A systematic approach to major project sustainability assessment

Zhen Chen[1] , Andrew Agapiou[2], and Heng Li[3]

Abstract: This paper describes a multicriteria decision making approach to lifecycle sustainability assessment (LiSA) in major project development. It aims at an alternative quantitative method for effectively supporting the justification of major project development plans and related design at various work stages specified by RIBA Plan of Work 2013, so as to satisfy the need for and to demonstrate the advantage of multicriteria underpinned assessment on the lifecycle value of development options and technical designs with regard to the whole range of requirements on sustainability in relation to social, technical, economic, ecological, and political (STEEP) issues within an imaginable lifespan of individual projects. The described research consists of three main parts, including the identification of sustainability assessment criteria, the development of a multicriteria evaluation model, and a case study on plan or design evaluation in major project development. The LiSA methodology presented here has been developed for and applied in one experimental case study on the new Royal Hospital project in Liverpool; and it has yielded a promising result which showed an exact match to the development plan actually adopted. It is expected that the LiSA methodology described could be useful for well-informed sustainability assessment in major project practice.

Keywords: Sustainability; Assessment; Lifecycle; Major project; Plan of Work

[1] Lecturer, Department of Architecture, University of Stathclyde, 75 Montrose Street, Glasgow G1 1XJ, Glasgow, UK *Corresponding author*. Phone: +44 (0)7532075319. E-mail: z.chen@live.com

[2] Senior Lecturer, Department of Architecture, University of Stathclyde, 75 Montrose Street, Glasgow G1 1XJ, Glasgow, UK. E-mail: andrew.agapiou@strath.ac.uk

[3] Professor, Department of Building and Real Estate, The Hong Kong Polytechnic University, 11 Yuk Choi Road, Hung Hom, Hong Kong, China. E-mail: heng.li@polyu.edu.hk

Introduction

Multicriteria decision making process and solutions are crucial to support informed assessment on engineering and management strategies as well as technical solutions for construction projects, especially major projects which have significant impacts to many areas relating to the society, the economy, and the profession etc. in short and longer term. As one of the most powerful multicriteria decision-making approaches, the analytic network process (ANP) (Saaty, 2005) has been coming into practice oriented experimental applications in construction related areas in the past decade, and it has been experimentally adopted in the following applications (Chen, 2007) to evaluate alternative

- Design solutions for buildings and building façade systems,
- Learning materials in professional education,
- Partners for specific projects,
- Places for locating new construction projects,
- Plans for either construction or demolition projects, and
- Systems for either enterprise or project management.

As the ANP approach allows decision makers to set up their decision-making models based on not only an entire consideration on complex inter-relations among all main criteria and their sub-criteria for evaluation, but also a reliable collection and reuse of experts' judgments and knowledge in related technical domains, ANP models can therefore be regarded as a practical interpretation of collective expertise to support useful informed decision making. Although ANP has been proved powerful in terms of an effective use of experts' knowledge and an objective interpretations of the situation of interactions among all evaluation criteria, there are related issues such as the quality of evaluation criteria need to be dealt with to further prompt the application of this advanced multicriteria decision making technique in order to derive dependable results from ANP modelling.

In response to the need for reliable evaluation criteria in multicriteria decision making support, and the use of sustainability checkpoints specified in the RIBA Plan of Work 2013, a preliminary research into developing a lifecycle sustainability assessment methodology for major project development has been recently conducted, and this paper aims to describe this research in the following sections:

- The methodology of lifecycle sustainability assessment (LiSA),
- TRIZ (Gadd, 2011): An inventive problem solving approach to deriving reliable evaluation criteria for sustainability assessment,
- ANP (Saaty, 2005): A powerful multicriteria decision making approach to supporting sustainability assessment, and
- Experimental case studies on sustainability assessment for major projects.

The contributions of the research described in this paper include a new methodology of lifecycle sustainability assessment for major project development, a set of evaluation criteria that has been tested in experimental case studies. It is expected that research outcomes as described in this paper could be useful for sustainability assessment in major project development. The set of exemplar evaluation criteria has been used in developing ANP models described in experimental case studies, and these experiments have yielded a promising result that has shown a good match between experimental results and practical solution in those selected major projects. Further research will focus on improving the quality of evaluation criteria in order to develop more reliable assessment to support decision making towards sustainability in major project development.

