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A Search for Consensus

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UNDERSTANDING DESIGN RATIONALE AND INTENT THROUGH NATURAL LANGUAGE PROCESSING ANALYSIS: A SEARCH FOR CONSENSUS

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SUMMARY*: Design and construction projects have become increasingly complex throughout recent decades, resulting in a heightened focus on knowledge management. Two specific knowledge types, which have received consideration in the literature are design intent and design rationale, as means for describing what is designed and why a design is the way it is. However, a definition of what design rationale and design intent are and what they consist of, in context of the AEC industry, has not been fully explored. In this study, a literature review, was conducted to summarise the definitions of design rationale and intent presented in the existing body of scientific literature across scientific disciplines. Both qualitative evaluation of the identified literature and Natural Language Processing (NLP) was utilised, identifying the distinctions between design rationale and design intent, and their hidden specificities. The study revealed that a design project must have both explicit design rationale and intent available to be successful, which can guide a designer or project manager in the direction of unexplored design alternatives if something in the design must be changed, instead of exploring already tested and discarded solutions. The study, furthermore, showed that having DR and DI available can support decision makers during design, pre-planning, and construction to ensure that their design solution lives up to the intent of the designer or building owner, through specifying the explicit justification for the solution, and not just* what *the solution is, should be, or consist of.*

KEYWORDS*: Design rationale, Design intent, Natural Language Processing (NLS), Literature review, Building Information Management.*

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1. INTRODUCTION

An increase in building complexity due to demands set by legislation, building owners and end-users has resulted in a growth of participating actors on projects in the architectural, engineering, and construction (AEC) industry. This has led to a variety of research and development of digital tools to support designing and collaboration between actants in project organisations, to solve the advancing complexity of buildings and collaboration between project participants. Such digital tools have, additionally, been introduced in the industry to improve building quality, as well as reducing construction time and costs (Bryde *et al.*, 2013; Wyke *et al.*, 2021, 2024; Zou and Tang, 2012). Computer aided design (CAD) and building information management (BIM) technology has also seen increased implementation and usage for development of product and analysis models, to facilitate improved information modelling, quantity take-off, scheduling, construction-site planning, and simulation, as well as collaborative designing.

Decision making during construction planning is, however, according to Feng *et al.* (2022), challenging, because much information has not been determined, and because new technologies such as Internet-of-Things, and BIM, do not have reliable references for construction planning. Focus on pre-planning, is according to Larsen *et al.* (2018) a way to improve project-outcomes, in terms of cost and time, and is according to Gibson *et al.* (2006) a process *defined as the process encompassing all the tasks between project initiation and the beginning of detailed design*. The process, furthermore, entails 1) organising of pre-project planning, 2) selection of project alternatives, 3) development of a project definition package and 4) the decision making of whether to do the project or not (Gibson *et al.*, 2006). Organising pre-planning in terms of selecting the project team, completing the draft charter and preparing materials and selecting project alternatives, in terms of technology, site, concept and estimates is based on having the right information and knowledge available on a project. The same goes for the development of a project definition package, which entails analyses of project risk, project scope and design documentation, project execution approach definition and project control guideline establishment etc. All of which is information which makes it possible to decide if a project can move forward or not.

Making the right information from the design process available is, therefore, important for supporting the decision maker in making the right decision, in both during later design phases and during pre-planning, construction and potentially also operational phases. Information and knowledge can, nonetheless, be hard to document, store, and exchange on a project, even when using CAD and BIM technologies. Experiences in this regard show that building information is frequently developed based on a poor modelling strategy (Alducin-Quintero *et al.*, 2012),and that the design and building information is often fragmented on a project and exchanged as well as stored in multiple analogous and digital representation formats (Wyke et al., 2021).

Design rationale (DR) and design intent (DI) are two concepts which are used to describe specific design decisions and design knowledge which can represent some of the essential building information and knowledge which can provide a positive impact on time and/or cost associated with downstream efforts needed to resolve conflicts or solve problems resulting from an inadequate understanding of interactions amongst design decisions Szykman, Sriram, & Regli (2001). Research by Peña-Mora *et al*. (1995), moreover describe how such knowledge can lead to improved designing, resulting in life-cycle-cost savings as well as improved product quality. DR and DI, furthermore, has the potential to answer many questions relevant to a design which are not answered in design documents and product models, including questions of the "what", and the "why" of a design and why some design alternatives were selected instead of others, in addition to the question of "why not" (Garcia and Howard, 1992). In their research, Kozemjakin da Silva, Reyes Carrillo, & Rem (2013), also argue that a strong potential is observed in knowing more than *what* has been done in the past design, but also in knowing *why* it has been done in a specific way, seconding the argument of Garcia and Howard (1992). Having documentation of why a solution is designed as it is can, furthermore, reduce the risk of a solution being changed and thus no longer lives up to the designer's intent.

Looking outside of the AEC industry, an overall understanding of the DR and DI concepts exists, in which the intentions of the designer in choosing a design is defined as the DI, whilst the underlying logic to the knowledge of why a design is the way it is, often is described as DR (Conklin and Yakemovic, 1991; Lee and Lai, 1991; MacLean *et al.*, 1989). In the AEC industry DR and DI are, nonetheless, often used as synonyms, without a clear specification for what DR and DI should entail, lowering the potential gains achievable from utilising the two types of knowledge.

The international organisation for standardisation, has provided overall definitions for both DR and DI, differentiating between the two concepts (ISO, 2005a, 2005b) yet without presenting or evaluating the definitions in the context of the AEC industry, nor ensuring consensus between their definitions and definitions used in the scientific literature. Hence, a deeper understanding of what DR and DI are, consist of, and how they can be utilised, is needed in an AEC industry context.

To fill this gap and identify a consensus for defining the concepts in the AEC industry, this article presents a literature review, investigating various definitions of DR and DI, as well as a Natural Processing Language (NPL) analysis of the identified literature, answering the research questions:

What are the existing understandings of DR and DI, and which AEC related definition of DR and DI can be derived from the existing scientific literature?

The research question is answered using qualitative evaluation of the reviewed literature identifying different nuances to DR and DI to highlight similarities and discrepancies between the various definitions and in the existing body of scientific literature. The answering of the research questions also relied on quantitatively studying the contents of the identified literature using NLP analysis. This methodology utilises the powers of Machine Learning which, allows for a more thorough review of the content of the literature. Using the two approaches in combination, a broad unbiased evaluation of the identified literature was ensured, providing both the numeric truth about the use and extent of DR and DI in the literature, as well as a nuanced description of the various descriptions contained in the literature. Besides answering the research question and increasing the validity of the findings, the dual approach confirmed the applicability of utilising NLP to create consensus regarding the literature contents.

