savings
Maintenance	
M_1	Watering (dry months)
M_2	Cleaning out debris
M_3	Weeding
M_4	Trimming
M_5	Other (mulch/mow/etc.)
Suitable	
S_1	Buildings
S_2	Streets
S_3	Landscape
Key	
K_1	Most appropriate
K_2	Moderately appropriate
K_3	Least appropriate

For building the decision tree, decision tables are used to acquire rules for designing the ES-GSI knowledge base. One decision table as an example is presented in Table 4. Decision tables were checked by experts to confirm consistency between these rules and used the results to build the knowledge base. To confirm this rule, expert’s recommendations were achieved by application of Certainty Factor (CF) where some conditions have one solution. Certainty factor (cf) is a number to measure the expert’s belief that its minimum and the maximum value are -1.0 (definitely false) and the maximum +1.0 (definitely true) respectively. The net certainty of hypothesis H for conjunctive rules is established as Equation 1 (Negnevitsky, 2005):

IF<evidence E1> OR <evidence E2> … OR<evidence En> THEN <hypothesis>{cf}.

$$cf\ (H, E_1\ E_2 \ldots E_n) = \max\ [cf\ (E_1), cf\ (E_2), \ldots, cf\ (E_n)] \times cf. \quad (1)$$

Table 3 Regulation for assessment of site sub-characteristics.

Characteristics	Sub-characteristics	Assessment
Constrains	C_1	$I_1, I_2, I_3, I_5, I_6, I_7$
	C_2	$I_1, I_2, I_3, I_5, I_6, I_7$
	C_3	I_1, I_2, I_3, I_6
	C_4	$I_1, I_2, I_3, I_5, I_6, I_7$
Benefits	B_1	$I_2, I_3, I_4, I_5, I_6, I_7$
	B_2	I_2, I_3, I_4, I_5, I_7
	B_3	$I_1, I_2, I_3, I_4, I_5, I_6, I_7$
	B_4	I_2, I_3, I_4, I_5, I_7
	B_5	I_2, I_3, I_4, I_5, I_7
	B_6	I_1, I_4, I_5, I_7
	B_7	$I_1, I_2, I_3, I_5, I_6, I_7$
Maintenance	M_1	I_2, I_3, I_7
	M_2	I_1, I_2, I_4, I_5
	M_3	I_2, I_7
	M_4	I_3
	M_5	$I_1, I_2, I_3, I_4, I_5, I_6, I_7$
Suitable	S_1	I_1, I_2, I_3
	S_2	I_3, I_4, I_5, I_6
	S_3	I_3, I_5, I_6, I_7
Key	K_1	$I_1, I_2, I_3, I_4, I_5, I_6, I_7$
	K_2	$I_1, I_2, I_3, I_4, I_5, I_6, I_7$
	K_3	I_4

Table 4 An example decision table for GSI selection.

Rules	Condition																			Action
	C_1	B_1	B_2	B_3	B_4	B_5	B_6	B_7	M_1	M_2	M_3	M_4	M_5	S_1	S_2	S_3	K_1	K_2	K_3	Suggestions
1	T	T	-	-	-	-	-	-	T	-	-	-	-	T	-	-	T	-	-	I_2, I_3
2	T	T	-	-	-	-	-	-	T	-	-	-	-	T	-	-	-	T	-	I_2, I_3
3	T	T	-	-	-	-	-	-	T	-	-	-	-	T	-	-	-	-	T	I_4
4	T	T	-	-	-	-	-	-	T	-	-	-	-	-	T	-	T	-	-	I_3
5	T	T	-	-	-	-	-	-	T	-	-	-	-	-	T	-	-	T	-	I_3
6	T	T	-	-	-	-	-	-	T	-	-	-	-	-	T	-	-	-	T	I_4
7	T	T	-	-	-	-	-	-	T	-	-	-	-	-	-	T	T	-	-	I_3, I_7
8	T	T	-	-	-	-	-	-	T	-	-	-	-	-	-	T	-	T	-	I_3, I_7
9	T	T	-	-	-	-	-	-	T	-	-	-	-	-	-	T	-	-	T	I_4

For some conditions by more than one solution, ES-GSI recommendation was achieved by Expert Choice software. To achieve best alternative, the experts defined three criteria such as social, economic, and environmental (Fig. 2). An example decision tree for selection of GSI is illustrated in Fig. 3.