Lifecycle sustainability assessment

The principle on the value for money has been widely adopted in project management, and the approach to lifecycle value assessment (LCVA), which involves a series of techniques and tools to help decisionmakers elicit more complete financial, environmental and social information about the impact of individual projects, products, or services, has been recognized as a unique, practical and multidisciplinary systemsanalysis methodology for business decisions and technical design (Row and Neabel, 2005). As mentioned by Cook (2007), the LCVA tool is designed to look at a project's metrics and impacts in a holistic manner, which is highly beneficial to major stakeholders on decision making support in major project development. This research has therefore aimed to adopt the concept of LCVA into a multicriteria lifecycle sustainability assessment (LiSA) framework for major project development.

The LiSA methodology consists of several available techniques that can be integratively used to support the purpose. Fig. 1 illustrates how two selected core techniques including TRIZ (Gadd, 2011) and ANP (Saaty, 2005) respectively underpinned by case studies and experts' judgments are connected to each other and integrated with the RIBA Plan of Work 2013 (RIBA, 2013). The reasons for choosing the two core techniques for LiSA are given below:

- TRIZ was chosen to facilitate a formal process in literature and practice review so as to derive a set of reliable evaluation criteria for sustainability assessment with regard to a comprehensive consideration on STEEP issues in relation to various characteristics of development on different scales at project, programme, and portfolio levels over a chosen time period covering the whole project lifecycle.
- ANP was chosen to facilitate another formal process in multicriteria decision making in order to quantitatively measure the importance of evaluation criteria, which have been derived from a TRIZ process, and their interactions among each other in relation to the sustainability of major project under assessment.

Details of how to use the two core techniques are given in the next two sections.

<Insert Figure 1. A TRIZ and ANP integrated decision-making support framework for LiSA.>

The work procedure specified by the RIBA Plan of Work 2013 has been adopted to integrate within the LiSA framework (see Fig. 1) as embedded work stages where multicriteria sustainability assessments are required and/or necessary, and it was chosen in this research to facilitate a formal process on lifecycle sustainability assessment with regard to its supports to staged work under specific sustainability checkpoints, which are summarized in Table 1, at the eight work stages. Besides the integration of ANP driven multicriteria sustainability assessment into each work stage, there are also necessary connections between the TRIZ process, which is underpinned by case studies to derive evaluation criteria, and the technical details of specific sustainability checkpoints (RIBA, 2013) in relation to specific STEEP issues at individual work stages in order to ensure a set of reliable evaluation criteria to be used in individual sustainability assessment.

<Insert Table 1. Lifecycle sustainability checkpoints.>

TRIZ

In sustainability assessment, it is important to define a set of evaluation criteria which can be used for reliable assessment. In general, the evaluation criteria to support a reliable sustainability assessment needs to be derived and defined according to a thorough understanding on issues related to the sustainability of the building or civil infrastructure under assessment. Form this point of view, an extensive review on literature and practice in relation to characteristics of the specific project could be essential and helpful to build up the reliability of evaluation criteria at the start of assessment, while it is expected that such an extensive review is guided under a formal procedure. Based on the authors' experience and observation in research into multicriteria sustainability oriented assessment relating to buildings and civil infrastructures over the past decade, a practical 9-window approach from the TRIZ theory was chosen to integrate into the LiSA framework.

TRIZ is the Russian acronym for "Teoriya Resheniya Izobretatelskikh Zadatch" (Theory of Inventive Problem Solving) and was developed in 1940s by soviet inventor Genrich Altshuller and his colleagues (Gadd, 2011), and it has been widely received and applied in the creative sector and some other sectors. One particular approach of applied TRIZ is the 9-window process, which can facilitate a systematic review into a specific problem with regard to its scale covering micro-system, system and macro-system level, and timeline covering past, present, and future scopes. In research into the sustainable built environment, the 9window process has been applied in conducting a multicriteria assessment of façade systems with regard to the whole life value of the design (Chen, et al., 2007) and deriving the framework of the body of knowledge of facilities management (FMBOK) and a set of principles of facilities management (Chen, 2017). These two applications demonstrated that the 9-window process is a useful method in finding appropriate evaluation criteria for sustainability oriented assessment.

<Insert Table 2. Exemplar LiSA criteria for major project development.>

In this research, a set of evaluation criteria was derived from an extensive review into literatures and practice through the 9-window process illustrated in Fig. 1, and the process across the 9 windows focuses on the sustainability with regard to the scale and timeline of major project development:

- Scale: The review focuses on the scale of major project development within the same project category based on three levels including individual projects within the entire programme of major project development, the single major project programme, and the portfolio of major project programmes.
- Timeline: The review focuses on three time scopes including the experience and knowledge in response to related queries on what have happened in the past, what are happening at present, and what may happen in a short and longer term in the future on individual projects, their major project programme, and the portfolio of major project programmes in the same project category.