As shown in figure 1, the next section, present the methodologies which guided the data collection and analyses. In section three the results of the literature review and NPL analysis is then presented, whilst section four presents a discussion of the findings of the study. Finally, a summary, conclusion and perspective on future research is presented in section five.

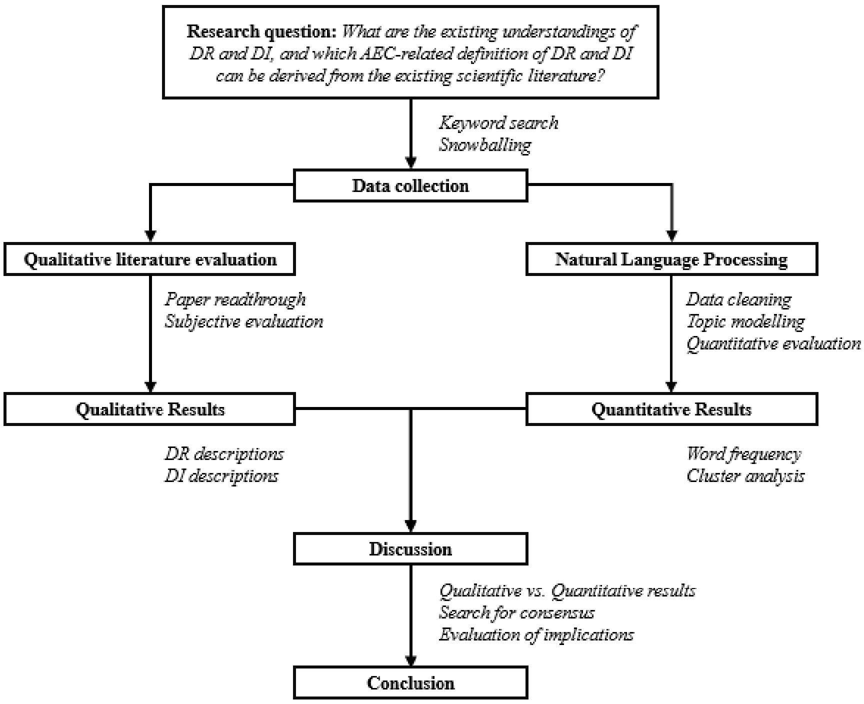

Figure 1: Article structure and research design.

2. METHODOLOGY

2.1 Research design

A systematic literature review was conducted using the snowballing methodology (Wohlin, 2014), to attain an thorough understanding of the investigated topic. According to Randolph (Randolph, 2009) electronic search, using keywords, often only reveals about 10 percent of the relevant literature, whilst using the references from such search to guide a literature search can reveal the remaining 90 per cent of literature.

Literature was, thus, identified and analysed to index which articles present or describe a definition of DR, DI and/or a combination of the two, as well as which studies present tools for managing DR, DI or both. AEC related articles were, furthermore, specifically indexed during the qualitative analysis. Based on the identified articles in the literature review, a quantitative analysis was also conducted, applying natural language processing (NLP) to identify nouns in the identified literature and ranging the nouns. The process, thus, entailed a subjective readthrough and an NLP analysis of the identified articles. This provided firstly, a qualitative and critical evaluation of the papers, and secondly, an objective evaluation using NLP, allowing an in-depth understanding of the literature as well as an identification of the nuances in the various articles.

2.2 Data collection

The literature review was initiated by a keyword search of the topics: design rationale, design intent, information management, building information management, and decision making. Based on this search, 12 articles were identified and read, after which five of them were selected for use for snowballing, based on their contents and year of publication, resulting in the articles shown in table I. The reasoning for using year of publication as criterion for selection of articles for snowballing, was to ensure an adequate representation of both old and recent literature . The five articles selected represented 26 years of research from 1993 to 2019, which was deemed as representative by the authors, as a starting point for the snowballing literature collection process. Finally, citations were not used as a selection criterion.

As shown in table I, the five initial articles had 234 references, which were filtered down to 53 articles, through title reading, and a criterion of containing at least one of the initial keywords, and/ or synonyms to the keywords in the title. After the title reading, all abstracts were read, yielding 30 articles to include in the study. This was followed by a forward snowballing process, in which 274 citations of the five initial articles, were condensed into 49, based on a title reading, which then resulted in 33 articles to include in the study, after abstract reading.

Table 1: Overview of literature search results.

Initial articles: (Camba and Contero, 2015; Cheng et al., 2019; Lee, 1997; Peña-Mora et al., 1993; Zou and Tang, 2012)

	Backward			Forward		
	References	Title sorting	Abstract sorting	Citations	Title sorting	Abstract sorting
1st.	234	53	30	274	49	33
2nd.			30			5
Final no.			60			38
				∑		103

The snowballing was conducted as both backwards and forward snowballing, using the Scopus database, considering only journal and conference articles.

Based on the initial backwards snowballing, only ten articles were AEC related. Those ten articles were, therefore, used for an AEC specific forward snowballing process, identifying five additional articles to include in the study.

In all 103 articles were identified, read and indexed, as shown in appendix A, providing a representative overview of the existing body of DR and DI knowledge.

2.3 Data analysis

NLP is a computer aided technique, based on machine learning and artificial intelligence concepts, which is utilised to understand the human language (Kang et al., 2020; Schütze and Manning, 1999). Overall, NLP can be divided into two key subareas: Natural Language Understanding, which relates to linguistics and Natural Language Generation which relates to the ability to generate text (Khurana et al., 2023).

In the study presented in this article, NLP has been used for linguistics purposes. Python was used to automate the extraction of knowledge hidden in the documents. Two primary analyses ware carried out, a part of speech (POS) analysis focusing on nouns, and a topic modelling analysis focusing on revealing underlying topics

2.3.1 Data cleaning

The identified articles from the snowballing process were subsequently retrieved in.pdf format and imported into Python. The first step before conducting the actual analysis was to clean up the data and make sure that it was suitable for analysis. As part of the cleaning process, the core document was extracted, entailing the text starting from the abstract and ending before the references.

Afterwards the text was cleaned, and blank spaces, backslashes and other special symbols were removed, together with brackets, squared brackets, and their content. Abbreviations were, moreover, identified and replaced with the actual words. Finally, special words and word combinations, like "et al." were removed from the documents. The documents were then manually reviewed. Of the 103 documents, 5 documents were excluded because the documents could not be imported correctly into Python. Thus, a total of 98 documents were included, constituting the corpus in the analysis.

2.3.2 Noun frequency

A language consists of eight key components: nouns, verbs, pronouns, adjectives, adverbs, determiners, prepositions, and conjunctions (Tampangella and Rokhayati, 2021). Of those, nouns are in particular important because they carry the important messages in the language and thus are the part of the language that names a person, place, thing, idea, action, or quality (Tampangella and Rokhayati, 2021). Therefore, the nouns can be used to describe the content of a text.