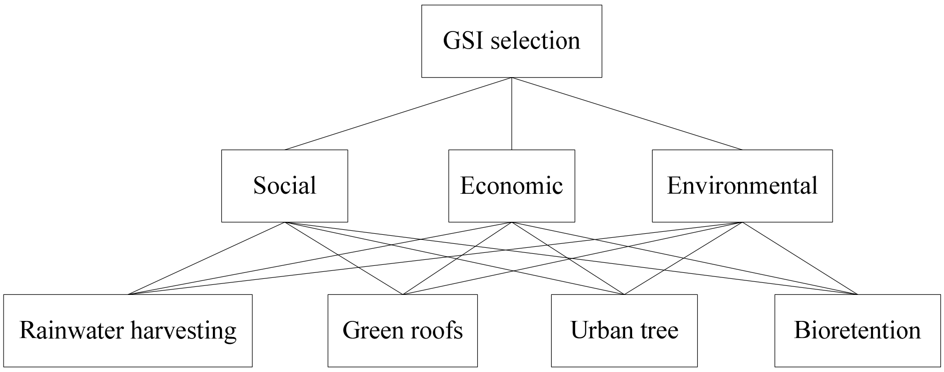

Fig. 2 Goal evaluation by criterion and alternative.

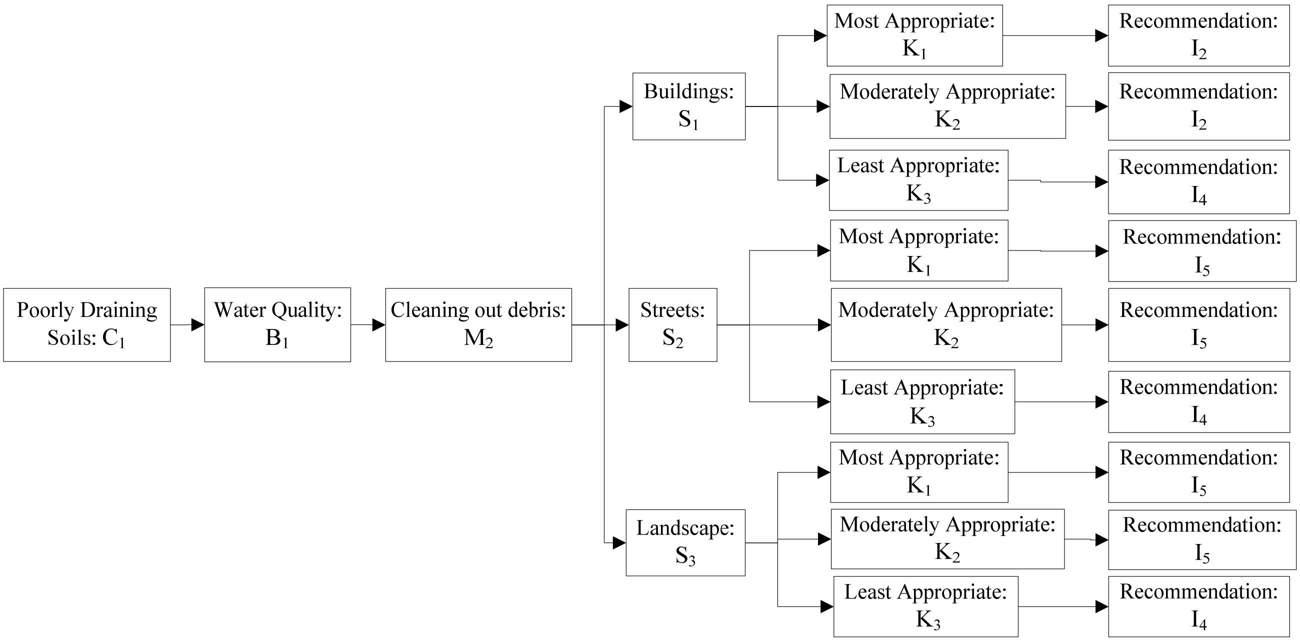

Fig. 3 An example decision tree for knowledge base.

2.2 Inference engine

ES-GSI inference mechanism is forward chaining. According to the request relevant data and information, ES-GSI inference engines check them by knowledge base rules to give suggestions.

2.3 User interface

ES-GSI user interface is developed by using Microsoft Visual Basic that provides graphical interface for user satisfaction. It supports friendly environment, help menus, easy reporting to the users. It enables users to achieve help and additional information such as conceptual flow diagram, glossary, and system description and guide. A sample screen of displaying GSI recommended is shown in Fig. 4.