Table 2 describes a set of exemplar evaluation criteria and their valuation methods for sustainability assessment considering relevant STEEP issues in major project development, and these evaluation criteria have been then used for sustainability assessment in experimental case studies described below. The evaluation criteria collected in Table 2 provides a broad range of coverage to STEEP issues related to major project sustainability. Although there was not specific criteria on some particularly given by RIBA (2013) about Sustainability Checkpoints as summarized in Table 1, for example, the Site Waste Management Plan at Stage 1, and the Building Regulations Part L assessment at stage 2, the set of exemplar evaluation criteria given in Table 2 can not only reflect these requirements on environmental protection in a different way such as the total environmental impact index (EII) (See Table 4), but also include other related evaluation for sustainability assessment.

Analytic Network Process (ANP)

The ANP (Saaty, 2005) is a general theory of multicriteria decision-making support through relative measurement used to derive composite priority. An ANP model consists of two functional parts, including a network of quantitative interrelationships among each paired clusters (main criteria) and nodes (subcriteria); and a network of all criteria to control interactions based on interdependencies and feedback according to experts' judgments. The process eventually gives priorities among options under evaluation with respect to the goal of a system being considered.

The use of ANP can follow four main steps, and these include model construction by setting up an interconnected network of clusters and nodes based on chosen criteria including main criteria and subcriteria; pairwise comparisons between each two paired clusters or nodes; super-matrix calculation based on results from pairwise comparisons; and analysis calculation results to complete an assessment. Details of the ANP procedure in four steps are given below.

Step 1: ANP model. It aims to set up a network model based on determining the control hierarchies of STEEP factors, as well as the corresponding criteria for comparing both the main criteria (clusters) and subcriteria (nodes) of the system, together with a determination of the clusters and their elements for control criteria or sub-criteria. Regarding how to quantitatively select the most appropriate sub-criteria for defined control criteria, two approaches have been previously developed (Chen, Li and Turner, 2008), including the Energy-Time use Index and the Environment Impacts Index. In this research, these two approaches were incorporated into the use of 9-window process to derive a set of reliable evaluation criteria.

Step 2: Pairwise comparisons. It aims to perform pairwise comparisons among clusters and nodes, which are interdependent to each other on various scales. Upon pairwise comparisons, the relative importance weight of interdependence is determined by using a scale of pairwise judgment, where the relative importance weight is valued from 1 to 9 (Saaty, 2005). The weight of interdependence is determined by experts who are abreast with professional experience and knowledge in the application area, i.e., major project sustainability in this research. In order to facilitate the process of effectively collecting experts' opinions in regard to the importance of sub-criteria as well as control criteria through questionnaire survey, a pairwise table approach called Pairwiser (Chen, 2010) was adopted to facilitate the collection of experts' judgments.

Step 3: Super-matrix calculation. It aims to form a synthesized super-matrix to allow for the resolution of the effects of the interdependences that exists among elements (nodes and clusters) of the ANP model. In order to obtain useful data for the final assessment, the calculation of super-matrix is to be conducted following three sub-steps, which transform an initial super-matrix to a weighted super-matrix, and then to a synthesized super-matrix. The super-matrix calculation can be implemented by using the SuperDecisions software.

Step 4: Final assessment. This step aims to identify the most appropriate optional solution from all options in order to support final decision making. This selection is to pick up the one that could have the highest weight from the synthesized super-matrix.

<Insert Figure 2. An ANP model.>

The ANP is a mathematical process that can provide a calculation result to support assessment. As it is essential to ensure quality assessment on each specific project, assessment criteria selected should be comprehensive, identical, and practical with regard to general and specific sustainability requirements in major project development. Therefore, an extensive literature review through the use of TRIZ process can better help ANP modellers to form an initial list of reliable criteria, which can further be reviewed and modified by an expert group. As outcomes from this research, Table 1 summarizes the initial criteria in five categories on STEEP issues relating to sustainability assessment in major project development, and provides valuation methods to quantify those identified factors before the next step on ANP modelling; in addition, Fig. 2 illustrates an ANP model set up using exemplar evaluation criteria for sustainability assessment in major project development.

Experimental case study

The concept of LiSA has been applied in several experimental case studies over the past more five years. In order to demonstrate the procedure and effectiveness of using the LiSA methodology in sustainability oriented assessment for major projects, this section describes one experimental case study on the new Royal Liverpool University Hospital, one major project development in Liverpool, England.