The NLP library spaCy (Honnibal and Montani, 2017) was applied, in the analysis, to create meaning out of the text. To do this the big English language multi-task Convolutional Neural Network (CNN) "en_core_web_trf" algorithm was applied. As part of the analysis, the text was divided into sentences, transformed into lower case only and tokenized. The CNN was used to POS tagging by identifying nouns unigrams and noun phrases of noun bigrams and to lemmatize the nouns. The output from the spaCy algo-rithm was a list of noun uni- and bigrams contained in each document in the corpus. These lists were used later, as input to the topic model. A counter function was, additionally, applied to identify the noun frequency. This was done to the unigrams and bigrams separately.

2.3.3 Topic modelling

The topic modelling originated in the noun unigrams and noun bigrams identified during the word frequency analysis. Firstly, the text was double checked for irrelevant nouns and noise like "case", "project" or "copyright" which could have disturbed the topic generation. Furthermore, as part of this process nouns occurring in less than 3 articles were removed. This removed both noise but also uncommon nouns irrelevant to the topics.

After the second cleaning, a dictionary was created using all the remaining words in the corpus. In total 3,525 words were included.

To carry out the topic model the NLP library Gensim (Rehurek and Sojka, 2011) was applied using the Latent Dirichlet Allocation (LDA) model. The LDA model is an unsupervised probabilistic machine learning topic model algorithm which reveals underlying topics when introduced to a corpus of documents (Blei, 2012). The topics were identified by separating the corpus into topics with a coherent distribution of words (Zhou et al., 2023). As its output it identified the probability distribution for each word for each topic and thus enabled a calculation of distribution per document per topic (Blei et al., 2003; Zhou et al., 2023).

The LDA model was applied with manual hyperparameter optimization using a grid search method, while maximizing the model's coherence score, resulting in a max CV score at 0.45. Most hyperparameters were set to the default value. The tuned hyperparameter which resulted in the maximized model were as follows:

- Number of topics is set to 2.
- Random state was set to 100, for ensuring reproducibility.
- Update every was set to 1 for indicating online iterative learning.
- Chunk size, defining how many documents were used in each training chunk. Set to 13.
- Passes, defining how many times the corpus was passed: Set to 12.
- Alpha was set to auto, indicating that the model learns from the corpus.
- Iterations, defining the maximum number of iterations through the corpus. Set to 30.

As an output of the LDA model, the per topic per word probability often just referred to as beta was calculated, with the word with the highest probability was used to create an understanding of the identified topic.

To create an in-depth understanding of the topics the traditional word probability can be supplemented with a comparison of biggest differences in word probability. To make sure that only relevant terms were included a threshold in beta was set at 0.001. This ensured that a single uncommon word was not identified as defining the difference between the two topics. The difference in probability was calculated by taking the log 2 value to the ratio of the beta values.

By calculating the difference in probability for all the relevant nouns in the corpus, the words describing the biggest difference between the topics were the words with either the largest or smallest value. A value above 0 indicates how much more probable a word is for accruing in topic 1 compared to topic 2, whilst a value below 0 indicates how much more probable a word is for accruing in topic 2 compared to topic 1 (depending on how the ratio was calculated). Words with a similar probability between the two topics have values close to 0.

3. RESULTS

3.1 Qualitative results

Out of the 103 articles, which were identified and analysed for this study, 17 studies were directly, and two studies were partly related to the AEC industry, as shown in appendix A. 89 studies were not related directly to the AEC industry, but were concerned with software engineering, software architecture, mechanical, industrial, and chemical engineering. Four of the studies identified were, furthermore, concerned with both the AEC and non-AEC industries. Finally, two studies primarily focused on non-AEC industries, whilst partly directing attention towards the AEC industry.

With respect to presenting or describing a definition of DR, DI or a definition combining the two concepts, or using DR and DI as synonyms, 62 studies described or defined DR, 19 studies defined DI, whilst 7 studies used a combined definition or used DR and DI as synonyms. Seven studies, additionally, described or defined both DR and DI directly, whilst one study presented a definition of DR but only vaguely defined DI. Three studies described or defined DR and DI, whilst at the same time partly combining them. This means 60 per cent of the identified literature presented a definition of DR, 18 per cent a definition of DI, 7 per cent a combined description or definition, whilst 18 per cent of the identified papers did not provide a description or definition at all.

Even though 14 of the studies did not define or describe what DR or DI is, they nonetheless still presented the development of tools for managing DR and/or DI, revealing a tendency in the literature to not fully present what new tools and methodologies are developed for exactly, or only assuming a consensus regarding what DR and DI contain. Such consensus has, however, not been described directly in any of the identified studies. Finally, it is worth noting that, what developed tools for DR and DI management can be used for, is dependent on what is meant when the developers say it supports DR or DI management, or management of both.

3.1.1 Design rationale descriptions

In the identified literature MacLean *et al.* (1989), Conklin and Yakemovic (1991), and Lee and Lai (1991) define DR as the explanation of why an artefact or entity is structured or designed the way it is and has the behaviour it has. A definition which is widely used in much of the DR literature (Dorribo-Camba *et al.*, 2013; Lin, 2021; Liu *et al.*, 2010; Poorkiany *et al.*, 2016a, 2016b; Tsutsui *et al.*, 2021; Zhang *et al.*, 2013). Shum and Hammond (1994), also present a definition of DR, describing it as the expression of elements of the reasoning which has been invested behind the design of an artefact.

Conklin and Yakemovic (1991) further describe how DR "provides a dimension of description that is usually missing", by augmenting the "what" of the artefact's structure and function with the "why" behind its design. It is thus, a kind of communication from the creator of an artefact to those whom later must use or understand the artefact. Therefore, like any communication the successful use of DR depends on the writer and the reader of the rationale document having some degree of "shared background, or shared understanding.

DR, according to Conklin and Begeman (1988), consist of a variety of information, including: design problems, alternative resolutions, (including those which are later rejected), trade-off analysis among these alternatives, and a record of the tentative and firm commitments that were made as the problem was discussed and resolved. This is in line with, Potts and Bruns (1988) who described DR, as design deliberations, representing issues, alternatives or justifications, as well as Lee (1997) describing DR as including all background information, such as the reasons and justifications for a design decision, other alternatives considered, trade-offs made, and the argumentation that led to the decision. A definition which is utilised in multiple studies (Falessi et al., 2006; Gonsalves and Itoh, 2007; Liu and Hu, 2013; Rockwell et al., 2009), and seconded by Bañares-Alcántara and King (1997) who defines DR as the alternative design paths considered during the design process and the justifications supporting decisions made by a designer or a group of designers when producing an artefact.