2.4 Explanation facility

The explanation facility in ES-GSI presents results procedures and justification that means when a rule is matched; its related regulations and accuracy grade are shown. By this, a user can rely to the system results assessment.

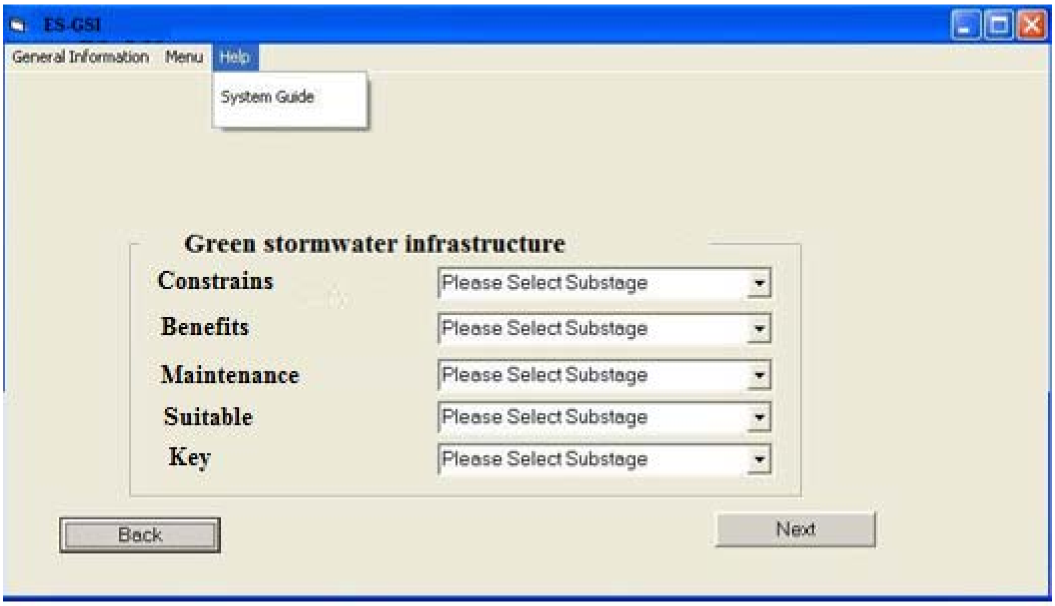

Fig. 4 An example of displaying GSI recommended.

3 System Testing and Evaluation

The developed ES-GSIwas evaluated, and at each stage its outputs were validated and revised. This was done during all stages of system development for its performance accuracy.

3.1 Unit testing

Only one unit is tested in unit testing (Aguilar et al., 2008). The ES-GSI was divided into two parts including system and graphic interface. Knowledge engineer was verified what each unit does to check all components of the developed system for correction of internal structure. Only normal mistakes were made during the testing that their code structures were modified.

3.2 Integration testing

Knowledge engineer was verified the correction of units working together in the integration testing (Aguilar et al., 2008). Interactions between the participants; end-user and system, present in Fig. 5. Knowledge engineer were tested the interactions between the participants; user data and system recommendation. Only normal mistakes were made during the testing that modified on the code structure.

3.3 User interface testing

The ES-GSI user interface was tested by four domain experts and two software development specialists to score a typical questionnaire (Durkin, 1994). The questionnaire parameters were ranked from 1 to 5 (Li and Li, 2009). Based on the experts feedback, developed system was evaluated and improved until it was fulfilled 90% of the maximum scores that presented in Table 5 (Azadeh et al., 2009).

3.4 Comparison of system results, internal experts, and external experts

External experts by using ES-GSI were conducted the evaluation of system recommendations and internal experts suggestions. In this case, interview was conducted with tow internal experts and four external experts.

According to Durkin (1994) the external experts can judge results accuracy in a range of percentage of the cases, or system did as well, or better than the experts. The external expert feedback and internal expert suggestions are illustrated in Table 6.