The case study has been conducted through the collection of data and information on site visits to, consultation documents received from, as well as news reports about the new Royal Hospital in Liverpool. The development of the new £429m Royal Liverpool University Hospital has experienced an extensive preparation stage while many multidisciplinary connected aspects on sustainability have been carefully addressed through consultations, design, construction and operation. Based on client's feasibility study at early stage, a wide range of stakeholders were consulted from July to October 2008 regarding two optional plans for a new hospital to replace the old Royal Liverpool University Hospital. According to the Liverpool NHS Trust (2008), the client has investigated the options available for the future provision of the hospital services planned under its service model to be based at its hospitals, and the following two overall options for the Royal site were considered at consultation stage:

- Plan A: developing a new hospital building next to the existing hospital building, and
- Plan B: refurbishing the existing hospital building.

<Insert Table 3. Assumptions of alternative development plans for ANP evaluation.>

While both development plans entail investment to improve facilities at related hospitals and related services, and were considered in a detailed option appraisal involving its stakeholders, the client's preferred solution was Plan A, which is based on a comparison among a range of criteria in terms of how each option would improve service delivery, facilities, health outcomes, patient experience and satisfaction, staff experience and motivation, as well as how difficult it would be to implement each option and their impact on the wider community (Liverpool NHS Trust, 2008). In addition to the initiative on the development of a new modern region-wide university hospital, the Liverpool NHS Trust (2015) launched its first Sustainable

Development Management Plan in 2014 and has continuously conducted annual Good Corporate Citizen

Assessment to manage sustainability and the responsibilities at post-construction stage. The new hospital project therefore has demonstrated an excellent example with regard to lifecycle assessment in major project development.

With regard to the use of LiSA methodology at the preparation stage of major project development, it is of the authors' interest to identify whether it could support the justification of this client's preferred option with calculated results. Although interdependences among the 31 chosen evaluation criteria can be measured based on experts' knowledge, i.e., experts' judgments as illustrated in Fig. 1, the ANP model should comprehend all specific characteristics of each option. Therefore Table 3 is adopted to transform specific features of optional plans into a worksheet that can be further used for setting up an

ANP model. Based on technical information and scenario of the two development options in this specific major project, further assumptions are made in Table 3. In order to make more reasonable assumptions, data and information available from past construction projects in the same type were also considered; and one of most important sources of related data and information is Building Cost Information Service (BCIS) of RICS.

<Insert Table 4. The environmental impacts of alternative development plans.>

<Insert Table 5. Comparison of alternative development options.>

In complying with the fundamental scale of pair-wise judgments (Saaty, 2005) in ANP, all possible interdependences between each option and each evaluation criterion and between paired evaluation criteria in regard to each alternative plan are measured for the ANP model (see Fig. 2), and this forms a twodimensional super-matrix for further calculation, which transform an initial super-matrix based on pair-wise comparisons to a weighted super-matrix, and then to a synthesized super-matrix. Results from the synthesized super-matrix are given in Table 5. According to the results, Plan A was identified as the most appropriate plan for this specific project because it has the highest synthesized priority weight among the two alternatives and this result was derived as a reliable collective decision jointly made by a group of experts who provided judgments on the sustainability of this major project. As result, it is the LiSA's suggestion to select Plan A for this hospital regeneration project in Liverpool.

Conclusions and recommendations

This paper describes a research into a novel methodology for sustainability assessment at different stages in line with the procedure of the RIBA Plan of Work 2013 through the lifecycle of major projects, and presents an experimental case study on the use of this methodology in the sustainability assessment at preparation stage. The STEEP criteria have been introduced to set up an ANP model, which has been tested in the experimental case study and has provided a promising result in terms of an exact calculation result that matches client's preference and actual choice.

Future research are expected in other related areas such as a series of evaluation criteria sets that can not only reflect the need for generic sustainability assessment at each work stage in relation to sustainability checkpoints specified by the RIBA Plan of Work 2013, but also support better consideration on challenging issues such as risks on possible cost and time overruns in relation to the lifecycle sustainability of major projects.

References

Chen, Z. (2007). *Multicriteria decision-making for the sustainable built environment*. University of Reading, Reading, UK. ISBN: 0-7049-1209-0.

Chen, Z., Clements-Croome, D.J., Li, H., Shen, G.Q.P., Chung, J.K.H. (2007). "A TRIZ based ANP approach to value management in façades assessment." *The Value Manager*, 13(2): 3-8.

