Leveraging IS Theory by Exploiting the Isomorphism between Different Research Areas

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The discipline of Information Systems is sometimes accused of being heavy on practical technology but light on conceptual theory. Identifying 'isomorphisms' between specialist research areas in other disciplines (especially mathematics) has produced spectacular results. This paper suggests that isomorphic thinking could also benefit IS research, in particular by leveraging existing frameworks and applying them outside their original context in isomorphic IS research areas.
The paper briefly defines the concept of isomorphism and illustrates the principle of isomorphic mapping using some well-known IS frameworks and theories which originate from other disciplines. This is followed by a practical case study on how a suggested framework for evaluating models could be applied almost literally to seemingly unrelated research areas such as website analysis. This case study exposes the underlying similarities ('isomorphism') between these research fields. The article concludes with some additional suggestions on how isomorphic thinking could advance research in other IS areas.

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Additional Key Words: Isomorphism, theory building, frameworks, enterprise modelling, website analysis

1. THE CASE FOR EXPLORING ISOMORPHISM

The discipline of Information Systems (*IS*) is very dynamic because of its relative youth and the fast-changing nature of the underlying information technologies and the business environment. This often leaves IS theory (and its researchers) lagging behind practices – in sharp contrast to our sister discipline of computer science where practice is often driven by theoretical advances. This relative lag of theoretical frameworks is evident in a number of research areas such as e-commerce, distributed systems development, or organizational knowledge management.

This article suggests a possible way to *fast-track* IS theory development by employing the hallowed principle of re-use and applying it to theoretical frameworks. The main premise of this article is that frameworks that have been developed in particular research areas could potentially be applied apparently unrelated research areas as long as there is a sufficient degree of structural similarity or *isomorphism* between the original (source) and target areas. It is important to realize that this isomorphism does not require that there is any apparent similarity, conventional association or other (semantic) relatedness between the research areas. This explains why the re-application of IS frameworks in isomorphic areas is not an intuitive or natural process and hence a conscious effort at creatively exploring the isomorphism between research areas is required.

The power of isomorphic analysis has been well-demonstrated in particularly the natural sciences and specifically in mathematics. It is hereby argued that a less formal version of this type of isomorphic thinking can be very productive in the field of Information Systems.

2. ANALOGY, SIMILARITY, METAPHOR AND ISOMORPHISM

2.1 The Concept of Isomorphism

The concept of *isomorphism* is a very general one, appearing in several disciplines. It derives from the Greek ισο (*iso*), meaning 'equal', and μορφωσισ (*morphosis*), meaning 'to form' or 'to shape', i.e. equal form or shape. Isomorphism is defined and applied in a formal way in various mathematical disciplines such as topology, universal algebra and category theory. A more operational and less formal definition is considered suitable in the context of information systems research:

'The word 'isomorphism' applies when two complex structures can be mapped onto each other, in such a way that to each part of one structure there is a corresponding part in the other structure, where 'corresponding' means that the two parts play similar roles in their respective structures.' [Hofstadter, 1980:49]

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The complex structures referred to will be taken to be IS research fields such as system development methodologies or IS project management. The value of identifying isomorphisms is that a set of principles may be transferred from one field to another without the need to duplicate the effort [Weinberg, 1975].

Figure 1 gives a graphical illustration of the concept of isomorphism between a simple network of two columns of connected nodes, and a possible isomorphic representation as a three-dimensional cube. Reinterpreting the network as cube allows a quick answer to the certain questions such as what the longest possible path (number of vertices) is between any two nodes, because mental methods (principles) of 3-dimensional space can be used.

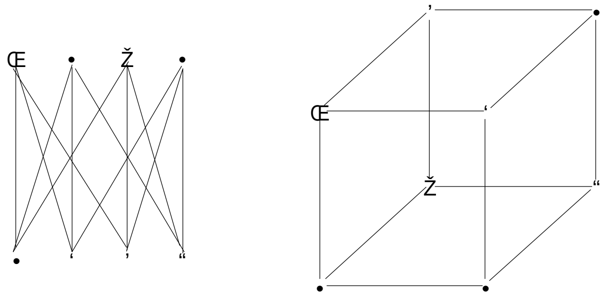

Figure 1: *Isomorphism between a network and a cube.*

A deeper example of isomorphism is the well-known programmer's 'chestnut' of the 'game of 15'. Players select, in turn (and 'with removal'), a number from 1 to 9. The first player who has a (sub-)set of numbers adding up to 15, wins. This is nothing but a different algorithmic implementation of the traditional game of noughts and crosses (where humans use a graphical solving approach) as demonstrated in Figure 2.