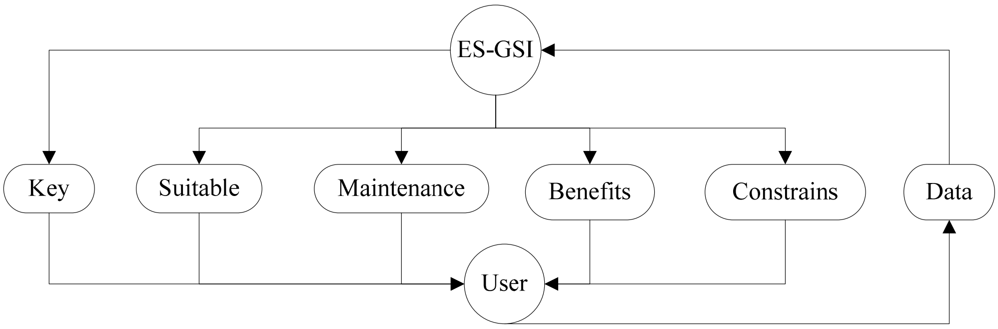

Fig. 5 Interaction between participants.

Table 5 User response for typical usability design factors.

Measurement
General considerations:
System is useful (not useful 1 2 3 4 5 extremely useful), speed of system (low 1 2 3 4 5 very high)
System utilities:
Complete (not confident 1 2 3 4 5 extremely confident), easy to access (not easy 1 2 3 4 5 very easy)
Ease of use (not easy 1 2 3 4 5 very easy):
Starting the system, interface technique, help facilities, obtaining explanation
Nature of questions (not helpful 1 2 3 4 5 extremely helpful):
Clarity of terms, clarity of questions
Nature of explanations (not use 1 2 3 4 5 extremely useful):
Why explanation
Presentation of results:
Complete (not confident 1 2 3 4 5 extremely confident), easy to follow (not easy 1 2 3 4 5 very easy)

Table 6 Feedback from external expert to compare system and internal experts recommendations.

Review session	Internal experts (%)		External feedback			
	Expert1	Expert2	Reviewer1	Reviewer 2	Reviewers3	Reviewers4
Type 1	100	90.9	ES adequate	ES did as well	ES adequate	ES acceptable
Type 2	100	100	ES did as well	ES acceptable	ES acceptable	ES adequate
Type 3	100	100	ES adequate	ES did as well	ES adequate	ES adequate
Type 4	98	100	ES acceptable	ES acceptable	ES did as well	ES did as well
Type 5	100	100	ES acceptable	ES adequate	ES acceptable	ES acceptable

3.5 Reviewers feedback by ES-GSI application

The ES-GSI was demonstrated to four experts who are specialist in green stormwater infrastructure to evaluate the developed system. A special questionnaire that covered topics and sections such as knowledge base contents, knowledge acquisition techniques, decision-making speed, explanation and help facility, recommendations confidence was designed to acquire experts recommendation (Table 7) (Lee et al., 2008; Li and Li, 2009). Due to law and regulations change over time, the reviewers recommended to maintain the ES-GSI knowledge base continuously.

3.6 Validation of system reasoning

During testing knowledge integrality, all rules from rule base were checked to find any erroneous types to modify them.

Table 7 Feedback from reviewers to validate system.

Review session	Reviewers feedback			
	Expert 1	Expert 2	Expert 3	Expert 4
Knowledge acquisition techniques	Acceptable	Acceptable	Adequate	Acceptable
Knowledge base contents	Adequate	Adequate	Acceptable	Acceptable
Explanation facilities	Acceptable	Adequate	Adequate	Adequate
Speed of decision-making	Adequate	Acceptable	Adequate	Acceptable
Help facilities	Adequate	Adequate	Acceptable	Adequate
System recommendations	Acceptable	Acceptable	Adequate	Acceptable

4 Conclusion

This research has described the green stormwater infrastructure selection with respect to its use in urban area. VB is used to develop the database and user interface to provide system recommendation. The study employs questionnaire, decision trees and tables to acquire expert experience and knowledge, transforms knowledge and experience into rules, stores rules in knowledge base, certainty factor application for rules assessment, uses a forward chaining mechanism for inference engine building, expert choice software application for various alternatives by social, economy and environment, develops an explanation facility to give assessment details, and provides assessment recommendation and suggestions in pdf format. Knowledge sources in this study include manuals, textbooks, guidelines, research publications, law, and expert expertise on green stormwater infrastructure selection for urban area. During ES-GSI development, it is found that the knowledge base establishment is the time-consuming and important task. The ES-GSI applied for selection of green stormwater infrastructure in urban area. Other perspectives in terms of applications such as green stormwater infrastructure design may need particular principles and special knowledge bases.

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