In their research, MacLean *et al.* (1991), specified how DR representation must explicitly document the reasoning and argumentation that make sense of a specific artefact, which is also argued in other research, describing how DR is the explicit listing of decisions made during a design process and the reasons why those decisions were made (Van Schaik *et al.*, 2011; Verries *et al.*, 2008), as well as the justifications (Sahraoui, 2013).

Lee and Lai (1991) presents a simple definition of DR in their research, in which an artefact is associated with a body of reasons for the choice of the artefact, whilst Brissaud, Garro and Poveda (2003) defines DR, in a similar simple way, as generally representing design alternatives, decision making, and design constraints. Dellen *et al.* (1996), on the other hand, define DR as design decisions and their dependencies, or the underlying intent and logical support for decisions (Klein, 1993). De Jong *et al.* (2019), similarly define DR as the reasons underlying design decisions. These studies, thus, underscore a need on design projects to have DI available to complete the DR.

In a study by Tang *et al.* ,(2007) it is described how DR also entails how a system design satisfies the requirements, why certain design choices are selected over alternatives, and how environmental conditions influence the system architecture. Wang *et al.* (2011), further highlights that DR can allow understanding of why a solution should (or might not) work, which is a valuable intellectual asset of an enterprise. Sutcliffe (1995) furthermore, describes DR as a means of exposing designer reasoning.

When it comes to how DR is managed, Burge and Brown (2008) defines DR as different from other types of documentation, because it documents more than the result of each (design ed.) decision, as it documents the elements described by Lee (1997), as introduced previously.

In their literature review Chandrasegaran e*t al.* (2013), highlight how DR systems were introduced as a basis for reasoning and communicating amongst design teams, adding to the discussion of DR, that knowledge representations used to capture DR, fall into two categories. Firstly, argumentation-based techniques, and secondly, descriptive techniques; with argumentation-based techniques being characterised by having a structured, (semi-formal) graphical format of nodes, or basic unit of data, and edges for connecting design issues and relationships, and descriptive approaches recording the sequence and the history of activities in the design process (Chandrasegaran *et al.*, 2013), or more specifically the record of what decisions were made by designers, as well as when, and why they were made (Szykman *et al.*, 2001). DR in the detailed design phases, has also been described, as focussing on how a given design works, and why the specific detailed design choices were made, with a definition of DR, encompassing any information that will increase the understanding of design and its development (Myers *et al.*, 2000)

Otey *et al.*(2018), finally, describe how DR must support and help understanding the choices made, and should be a product of the design process, just as much as the final artefact, thereby arguing for a focus on the full design process when managing DR. This is in line with De Medeiros and Schwabe (2007), who describe how design reuse can be defined as the experience and the knowledge invested in a design, so that the proposed solutions for an artefact can be reused in designing other artefacts. Nkwocha *et al.* (2013), furthermore, describe how DR fills the gaps between the original requirements of a system and the finished product. In this regard, Dalsgaard and Halskov 2(012), argue that well-documented DR may improve the quality of the product, as well as the design process.

3.1.2 Design intent descriptions

In their research, Peña-Mora et al. (1993, 1995), refers to DI in terms of the four attributes of a design, 1) objectives, 2) constraints, 3) functions, and 4) goals, whilst others, have defined DI as the reasons that motivate a designer to follow a specific CAD modelling procedure, further expressing the manner in which the designer expect the geometric model to behave when it is modified (Dorribo-Camba et al., 2013). According to some research, however, there is a lack of consensus with respect to the definition of DI (Camba and Contero, 2015; Otey et al., 2018)

Otey *et al.* (2018), nonetheless, summarise the research of Peña-Mora et al. (1993), describing how representation of explicit DI can significantly improve design productivity, increase the overall quality of a product (or design ed.), facilitate more intelligent use of resources and knowledge and expedite integrated solutions and transferring of design knowledge.

Horváth and Rudas (2003) on the other hand, describes how DI is background information for a well-defined step of a decision. A study by Kim et al. (2008), one the other hand, describe construction history, parameters, constraints and features as parts of DI. Cheng et al. (2017, 2019), additionally, describe DI as a special kind of design knowledge, encompassing a broader context surrounding the product development process, and a description of the collaboration process, a coordination procedure of DI from every participant and an optimal design solution as a result of a collective intelligence.

In context of DI communication of CAD in mechanical systems, Otey et al. (2018),additionally, found that DI may be embedded at three different levels: 1) sketch constraints, 2) relationships between modelling operations, and 3) modelling operations. Their research, furthermore, describe how proper labelling of modelling operations are simple ways to convey DI, through having proper names utilised during modelling instead of using generic naming only.

In their research, Iyer and Mills (2006) argue how the DI that can be captured in 2D CAD drawings will be limited due to the nature of the information present in it, as 2D drawings "*contain only… graphic entities such as lines, text and symbols*", whilst it is the human actors using and working with these entities, whom interpret the semantic meanings of the entities.

Other research describes DI, as being governing the relationship between modelling features in part, and between parts in assemblies, consisting of two kinds of knowledge. Firstly, declarative knowledge that consist of facts (knowing that or knowing what), and secondly, procedural knowledge that is knowledge of how to do things (knowing how) (Alducin-Quintero et al., 2011; Rynne and Gaughran, 2007).

Finally, Cheng et al. (2019), argue that the essence of communicating DI is to provide an environment so designers are free to share, discuss their perceptions and eventually come up with an optimal solution, revealing information about modelling decisions, why they have been made, as well as relationships or dependencies that may either link decisions to part of the product representation or to other decisions. In their research they, further, created an information model to describe the designer's intentions in the artefact developing process, based on the concepts: artefact, design history, participants, artefact structure and boundary representation, thereby also hinting that DI and DR are interrelated and complementary to each other.

3.2 Quantitative results

Using NLP, the nouns used in the identified literature were mapped, and a noun frequency was generated, including unigrams and bigrams. Focussing on the unigrams, 7113 nouns were identified with the primary noun used being "design", and the second most used noun was "rationale". The top 10 unigrams are shown in table II.

When looking for bigrams, 14750 bigrams were identified, with "design rationale" being the most common bigram in the literature, "design process" the second most common, and "design intent" being the third most common noun bigram. The top 10 bigrams are also shown in table II.

Table 2: Top 10 frequent unigrams and bigrams in the entire corpus.