Chen, Z., Li, H., and Turner, J.R. (2008). "Environmental management." In J.R. Turner (Ed.), *Gower Handbook of Project Management*, 4th Edition, Gower Publishing Ltd., UK. 483-521.

Chen, Z. (2010). "A cybernetic model for analytic network process." *Proc. of the 9th IEEE Intl. Conf. on Machine Learning and Cybernetics*, 11-14/07/2010, Qingdao, China. 194-199. DOI:

10.1109/ICMLC.2010.5580528.

Chen, Z. (2017). "The principles of facilities management and case studies." *Proceedings of Doctoral Workshop in Building Asset Management*, Association of Researchers in Construction Management (ARCOM), 21 January 2017, Glasgow Caledonia University, Glasgow, UK.

Cook, D.L.M. (2007). "From the Cradle to the Grave: triple-bottom-line planning tool makes its place in the oilsands industry." *Oilsands Review*, 12: 40-43.

Gadd, K. (2011). *TRIZ for Engineers: Enabling Inventive Problem Solving*, Wiley, UK.

Liverpool NHS Trust (2008). *A new health service for Liverpool*. Royal Liverpool and Broadgreen University Hospitals NHS Trust, Liverpool, UK.

Liverpool NHS Trust (2015). *Sustainability Plan 2015-16*. Royal Liverpool and Broadgreen University Hospitals NHS Trust, Liverpool, UK.

Row, J., and Neabel, D. (2005). *Integrated Manure Utilization System Life-Cycle Value Assessment*. The Pembina Institute, USA.

RIBA (2013). *Guide to using the RIBA plan of work 2013*. RIBA Publishing Ltd., London.

Saaty, T.L. (2005). *Theory and applications of the analytic network process*, RWS Publications, Pittsburgh, USA.

Figures

Figure 1. A TRIZ and ANP integrated decision-making support framework for LiSA. Figure 2. An ANP model.