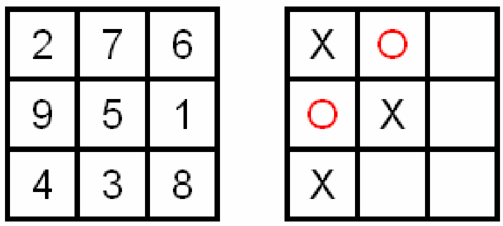

Figure 2: *Comparing the 'game of 15' with noughts and crosses*

2.2 Analogy and Similarity

The concepts of analogy and similarity will not be used in this article because of their multiple meanings and less formal connotations. More specifically, the concept of *analogy* is commonly used in the context of the activity of reasoning e.g. following of a thinking process which is similar to a process that was applied in a slightly different context. By contrast, isomorphism refers to a *static* correspondence between two conceptual structures. *Similarity* is a much more ill-defined concept and carries multiple meanings. It is avoided here because it is quite easy to draw networks which appear to be similar but not isomorphic to the network on the left of figure 1; whilst it can also be said that the cube does not appear to be similar to the network drawing. Isomorphism refers to a *deep similarity* of a structural nature.

2.3 Metaphor and its Use in IS

The concept of a *metaphor* is already well established in various social sciences [Hirschheim, 1991; Hallyn 2000]. Although Leary [1990] claims that 'all knowledge is ultimately rooted in metaphorical (or analogical) modes of perception and thought', this paper is more modest in its attempt to advocate its possible use to generate theory in information systems. A metaphor employs a concept to denote another concept in a different context. The usefulness of employing a metaphor is due to the fact that it conveys a lot of meaning because of the unspoken but implied underlying similarities [Young 1987]. For instance, by saying that a camel 'is the ship of the dessert', one does not only convey the fact that the camel is a transportation vehicle, but the metaphor arguably also conjures the images of the sand dunes (waves), oasis (harbour), motion-sickness (sea-sickness), featureless expanses etc.

The metaphor has seen many fruitful and imaginative applications in Information Systems. Anyone involved in interface design is familiar with various GUI metaphors, of which the windows-desktop-notepad is perhaps the best known [Averbukh, 2001]. Gazendam [1991, 2003] has explored various metaphors for information systems such as IS as a mill, as a cell and as a mind. Kendall & Kendall [1993] have investigated a number of metaphors for the process of IS development: they have likened it to a game, a machine, a journey, a jungle, a family, a zoo, a society, a war and an organism.

Perhaps the best example is the set of metaphors suggested by Gallupe [1999] for IS research (as an activity). He likened it to a game (with players, rules, too few good coaches); a machine (with a purpose, funding, optimality, replacement of parts, finely tuned); a garden (a life cycle of growth and renewal, different environmental conditions); a journey (process view, new territory, direction, unpredictable view).1

2.4 How Isomorphism Differs From Analogy and Metaphor

The concept of isomorphism is more formal and requires a more rigorous identification of the underlying correspondence, namely the explicit mapping between the structures. In the natural and mathematical sciences, this rigour is enforced by the use of formal notations. In the social sciences, the explicit mapping can be done in a table format.

It is not suggested that isomorphistic reasoning is better or more desirable than the use of metaphors: each have their own applicability and usefulness. A metaphor is more evocative, natural and intuitive. Isomorphism requires more effort, is less universal but potentially more powerful in creating more comprehensive theoretical frameworks.