Unigrams		**Bigrams**	
Nouns(s)	**Frequency**	**Nouns(s)**	**Frequency**
design	12828	design rationale	2564
rationale	5359	design process	931
model	3501	design intent	456
system	3428	design model	389
process	2957	design system	378
information	2948	design decision	372
designer	2392	design knowledge	240
knowledge	2266	case study	190
decision	2223	design solution	185
issue	1714	design history	182

The bigram analysis, reveal the use of "design intent" as a concept, occur as a combination of "design" and "intent", less often than "intent" as a standalone concept, with "design intent" being used 456 times in the literature, and "intent" being used 726 times. "Rationale" being used 5359 times, is found in the top of both the unigram and the bigram list, whilst "design rationale" is used 2564 times in the literature, making it occur approximately in the same frequency alone as combined with design, whilst "design intent" is used approx. twice, for every time "intent" is used in the literature on its own.

Table 3: Noun likelihood of cluster 1 and 2. The likelihood expresses how frequent a noun is expected to occur in the cluster.

Cluster 1		**Cluster 2**	
Nouns	**Likelihood**	**Nouns**	**Likelihood**
design	0.0643	design	0.0591
model	0.0408	rationale	0.0375
system	0.0194	decision	0.0196
knowledge	0.0191	design rationale	0.0177
computer	0.0173	designer	0.0143
product	0.0165	information	0.0137
information	0.0164	process	0.0135
process	0.0148	system	0.0131
annotation	0.0137	issue	0.0130
feature	0.0105	solution	0.0095

Evaluating the methodological approach of acquiring scientific literature the revealed unigrams and bigrams are quite similar to the keywords used for the initial search ahead of the described snowballing process, indicating a commonality between expected content of the scientific literature and the actual content of the literature in terms of nouns. The frequency of the bigrams is noteworthy, with respect to “design” as a noun and concept, being significantly more common in the literature than other unigrams. The same goes for “design rationale” which as a bigram is substantially more common than other bigrams in the literature.

Topic modelling was applied to group the nouns in two clusters. The most frequent nouns are presented in table III. Because nouns can be used to describe the content of a text, the most frequent nouns express the most important content of each cluster. Looking at the clusters the most likely noun is “design”, whilst the second and third most likely noun in cluster 1 are “model” and “system”, and “rationale” and “decision” in cluster 2.. With the respect to the two focal concepts of the study, rationale and intent, “rationale” had a likelihood of 0.0375, being the second most likely noun in cluster 2, whereas “intent” did not make it into the noun top ten in cluster 1, with a likelihood of 0.0074.

The analysis of nouns showed similarities between the two clusters in terms of “design” with a likelihood of 0.0643 in cluster 1 and 0.0591 in cluster 2 and “information”, which has a likelihood of 0.0164 in cluster 1, and a likelihood of 0.0137 in cluster 2. However, noun likelihood only reveals the primary content of the clusters. To get a deeper understanding of the difference between the two clusters, the difference in noun likelihood was calculated. The proportional difference in noun likelihood is shown in Table IV.

As evident from Table IV, significant difference is observable between the two clusters. Top 50 differences are shown in the table; however, the significance of the difference goes on further throughout the top 100 of the analysis. The difference in frequence of specific nouns in the analysis, reveal how DR and DI differ. Nouns commonly used for explaining DR are, thus, uncommonly used while explaining DI and vice versa.

Cluster 1 primarily differentiate from cluster two in terms of the unigrams and bigrams: “design model”, “mark-up”, “annotation”, “design intent”, “mark-up language”, “geometry”, “design system”, “product model”, “shape”, and “event”. Whilst cluster 2’s unigrams and bigrams differentiated mostly from cluster 1 in terms of: “rationale”, “design rationale”, “permission”, “argumentation”, “owner”, “claim”, “decision”, “service”, “architecture rationale”, and “rationale representation”.

The findings underline the differentiation between “design rationale” and “design intent” in the two clusters. Design intent is occurring 11.54 times as frequent in cluster 1 as in cluster 2, while design rationale is occurring 11.82 times as frequent in cluster 2 compared to cluster 1.

This reveals that there are, firstly, significant differences between how the literature makes use of and describes DR and DI, and secondly, that a multitude of different words present in the identified and evaluated literature can be used to explain the nuances of the two concepts.

Table 4: Differences between cluster 1 and 2 in terms of unigrams and bigrams. The log2 ratio expresses the proportional difference in frequency between the two clusters.

	Cluster 1		**Cluster 2**	
	Biggest difference	**log2 ratio**	**Biggest difference**	**log2 ratio**
1	design model	-12.46	rationale	13.39
2	markup	-12.40	design rationale	11.82
3	annotation	-11.83	permission	11.04
4	design intent	-11.54	argumentation	9.95
5	markup language	-11.47	owner	9.81
6	geometry	-11.01	claim	9.52
7	design system	-10.67	decision	9.26
8	product model	-10.24	service	9.12
9	shape	-10.17	architecture rationale	9.11
10	exchange	-10.04	rationale representation	9.11
11	master model	-9.99	architecture element	9.01

12	design operation	-9.69	decision rationale	8.98
13	intent	-9.60	query	8.96
14	parameter	-9.38	meeting	8.92
15	sketch	-8.28	deliberation	8.68
16	correction	-6.63	people	8.65
17	matching	-6.56	justification	8.65
18	surface	-6.38	rationale system	8.55
19	assembly	-6.06	rationale capture	8.41
20	product development	-6.05	statement	8.14
21	modelling	-5.84	design decision	7.78
22	computer	-5.61	decision support	7.45
23	information model	-5.53	decision making	7.44
24	knowledge management	-5.47	subject	6.75
25	design case	-5.39	alternative	6.61
26	product design	-5.35	question	6.57
27	design history	-4.81	client	6.49
28	expert system	-4.68	making	6.02
29	entity	-4.59	use case	5.93
30	master	-4.43	design object	5.91
31	module	-4.37	documentation	5.80
32	sequence	-4.06	perspective	5.79
33	manufacturing	-4.04	layer	5.67
34	error	-3.73	option	5.67
35	feature	-3.59	issue	5.52
36	product	-3.59	discussion	5.19
37	command	-3.46	maintenance	5.14
38	history	-3.45	answer	4.86
39	reference	-3.35	specification	4.76
40	transfer	-3.28	design alternative	4.74
41	drawing	-3.23	node	4.27
42	operation	-2.99	improvement	4.19
43	pattern	-2.94	artifact	4.15
44	taxonomy	-2.92	idea	3.79
45	dimension	-2.80	goal	3.68
46	event	-2.73	network	3.56
47	model	-2.63	architecture	3.47
48	behaviour	-2.56	requirement	3.44
49	function	-2.55	criterion	3.40
50	edge	-2.51	link	3.40

4. DISCUSSION

Improving designing and reducing cost and time consumption, both during designing, pre-planning, construction and operation, is a continuously ongoing discussion in the AEC industry and in the AEC related scientific literature.