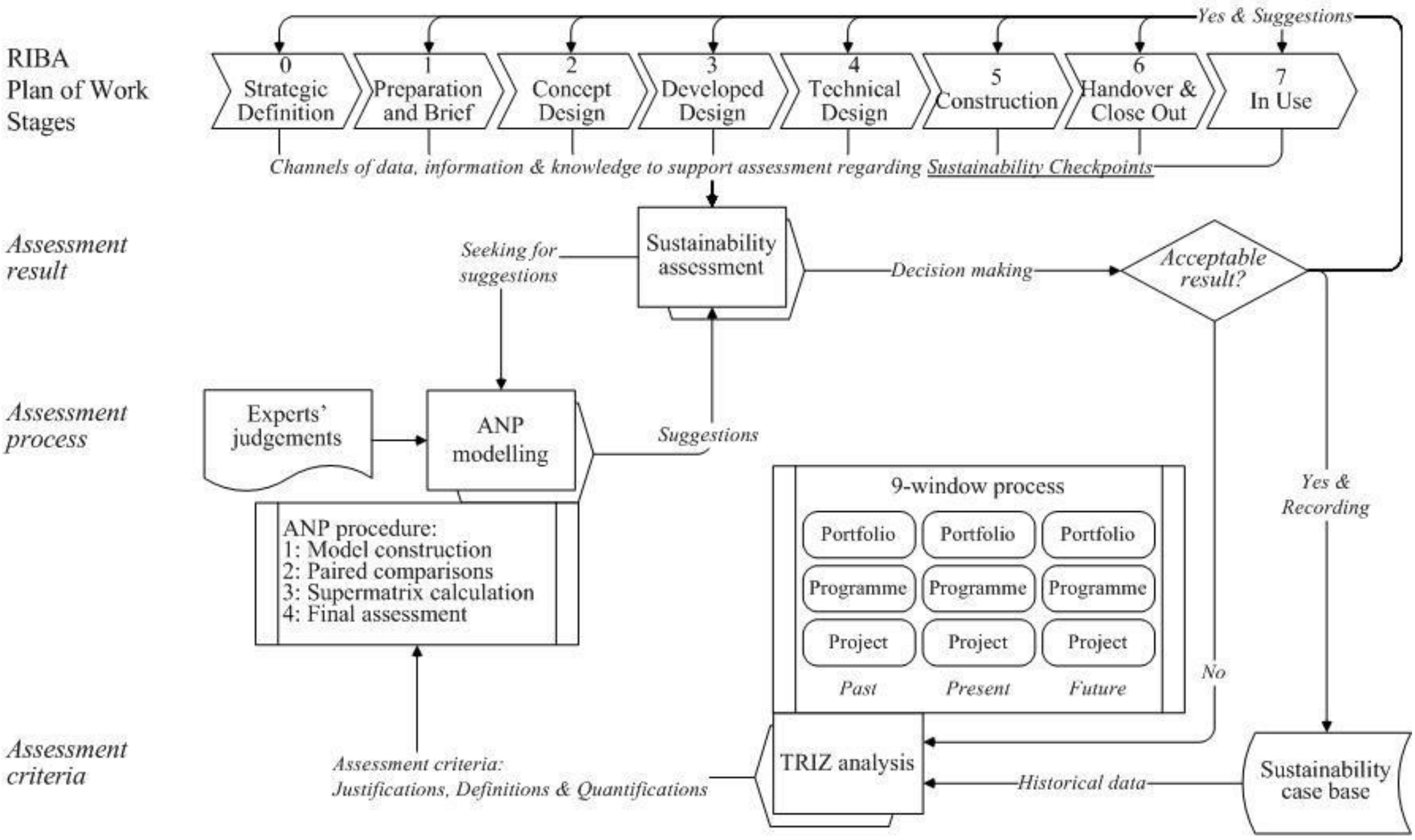

Figure 1. A TRIZ and ANP integrated decision-making support framework for LiSA.