The only systematic use of the term isomorphism appears to be in the discipline of Computer Science to pose the correspondence between formal logical systems, as used in proof theory, and computational calculus, as found in type theory: the so-called Curry-Howard isomorphism [Howard, 1980]

This paper motivates the use of isomorphic reasoning in the context of Information Systems, where one is unlikely to ever enjoy the luxury of a completely formal mapping as often encountered in the exact sciences. The notion of a more “formal” mapping between IS fields must therefore be read as per the normal Webster definition for ‘formal’: “relating to, concerned with, or constituting the outward form of something as distinguished from its content.” Thus, the type of isomorphic reasoning required refers to an explicit and conscious mapping of structural similarities without considering the semantics of the nodes and relationships between concepts. It is not the author’s view that the field of Information Systems would benefit greatly from attempting the mapping by means of the type of formal analysis or notation as is customary in mathematics or computer sciences. Rather, it argued that frameworks or approaches that have been found to be productive and successful in one field of research, may provide a fruitful jumpstart in fields which have a similar structure, bearing in mind that research domains in the social sciences are usually too messy to submit to a neat or fully mathematical correspondence. Readers with a computer science background are therefore invited to substitute the term “explicit” for the word “formal” and take cognisance of both the lack of theoretical frameworks and the limitations of formal analysis in the social sciences.

3. A WELL-KNOWN EXAMPLE OF ISOMORPHIC REASONING: THE ZACHMAN FRAMEWORK.

By far the most accessible example of isomorphism is that between the construction of a building (such as a house or factory), and the building or development of an information system. The isomorphism is based on the similarity in structural relationships between architectural, design, resources, project management, deliverables etc. This isomorphism has inspired the transfer of a significant theoretical body of knowledge from the construction and engineering sciences to IS. One very visible example is a substantial set of project management methodologies and another is the whole inspiration of the pattern movement as instigated by the architect Alexander and the ‘Gang of Four’ [Gamma et al 1995; Alexander 1977]

A more specific and layered example is the Zachman framework [Zachman 1987; Sowa 1992], a well-known 2-dimensional framework which maps various deliverables and processes in 30 ‘cells’ against views (scope, owner, designer, builder and detailed) and across aspects (why, who, how, what, when and where). The interesting angle is not so much that the entire framework has been inspired by the architectural engineering science, but that different authors have subsequently applied the framework to *other IS areas* which are isomorphic to a greater or lesser extent i.e. exhibit similar structural relationships between deliverables, resources, design etc. For example, Cook [1996] used the Zachman framework as the basis for building enterprise *information* architectures. Inmon [1997] proposes it as a guide for the implementation of data warehouses. De Villiers [2001] uses it to inform enterprise modelling methodologies. In fact, the Zachman framework has even been applied to non-IS areas. Zachman himself suggested that the framework could be applied to virtually anything, including life itself. De Villiers [20001] even uses the framework in a somewhat recursive manner on a meta-analysis level to analyse the Zachman framework itself.

4. A PRACTICAL CASE STUDY: APPLYING A FRAMEWORK FOR MODEL ANALYSIS TO WEBSITE ANALYSIS.

As part of a research project into the analysis and evaluation of conceptual enterprise data models, a framework was developed which used the well-known categories of syntax, semantics and pragmatics to suggest and classify a fairly inclusive number of specific modelling criteria who could be measured by various metrics. The various criteria and metrics were culled from a comprehensive literature survey and defined and the entire framework was operationalised and tested against a large number of different actual industry-strength models. The actual validation of the framework and its metrics is discussed elsewhere [ref omitted] but not particularly relevant for this discussion.

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1 I use this as a stimulating way of introducing the topic of ‘research’ to postgraduate IS students. Students are asked to come up with their best own metaphor for research. My last class came up with the following suggestions: research is like building a house, having a baby, learning to drive a car, having a mistress, a personal signature, one’s life, running an ultra marathon and, the winner, playing a jazz piece.

The important issue is that the author realized how this evaluative framework could be applied *as is* to other, ostensibly unrelated areas such as the analysis of web sites, user interfaces, algorithms, methodologies, programming languages, packaged software applications, in fact pretty much almost 'any' set of similar intellectual works of a conceptual nature. What is critical is that it was not just the overall framework that could be applied across the different domains, but the actual criteria and even the various specific metrics used to quantify or measure the criteria could be ported without change. Addendum 1 gives an illustrative example of how the various metrics originally formulated in the framework for model evaluation are applicable, in principle, to (static) website analysis. Note that it is not implied that these model-inspired metrics – or the framework and its high-level criteria – are equally *valid* in the different context of website analysis. However, it came as a partial vindication of the potential of this isomorphism based transfer when it was found that an independently developed website evaluation framework [Zhu, 2000] consisted of quality measures and associated metrics which were (a subset of, and) surprisingly similar to the ones suggested by the author's framework.