As described by Feng *et al.* (2022), construction planning can be challenging, because much information has not been determined, whilst Bryde et al. (2013), describe how information and knowledge gained from a project is rarely retained. Alducin-Quintero *et al.*, (2012) furthermore, describe how building information is frequently developed based on a poor modelling strategy.

DR and DI are concepts used to describe specific design knowledge about a project, and multiple definitions of DR have been proposed and discussed in the scientific literature in the past decades.In a historical perspective DR, has since the concept was introduced been described as containing the deliberations, representing issues, alternatives or justifications (Potts and Bruns, 1988), and more recently also all background information, such as the reasons for a design decision, trade-offs made (Falessi et al., 2006; Gonsalves and Itoh, 2007; Lee, 1997; Liu and Hu, 2013; Rockwell et al., 2009), supporting not only decisions made by designers, but also groups of designers (Bañares-Alcántara and King, 1997).

This is in line with the quantitative results of this study, identifying the same nouns, "deliberation", "issues", "justification", "design decision", and "alternative". The quantitative results provide additional nuances to these descriptive words such as: "permission", "argumentation", "claim", "decision", "query", "design support" and "design making", "perspective", "option", "answer", "specification", and "design alternative". Noun unigrams and bigrams which are all similar to the qualitatively observed descriptions in the literature. What is interesting in this regard, is that these identified words cluster in the context of design rationale only, allow an objective development of a DR definition, which is different than a definition of DI.

A definition containing the identified nouns seems to fit the AEC industry, as designing is often done by multiple people, from different companies, during different design phases, going from an initial design phase of pre-designing, conceptual and schematic design, through a project design phase, including a design proposal and a detailed design (Landgren *et al.*, 2019; Wyke *et al.*, 2021). Given such design phases occur over long time periods, this often result in changes of participants, who might have contributed to designing with valuable knowledge, which is not stored in any reliable format on the design project, and which is, therefore, lost when the person leaves the project organisation. Hence, Myers et al. (2000), described DR in the detailed design phases, as focussing on how a given design works, and why the specific detailed design choices were made, containing any information that will increase the understanding of design and its development. Using the nouns revealed in the NLP analysis: "owner", "decision", "query", "meeting", "people", "question", "client", and "option", this explanation makes sense to use in the definition of DR, contrasting it further from DI, whilst providing additional nuances to the explanation of what DR really is.

Looking deeper into the concept of DI, Peña-Mora et al. (1993, 1995), describe how DI consists of the four attributes of a design "objectives", "constraints", "functions", and "goals", which fathoms most of elements used for describing how a design is made, and what it contains. Similar to a strategy for how to design a building and what guides this process. This is in line with research by Otey et al. (2018), who found that DI is embedded in sketches, constraints, relationships between modelling operations and the modelling operations, which can convey DI through proper naming whilst modelling instead of using generic naming only. Others have finally found that DI is the reason that incite a designer to follow a specific CAD modelling procedure, further expressing the manner in which the designer expects the geometric model to behave when it is modified (Dorribo-Camba et al., 2013).

These descriptions of DI are in line with the results of the NLP analysis, revealing noun unigrams and bigrams such as: "design model" mark-up" and "markup-language", "annotation", "geometry", "design system", "product model", "shape", "modelling", information model", "knowledge management", and "design history",
which are different from nouns related to DR, by a large margin. DI can, hence, be defined as the explicit description of the criteria for the design, in terms of the design model, the mark-up, the annotation, the geometry, and the shapes describing the design solution. Knowledge which can significantly improve design productivity, increase quality of the design, provide more intelligent use of resources and knowledge, and facilitate integrated solutions and transferring of design knowledge (Peña-Mora *et al.*, 1993; Wyke *et al.*, 2024)

However, as described by Conklin and Yakemovic (1991), DR provides a dimension of description that is usually missing, by augmenting the "what" of the artefact's structure and function, or the DI, with the "why" behind its design. DR is thus, a kind of communication or knowledge representation from the creator of an artefact or design to those who later must use or understand the artefact or design. This reveals that the DR is the reasoning or the "why", which augments or explains the "what" of the design, identifying that no DR is complete without DI and vice versa, which was also identified in the qualitative analysis of the identified literature. The nuances of DR and DI based on both the qualitative evaluation of the identified literature and the quantitative NLP analysis is summarised in table V.

Table 5: A summary of nouns defining DR and DI based on the qualitative and the quantitative analysis. Overlapping nouns from the two analyses are written in italics.

	Qualitative	**Quantitative**
DR	"*deliberation*", "*issues*", "*alternatives*", "*justifications*", "background information", "reasons", "*design decisions*", and "tradeoff".	"*deliberation*", "*issues*", "*justification*", "*design decision*", and "*alternative*". "permission", "argumentation", "claim", "decision", "query", "design support", "design making", "perspective", "option", "answer", "specification", and "design alternative".
DI	"objectives", "constraints", "functions", "goals", "sketch", "constraints", "relationships between modelling operations", "modelling operations", and "CAD modelling procedure".	"design model" mark-up" and "markup-language", annotation, geometry, "design system", "product model", "shape", "modelling", information model", "knowledge management", and "design history"

In their research Klein (1993), described how designers can waste their time on issues that later prove unimportant, because current rationale capture tools do not let them focus on issues revealed by actual inspection of the evolving design description, as well as being limited by only capturing parts of the DR, generating inconsistency in the design descriptions. Therefore, a formal representation of DR is needed, to ensure the usability of DR between actors on a project and maybe even between projects. In the regard, Bryde et al. (2013), describe how information and knowledge gained from a project is rarely retained, which makes it impossible to reuse it on later projects. The substitution of personnel on design projects in AEC, is another factor, affecting reuse of design knowledge such as DR. Design organisation participants and pre-planning personnel can e.g. be substituted in and between design and pre-planning phases, having specific design solution knowledge stored in their memory only. Knowledge which might therefore be lost on the project, resulting in time and cost overruns on the project.