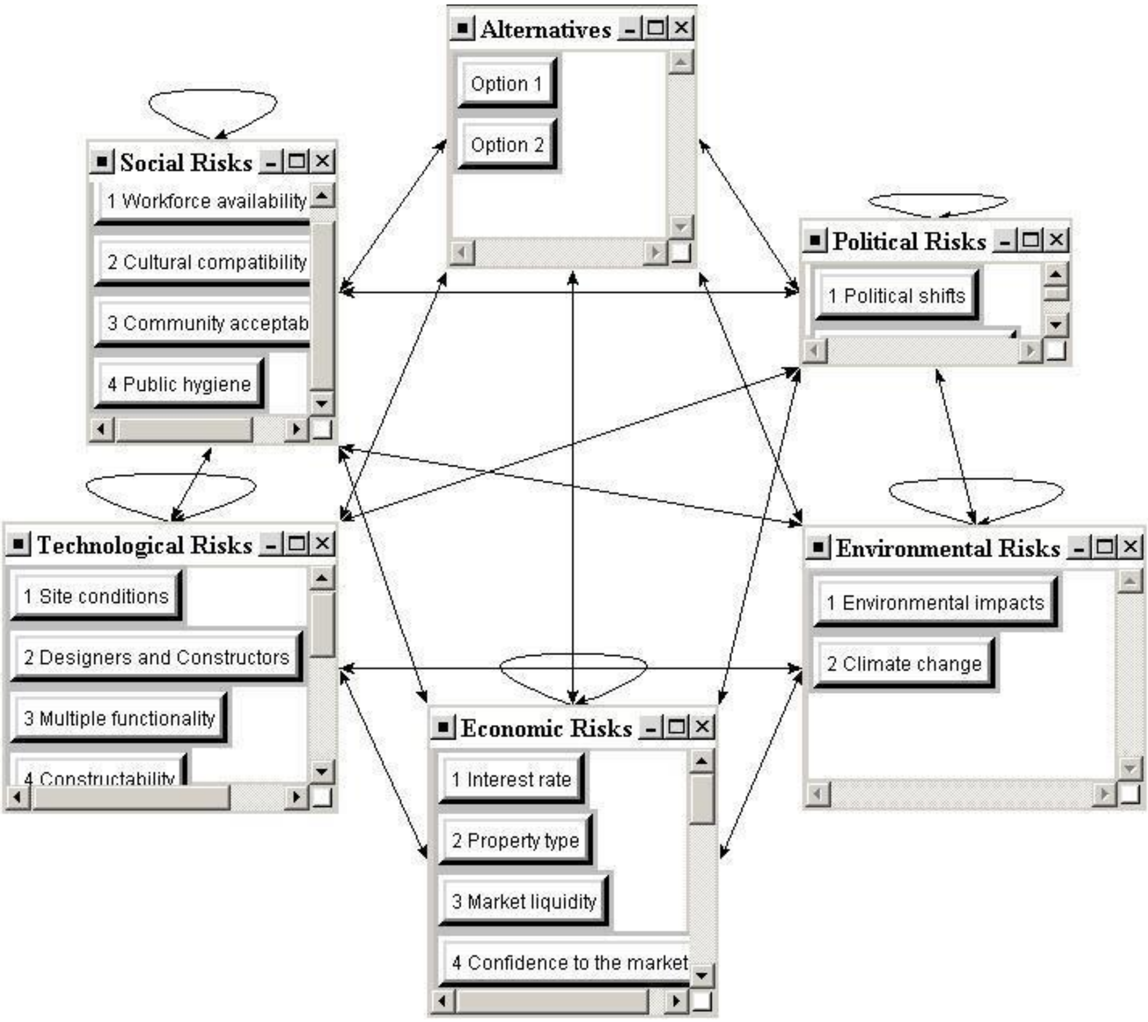

Figure 2. An ANP model.

Tables

Table 1. Lifecycle sustainability checkpoints.

Work Stage	**RIBA Work Task on Sustainability Checkpoints** (RIBA, 2013)
0 Strategic Definition	A strategic sustainability review of client needs and potential sites.
1 Preparation and Brief	• A statement of formal sustainability targets on environmental requirements, building lifespan and future climate parameters, etc. in the Initial Project Brief. • Early-stage consultations and surveys to meet assessment criteria and procedures. • Principles of Handover Strategy & post-completion services in Schedule of Services. • Implementation of the Site Waste Management Plan.
2 Concept Design	• Formal sustainability pre-assessment. • Identification of key areas of design focus. • Report and agreement on any deviation from the Sustainability Aspirations. • The initial Building Regulations Part L assessment. • Descriptions: internal environmental conditions, seasonal control strategies/systems. • The environmental impact of key materials and the Construction Strategy. • Consideration on the resilience to future changes in climate.
3 Developed Design	• A full formal sustainability assessment. • An interim Building Regulations Part L assessment. • A design stage carbon/energy declaration. • Design review to identify opportunities to reduce resource use and waste. • Record of design review results in the Site Waste Management Plan.
4 Technical Design	• A substantially completed formal sustainability assessment. • A detailed audit for airtightness and continuity of insulation. • A prepared Building Regulations Part L submission. • An updated design stage carbon/energy declaration. • A prepared future climate impact assessment. • A draft non-technical user guide. • An agreement on the format and content of the Part L log book. • Submission of all outstanding design stage sustainability assessment information. Specifications of building Handover Strategy and monitoring technologies. • Review on implications of changes to specification/design against agreed criteria. • Demonstration on the compliance of agreed assessment criteria.
5 Construction	• A certified design stage sustainability assessment. • A sustainability procedure with the contractor in the Construction Strategy. • A review on the detailed commissioning and Handover Strategy programme. • Review and observation on construction contractor’s interim testing and monitoring. A non-technical user guide and the aftercare service set up. • 'As Constructed' Information issued for post-construction sustainability certification.

6 Handover		Assistance with the collation of post-completion info for sustainability certification.
7 In Use	•	Observation of the building operation in use.
	•	Assistance with fine tuning and guidance for occupants.
	•	Declare the energy/carbon performance.

Table 2. Exemplar LiSA criteria for major project development.

Clusters and Nodes	Valuation methods
Social factors	
Workforce availability	Degree (%) of Developer's satisfaction to local workforce market.
Cultural compatibility	Degree (%) of business & lifestyle harmony.
Community acceptability	Degree (%) of benefits for local communities.
Public hygiene	Degree (%) of impacts to local public health & safety.
Technical factors	
Site conditions	Degree (%) of difficulties in site preparation for each specific plan.
Designers and Constructors	Degree (%) of Developer' satisfaction to their professional experience.
Multiple functionality	Degree (%) of multiple use of the property.
Constructability	Degree (%) of technical difficulties in construction.
Duration	Total duration of design and construction per 1,000 days (%).
Amendments	Possibility (%) of amendments in design and construction.
Facilities management	Degree (%) of complexities in facilities management.
Accessibility & Evacuation	Degree (%) of easy access and quick emergency evacuation in use.
Durability	Probability (%) of refurbishment requirements during buildings lifecycle.
Environmental factors	
Adverse environment impacts	Overall value of the Environmental Impacts Index
Climate change	Degree (%) of impacts to use and value due to regional climatic variation.
Economic factors	
Interest rate	Degree (%) of impacts due to interest rate change.
Property type	Degree (%) of location concentration.
Market liquidity	Selling rate (%) of same kind of properties in the local market.
Confidence to the market	Degree (%) of expectation to the same kind of properties.
Demand and Supply	Degree (%) of regional competitiveness.
Purchasability	Degree (%) of affordability to the same kind of properties.
Brand visibility	Degree (%) of Developer's reputation in specific development.
Capital exposure	Rate (%) of estimated lifecycle cost per 1 billion pound.
Lifecycle value	25-year property depreciation rate (%).