Initially, the ease with which each of the criteria in the framework for model analysis can be mapped to the analysis of websites, may appear surprising. At a more conceptual level, however, it can be argued that the website is also a conceptual reflection of its company i.e. it is a type of model representing the organization on the web.

This argument can be generalized by looking at the isomorphic features of the domain focus of a given research area on a meta-level. If sufficient isomorphic mappings exist between the main characteristics or attributes of the subjects being studied in two given research areas, then high-level analysis frameworks and techniques should prove to be fairly transferable. Note that it is this mapping that produces such powerful results in the field of mathematics, e.g. in group theory. The mapping requires a shift to thinking at a higher level of abstraction - a meta-level approach.

Table 1 illustrates some of these high-level correspondences between enterprise modelling and some of other research areas for which the framework is thought to be of use.

Table 1: *Mapping the Isomorphism Between Some IS Research Areas.*

A model	*A website*	*An algorithm*	*A methodology*	*A software package*
of a domain	for an organization	for a computable problem	for system development	for an application (user need)
is expressed in a modelling language	is coded in a markup language (eg HTML)	is coded in a language (or pseudo-language)	is expressed in a procedure manual or toolset	is coded in software instructions
and consists of a network of entities	and consists of a network of pages (concepts)	and consists of blocks of sequential computational steps	and consists of deliverables	and consists of dialogue screens
linked by relationships	linked by hyperlinks	linked by branches (loops, conditions and goto's)	produced by development processes	linked by user interactions (inputs values and icon clicks)

Note that the table is intended mainly for illustrative purposes. Different mappings may be possible, depending on the type of analysis in which the researcher is interested. For instance, a software application could also be seen (conceptually) as consisting of collection of data sets, linked by the procedures (create, modify, delete) that operate on the data. For the analysis of scientific applications, this may well be the desired perspective, whereas the mapping in the table may be more appropriate for very interactive applications such as computer arcade games.

Finally, it is important to realise that these isomorphic mappings are not limited to information systems research only. A painting represents a subject by means of a composition of graphic elements placed in different positions on a tableau. A fiction book or play tells a story by means of situations whereby characters (and objects) are placed in a more or less complicated plot. A building is a physical construction consisting of various building blocks (walls, windows, and arches) organized in certain spatial relationships.

Overall, the more tenuous the isomorphism, the more problematic the applicability of the framework (and the analysis techniques). Where the mapping appear to be more natural (e.g. between models and website), it is suggested that the transferability of the framework is accordingly more productive.

5. FURTHER DIRECTIONS FOR ISOMORPHISM IN IS

5.1 Tentative Observations and Initial Conditions

Firstly, it appears obvious that any proposed isomorphism in a human sciences context is likely to be partial. Complete or perfect isomorphism may exist between abstract mathematical structures, but the messier reality and subjectivity with which information systems researchers are confronted are most likely to result in isomorphism which give a less than perfect fit. The important criterion is expected to be the purpose or goal for which the theoretical framework or theory has been developed.

A second remark is that the applicability of a theoretical framework in a different context gives no indication about the actual validity of the framework in the new context. This implies that substantive empirical research will be necessary to check the validity, thus providing continued employment for IS researchers.

Finally, it is posited that the following conditions need to be fulfilled in order to allow the transfer of a framework to another area based on their isomorphism.

The goal and scope of the theoretical framework should be explicit and apply in all contexts. This scope will consequently also delineate the limitations of the applicability in the new context(s).

It should be possible to map the correspondences between the deep structure in explicit form using a table format with the rows indicating the various elements of the structure (i.e. the concepts and their relationships) and a column for each of the suggested areas of applicability.

The more comprehensive the overlap between structures i.e. the more rows in the table, the more likely that the framework is applicable.

Ideally, more than two IS research areas (i.e. more than two columns) can be identified – the more columns, the more the theory can be leveraged.

5.2 Some Suggested Isomorphisms in IS

To indicate the potential for isomorphistic thinking in information systems, the following are a few initial suggestions for further exploration. It is hoped that the reader will be stimulated to find his/her own examples for different (or the same) disciplines.