Design and construction projects, additionally, tend to be one of a kind projects (Molwus *et al.*, 2017; Zou and Tang, 2012), limiting the incentive of participants in the design phases documenting DR, for future issue resolving on a project or DR for future projects, because documenting DR might not benefit them directly in the future, and that documenting DR, generally will result in additional resource consumption for the designer and/or the project organisation. This is also described by Klein (1993), explaining how rationale capture systems impose significant overhead on the design process, which is exacerbated by the fact that the people who benefit from rationale capture often are not those who are asked to perform it. Designers might, additionally, be hesitant to give away knowledge without knowing who will use it, or how it will be used. This is, furthermore, the case with detrimental knowledge for the designers or certain other people on a project, which then might be omitted during documentation of DR (Horner and Atwood, 2006). Documentation of DR can finally, be difficult on design projects, due to the time involved in documenting it, as the reuse perspective of such design knowledge is often forgotten, even though having it available could help a designer to avoid certain solutions on future projects, or how to apply a specific solution to future project, with similar design properties or design intent Having DR available, could, furthermore, save time on future projects and when redesigning or editing DI on a project, because the justification for a solution, the argument describing why one solution was selected instead of another, and the documentation of the alternative solutions is documented explicitly, and not stored in the memory of a designer, which is not a reliable data repository (Wyke *et al.*, 2021), neither on nor between projects. Having DR and DI documentation available across projects, will also provide an ability to reuse DR and DI, and not start from scratch every time a "one-of-a-kind" project starts, which could potentially reduce the cost involved in DR and DI development and management for a company over time.

Lee (1997) and Burge and Brown (Burge and Brown, 2008), furthermore, describe that formalising knowledge is costly and that a DR system will not be used if the cost outweighs the benefits. It is, therefore, essential that methods to produce formal DR at less cost are developed Lee (1997). However, before such systems are developed it is imminent to define what they should document, highlighting why a definition of DR is essential.

Based on the existing body of scientific literature on DR, a consensus is observable, which show that DR is a structured documentation of the design solutions, the alternatives, the justifications for, or for not selecting a design solution, as well as other information that might enhance understanding of a design amongst project participants, and contribute to achieving improved project outcomes.

If people do not know how to document DR and DI, it will not be documented. If DR and DI are not available in a reliable and accessible format; it obviously cannot be used. If people do not understand why they are documenting DR and DI, they will not do it, especially if it does not provide any advantage to the ones documenting it. Finally, if people do not know what DR and DI consist of, they will not even attempt to document it (intentionally) in a reliable format and usable representation, which limits the potential use of DR and DI from one phase to another in the design and pre-planning process, as well as between projects.

The definition of DR and DI is therefore essential, as it makes it possible to firstly, prescribe exactly what is meant by DR and DI, increasing the likelihood of the concepts being understood by the ones responsible or able to document it. It is, furthermore, possible to prescribe to which degree DR and DI should be documented, by and to whom, when it should be documented and exchanged, and in which format and representation. Without a definition everyone can agree on, this is not possible.

The development of a definition of DR as well as DI, also have practical implications on multiple fronts. As described previously, availability of DR and DI can increase productivity (Otey *et al.*, 2018; Peña-Mora *et al.*, 1993; Wyke *et al.*, 2023), in terms of producing the right things, not just a larger volume of something. Common understanding of DR and DI can, additionally, reduce time being wasted documenting something which is not actually DR or DI, in addition to ensuring that opportunities to document DR and DI are not missed.

A final benefit of having a DR and DI definition lies in the construction and operational phases, in which DR and DI can be a contributing factor ensuring the final building or facility, is built and operated as intended by the designers and building owner(s). Time and money can, furthermore, be saved, because available DR and DI can guide decision making during construction and operation more efficiently, through reducing explorations into design alternatives which have already been tested and discarded during design and pre-planning and thereby guide project managers to look for new solutions in the unexplored.

5. CONCLUSION

This paper presents a literature review investigating various definitions of Design Rationale (DR) and Design Intent (DI) utilising forward and backward snowballing and qualitative analysis of the scientific literature as well as quantitative analysis of the literature using Natural Processing Language (NPL) to answer the research questions: *What are the existing understandings of DR and DI, and which AEC related definition of DR and DI can be derived from the existing scientific literature?*

The definition of DR as an explicit reason for why a design is the way it is, seems to be the most accepted across industries and scientific disciplines. However, this literature review has both qualitatively and quantitatively shown that DR entails the explicit description of design decisions, the justification for a solution, the argument describing why one solution was selected instead of another, as well as the documentation of the alternative solutions. Then nouns presented in table IV and V further elaborate on the nuances of DR.

DI on the other hand is in the literature described as the "what" of the design, meaning the "objectives", "constraints", "functions", and "goals", as well as being defined by the unigrams and bigrams: "design model" mark-up" and "markup-language", "annotation", "geometry", "design system", "product model", "shape", "modelling", information model", "knowledge management", and "design history".

The NLP analysis showed that a significant difference between DR and DI is observable in the literature, revealing a distinct collection of words describing each concept. Previous research has furthermore highlighted that a successful design project must include documentation of both explicit DR and DI, which is also the finding in this research, concluding that no DR is complete without the DI and vice versa.

Utilising both qualitative analysis of the identified literature, as well as NLP, amplified the nuances available to reach a definition of DR and DI. Obvious similarities and discrepancies were, thusly, observed in the literature through reading and indexing the content of the literature qualitatively, whilst specific distinctions between studies expressed in terms of which nouns were utilised were revealed through NLP, augmenting the available understanding of DR and DI the literature. NLP, additionally, proved adept in validating the qualitative results of the study, providing an unbiased basis for evaluating the qualitative results.

What is the point of developing and managing DR and DI then? Based on the results presented in this article, developing DR and DI can provide a better foundation for decision making during design and pre-planning, as well as during construction and operational phases of the building lifecycle. The primary conclusions derived from the results and discussion in this article, in this regard are that, documented, stored, and exchanged DR can guide a designer or project manager in the direction of unexplored solutions if something in the design must be changed, instead of exploring already tested and discarded solutions. The availability of DR, furthermore, ensures that a design solution lives up to the intent of the designer or building owner, through specifying the justification for the exact solution, and not just *what* the solution is, consists of, or should be. Developed and managed DR and DI, furthermore, provide a canvas to build on top of from project to project, guiding project participants in the direction of solutions which they know what consist of, why they work in specific contexts, as well the justifications for selecting such solutions, or why specific solutions might not work at all.

Future research must investigate deeper into the effects and benefits of having DR and DI available in the architectural, engineering, and construction industry. Moreover, more knowledge is needed regarding the challenges of documenting DR and DI and how to overcome them, including how to structure these explicit knowledge types and how to achieve the benefits the availability provides. The development and implementation of digital information and communication technologies in the AEC industry and how such development and implementation has affected DR and DI understanding, use, and tools for DR and DI management, should also be investigated and addressed in future research.

The methodological approaches presented in this research should, additionally, be reiterated in future research to evaluate the efficiency and practicability of combining qualitative literature evaluation with NLP to attain deeper understanding of nuances when conducting literature reviews.

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APPENDIX A: INDEXING OF WHICH PAPERS CONTAINS A DEFINITION OF DESIGN RATIONALE, DESIGN INTENT, OR A COMBINATION OF BOTH.