Area accessibility	Degree (%) of regional infrastructures usability.
Currency conversion	Degree (%) of impacts due to exchange rate fluctuation.
Buyers	Expected selling rate (%).
Commercial tenants	Expected annual lease rate (%).
Investment return	Expected capitalization rate (%).
Political factors	
Political shifts	Probability (%) for rapid political shifts.
Regulatory Impact	Probability (%) of regulatory impact.

Table 3. Assumptions of alternative development plans for ANP evaluation.

			Options	
Criteria	**Sub-Criteria**	**Unit**	Plan A	Plan B
Social risks	Workforce availability	%	100	90
	Cultural compatibility	%	90	70
	Community acceptability	%	100	80
	Public hygiene	%	80	100
Technological risks	Site conditions	%	20	20
	Designers and Constructors	%	100	100
	Multiple functionality	%	100	70
	Constructability	%	10	20
	Duration*	%	182	365
	Amendments	%	80	90
	Facilities management	%	90	100
	Accessibility & Evacuation	%	100	90
	Durability	%	70	90
Environmental risks	Environment impacts**	%	-179	-129
	Climate change	%	40	50
Economic risks	Interest rate	%	70	80
	Property type	%	80	80
	Market liquidity	%	90	80
	Confidence to the market	%	90	80
	Demand and Supply	%	100	70
	Purchasability	%	100	100
	Brand visibility	%	100	90
	Capital exposure*	%	48	62
	Lifecycle value	%	-15	-20
	Area accessibility	%	90	80

	Currency conversion	%	30	60
	Buyers (Patients)	%	80	50
	Business Tenants	%	100	80
	Investment return	%	10	7
Political risks	Political shifts	%	10	20
	Regulatory Impact	%	20	50

Notes:

* Rates about Duration and Capital exposure are based on real figures given in Table 5. ** Calculations are given in Table 4.

Table 4. The environmental impacts of alternative development plans (Chen, et al., 2005).

No.	**Factors of adverse impacts**	$\lambda_{i,j}$	***EII$_{i,j}$***	
			Plan A	Plan B
1	Soil and ground contamination	0.3	-0.5	-0.4
2	Ground and underground water pollution	0.3	-0.1	-0.1
3	Waste	0.7	-0.8	-0.5
4	Noise and vibration	0.7	-0.4	-0.6
5	Dust	0.7	-0.5	-0.5
6	Hazardous emissions and odors	0.5	-0.3	-0.3
7	Wildlife and natural features impacts	0.2	-0.1	-0.1
8	Archaeology impacts	0.5	-0.5	+0.3
	Total impact		-1.79	-1.29

Note: The calculation of the total environmental impact index: $EII_i = \sum_{j=1}^{8} \lambda_{i,j} EII_{i,j} \qquad (j = 1, 2, \ldots, 8)$

- *EII$_i$* is the total environmental impact caused by *KPI$_i$* or *Project$_i$*.
- *EII$_{i,j}$* is individual environmental impact leading to one of the eight possible pollutions and hazards, including Soil and ground contamination (*j*=1), Ground and underground water pollution (*j*=2), Waste (*j*=3), Noise and vibration (*j*=4), Dust (*j*=5), Hazardous emissions and odors (*j*=6), Wildlife and natural features impacts (*j*=7), and Archaeology impacts (*j*=8).
- $_{i,j}$ is the coefficient of *EII$_{i,j}$*. The value of $_{i,j}$ is defined to be a subjective weight that belongs to the range of [0, 1] in terms of the tendency of environmental management in a project; generally, if $_{i,j}$ is set to a outer extreme, say 0, it means that the specific adverse environmental impact *j* (j=1,2,…,8) is basically ignorable; and if $_{i,j}$ is set to 1, it means that the specific adverse environmental impact *j* (j=1,2,…,8) is extremely considerable.

Table 5. Comparison of alternative development options.

Main project characteristics (Liverpool NHS Trust 2008)	**Options**	
	Plan A	Plan B
Redevelopment plan	New build	Refurbishment
Expected period (years)	4	9
Estimated total investment (million pounds)	477	612
Fit for purpose of the client	Yes	Partially
Achieves the client's vision	Yes	Partially
ANP results		
Synthesized priority weights	0.7001	0.2999
Ranking	1	2