2.5.1 Portfolio management in finance, marketing and IS development projects

Comparing the corporate management of a number of capital investments, company products or IS (development) projects exposes many structural similarities: widely varying return/investment yield curves, different risk profiles, lots of uncertainty, financing options, optimal allocation of limited resources, different durations/life terms, chunkiness, project linkages (e.g. mutually exclusive or interdependent projects), etc. Financial theory has evolved a sophisticated set of tools for advanced multi-period optimisation of capital investment portfolio management. Although many of the detailed techniques may turn out not to be very applicable, some high-level approaches or principles are definitely worth investigating. One immediate observation is that it may not at all be desirable for a company to deliver all its IS development projects 'on budget and on time' – this would be a tell-tale indicator of not enough high-risk/high-value projects in the portfolio.

2.5.2 Searching for the dual problem: linear programming and system modelling

The field of operations research has a number of problems (mostly linear programming) whereby the solution of a problem can be reinterpreted from an alternative perspective: the primal versus the dual problem. Often the dual solution brings additional insights on the interpretation and analysis of the results (such as shadow prices for scarce resources). It may well be possible to identify similar problems in IS. Two candidates appear to be the fields of IS project/resource management and information system modelling. In the latter case, this may well be akin to exploring and formalising the interdependencies between a process and data (or deliverables) view.

2.5.3 IS development versus research methodology selection

Finally, an early reviewer pointed out the similarities between system development methodologies and research methodology. For instance, when an information system needs to be designed for a relatively novel problem domain, one would typically adopt a prototyping approach. This is comparable to the use of a qualitative, exploratory research methodology in the case of researching a relatively new problem domain. By contrast, structured system development methods are used in familiar settings and could be compared to situations where quantitative research methods are fruitfully employed. Researching the frameworks suggested by method engineers may well lead to more explicit decision frameworks for research methodology adoption.

6. CONCLUSION

The field of information systems has benefited much from the use of metaphors and a strong case can be made for more frequent use of metaphors. However, a more powerful exploitation of structural similarities between fields of research seems to have been ignored. This paper makes the case for the formal investigation and conscious application of isomorphisms between apparently unrelated fields of research.

Isomorphistic thinking requires a more abstract, high-level analysis approach and is thus perhaps better referred to as a meta-theoretical research method. It is used with great success in other sciences, especially mathematics, but some historical examples for the discipline of information systems have been identified. It is argued that this approach can be used both in an interdisciplinary manner (e.g. adopting the 'portfolio approach') as well as an intra-disciplinary way (e.g. comparing system development with research problems).

What remains to be done, is to conduct a wider search to identify more isomorphisms as well as additional applications. On a more theoretical level, it will be advisable to develop a more rigorous, and potentially more formal, set of pre-conditions to identify potential isomorphisms between research fields.

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8. ADDENDUM: AN ILLUSTRATIVE RE-APPLICATION OF THE FRAMEWORK FOR ENTERPRISE MODEL ANALYSIS TO WEBSITE ANALYSIS.

This addendum illustrates the application of the framework by contrasting the criteria that were used to analyse and evaluate enterprise models in such as way that the framework can also form the concrete research agenda in an unrelated area: the analysis of websites. A typical example would be to compare, say, the websites of a number of competing companies within the same industry e.g. comparing the websites of different universities, on-line book sellers or search engines. The following proposed metrics and analyses should be regarded as suggestions, intended to illustrate how easily but fairly straightforward the various criteria can be mapped directly from this research to other information systems research area. Note that, just like for models, the framework does not accommodate composite web criteria such as overall usability or quality. It is imperative to realize that the mere possibility of re-application does not imply any validity, reliability or completeness: the isomorphistic reasoning should be seen as a starting point (a kick start?) for the research.

Criterion	*Metrics used for Analysis of Enterprise Models*	*Possible Equivalent Metric for Website Analysis*
	Syntactic analysis	
Specificity (Size)	Size metrics are entity count, graph count (entities and relationships), CASE size (or concept count) and concept count adjusted for groupers and inheritance relationships.	Size of all information on the website, including a raw byte count (sub-grouped by text and multimedia elements), count of files (including graphics), pages, page widths etc. Could also include counts of tags (possibly according to categories), scripts, forms etc.
Correctness (Error Free)	Adherence to modelling standards (e.g. circular inheritance, orphan entities, conflicts between diagrams etc.).	Adherence to standards (e.g. HTML 4.0, XML well-formedness), use of browser-specific tags, broken links etc.
Correctness (Consistency)	Consistency in modelling notation and naming conventions.	Consistency of terminology across different pages (especially for large sites) as well as the formatting and layout style of web pages (including use of CSS etc.)
Architecture (Temperature)	Architectural temperature and architectural harmony indices as suggested by Salingaros (Salingaros 1997).	Measuring the temperature of websites would be a novel and useful approach to website analysis, resulting in e.g. a web EQ (Emotional Quotient) index!
Architecture (Interface Layout or Aesthetics)	Quantitative screen layout aesthetics metrics as suggested by (Coleman 1996, Purchase 2001, Ngo 2001)	These metrics can easily be applied to webpage layouts, e.g. the home page of each website under investigation. Many of Nielsen's usability criteria would belong here too!
Complexity	McGabe's cyclomatic complexity, absolute and relative connectivity, average / maximum and spread of entity-fanout, de Marco's data bang, distribution of entity fan-out.	Measure the density of hyperlinks, both internal (within the web / could be relative links) and external (links to & from other websites). This includes all the formal complexity-based measures suggested by Thimbleby (1994).
Other syntactic metrics	Structural metrics for measuring grouping and diagram clustering. Inheritance structure metrics e.g. inheritance depth, nesting level, depth of inheritance tree, average number of root classes/children, reuse ratio, specialization ratio.	Includes a large number of other web-site metrics suggested in the e-commerce literature including, for example, some of Nielsen's usability criteria (1999).
	Semantics	
Genericity (Coverage/ Completeness)	The capability of the enterprise model to be applied to enterprises in different industries, or more widely as applicability to different types of organizations. Measured by the number of model constructs that are applicable to all domains. An alternative measure looked more at the consistency by which high-level constructs apply across the range of different organizations.	Check website content coverage against typical information expected from an organization's website (not necessarily in separate pages): welcome, contact details, organizational information (including structure and history), search facility, support, FAQ, product/service overview (including graphics), website feedback, ordering info/form/shopping cart, and other industry specific or legal

		requirements (e.g. ECT Act).
Comparative Overlap	How closely related the various models are. Map the correspondence of the various model elements against each other (using synonyms and hypernyms) and calculate the cosine distance, the dice distance, and the Jaccard coefficient.	Compute similarity indices between the different websites, either on a lexical basis (using words), or on a syntactical basis (web structure)
Perspicuity (lexicon)	The extent to which the model can be understood by the intended users of the model; how self-describing the model is. Based on the matching or comparison of the model element names against common domain vocabulary lists.	Perform a readability analysis on the text of the website. Also map the vocabulary used in the website against the vocabulary of the intended audience.
	Pragmatics	
Validity (Authority)	Number of author citations (academic models published in articles or books).	Name brand recognition, corporate standing (including size, reputation etc.) and financial strength of the site owner
Validity (Use)	Relative sales ranking (book-based models)	Web traffic statistics for each website (a proxy is the web-traffic through key-routers close to the web host.
Validity (Web links)	For web-based models: popularity of a web page by counting the number of external hyperlinks (Google PageRank™)	Detailed analysis of how often and by which method the site is referenced by other websites. Could include relative ranking of the websites in search engines and banner analysis on other websites.
Purpose	The model's purpose or goal can be described and rated subjectively	What e-commerce model is being used? Level in the e-commerce hierarchy (from passive information, ordering, process integration etc.)?
Cost	Cost of the models includes availability and accessibility, physical size (for downloads), and whether the model is available in digital format.	Cost of website construction? Maintaince cost of website (two proxy measures could be how many people are involved with the website maintenance, web size)?
Support	Tool support, vendor support and user base (Support was found to be closely correlated to the model currency and maturity typology).	How quickly does the web-administrator or organization respond to feedback? (e.g. enquiry about an order or submission of details using a web form)?
Other Pragmatic Criteria	Flexibility: the extent to which models can be changed or adapted to different situations, customisability, implementation independence.	Hosting platform; browser compatibility; web-development tools used; web site responsiveness, empirical usability tests (Bevan 1994, Nielsen 1999

A framework that uses similar criteria is suggested by Zhu [2000] but includes (only) 6 quality measures for web pages. His quality measures include concrete metrics which are surprisingly similar to the ones used in this research: currency (when last modified), availability, information to noise ratio, authority (equivalent to the Google PageRank™), popularity (how often cited or referenced by other web pages) and cohesiveness (measured using a cosine similarity by mapping the number of concepts on a page against an 11-level 4385-node 'topics' ontology).