	AECO	NON-AECO	Defines or presents definition of Rationale	Defines or presents definition of Intent	Combined presentation or definition of rationale and intent	Presents tool(s) for documentation of design rationale	Presents tool(s) for documentation of design intent	Presents tool(s) for exchange of design rationale	Presents tool(s) for exchange of Design Intent
(Kunz and Rittel, 1970)		●	●			○*	○*	○*	○*
(Conklin and Begeman, 1988)		●	●			●		●	
(Potts and Bruns, 1988)		●	●			●		●	
(MacLean *et al.*, 1989)		●	●			●		●	
(Conklin and Yakemovic, 1991)			●			●		●	
(Lee and Lai, 1991)		●	●			●		●	
(Lubars, 1991)		●		○		●		●	
(MacLean *et al.*, 1991)		●	●			●		●	
(Garcia and Howard, 1992)	●		○		●	●		●	
(Gruber *et al.*, 1992)		●	○			●		●	
(Klein, 1993)		●	●			●		●	
(Peña-Mora *et al.*, 1993)	●		●	●		●	●	●	●
(Ganeshan *et al.*, 1994)	●			●		○	●	○	●
(Ramaesh and Dhar, 1994)		●				●		●	
(Shum and Hammond, 1994)		●	●			●		●	
(Teicholz and Fischer, 1994)	●		●						
(Fischer *et al.*, 1991)	●		●			●	○	●	○
(Malone *et al.*, 1995)		●				●*	●*	●*	●*
(Peña-Mora *et al.*, 1995)	●		●	●		●	●	●	●

(Sutcliffe, 1995)		●				●		●	
(Dellen *et al.*, 1996)	○	●	●			●		●	
(Karsenty, 1996)		●	○			●		●	
(Shipman and McCall, 1997)		●	●		○	●	○	●	○
(Bañares-Alcántara and King, 1997)		●	●			●		●	
(Brazier *et al.*, 1997)		●	●	●	●				
(Lee, 1997)		●	●			●	●	●	●
(Maher and De Silva Garza, 1997)	●					●*	●*	●*	●*
(Qureshi *et al.*, 1997)		●			●	●*	●*	●*	●*
(Chung and Goodwin, 1998)	●	●	●			●		●	
(Myers *et al.*, 2000)		●	●	○	○	●	○	●	○
(Regli *et al.*, 2000)	●	●	●			●		●	
(Hegazy *et al.*, 2001)	●		●			●		●	
(Szykman *et al.*, 2001)		●	●		○				
(Dutoit and Paech, 2002)			●			●		●	
(Bracewell and Wallace, 2003)		●				●		●	
(Brissaud *et al.*, 2003)		●	○			●		○	
(Horváth and Rudas, 2003)		●		●			○		○
(Gero and Kannengiesser, 2004)		●							
(Ahmed, 2005)		●	●	●		○	○	○	○
(de Medeiros *et al.*, 2005)		●				●		●	
(Douglas, 2005)		●	●			●		●	
(Kim *et al.*, 2005)		●	●			●		●	
(Sexton *et al.*, 2005)	●					○*	○*	○*	○*
(Tang *et al.*, 2005)		●	●						
(Falessi *et al.*, 2006)			●			●		○	
(Horner and Atwood, 2006)		●	●						
(Ishino and Jin, 2006)		●	●			○		○	
(Iyer and Mills, 2006)	●	●		●	●				
(Shum *et al.*, 2006)		●				●		●	
(Tang *et al.*, 2006)		●	●						
(Yang and Han, 2006)		●				○*	○*	○*	○*
(De Medeiros and Schwabe, 2007)		●	●			●		●	
(Gonsalves and Itoh, 2007)		●	●			●		●	
(Goulding *et al.*, 2007)	●					○*	○*	○*	○*
(Kim *et al.*, 2007)		●	○			●		●	

(Motawa *et al.*, 2007)	●								
(Rynne and Gaughran, 2007)		●		●			●		○
(Sandberg and Näsström, 2007)		●	●			●	●*	●	●*
(Tang *et al.*, 2007)		●	●			●	●*	●	●*
(Brandt *et al.*, 2008)		●	●			●	○*	●	○*
(Burge and Brown, 2008)		●	●			●		●	
(Kim *et al.*, 2008)		●		●			●		●
(Li *et al.*, 2008)		●				●	●	●	●
(Tang *et al.*, 2008)		●							
(Verries *et al.*, 2008)		●	●			●		●	
(Bracewell *et al.*, 2009)		●				●		●	
(Wang *et al.*, 2009)		●	●			●		●	
(Ding and Liu, 2010)		●			●	○	○	○	○
(Liu *et al.*, 2010)		●	●			●		●	
(Rockwell *et al.*, 2010)		●	●			●		●	
(Tang *et al.*, 2010)	●	●	○						
(Alducin-Quintero *et al.*, 2011)		●		●			●		●
(Du and Liu, 2011)		●	●			○		○	
(Van Schaik *et al.*, 2011)		●	●			●		●	
(Wang *et al.*, 2011)		●	●			●		●	
(Alducin-Quintero *et al.*, 2012)		●		●		○	●	○	●
(Dalsgaard and Halskov, 2012)	●		●			●		●	
(Miesbauer and Weinreich, 2012)		●				○*	○*	○*	○*
(Wang *et al.*, 2012)		●	●			●		●	
(Zou and Tang, 2012)	●							●	
(Chandrasegaran *et al.*, 2013)		●	●			○		○	
(Kozemjakin da Silva *et al.*, 2013)		●	●						
(Dorribo-Camba *et al.*, 2013)		●	●	●		●	●	●	●
(Falessi *et al.*, 2013)		●	●			●		●	
(Gedell and Johannesson, 2013)		●	●	●		●	●	●	●
(Liu and Hu, 2013)			●	●	●	●	●	●	●
(Nkwocha *et al.*, 2013)		●	●			●		●	
(Sahraoui, 2013)		●	●			●		●	
(Zhang *et al.*, 2013)		●	●			●	●	●	●
(Camba *et al.*, 2014)		●		●			●		●
(Camba and Contero, 2015)		●			●	○	●	○	●

(Sivanathan *et al.*, 2015)		●	○			●		●	
(Poorkiany *et al.*, 2016a)		●	●			●		●	
(Poorkiany *et al.*, 2016b)		●	●			●		●	
(Cheng *et al.*, 2017)		●		●			●		●
(Otey *et al.*, 2018)		●	●	●			●		●
(Peng *et al.*, 2017)		●	○			○*	○*	○*	○*
(Cheng *et al.*, 2019)		●		●	○		●		●
(De Jong *et al.*, 2019)		●	●			●		●	
(Lin, 2021)		●	●						
(Tsutsui *et al.*, 2021)	○	●	●						
(Eder *et al.*, 2022)		○		○			○		○

● Yes

○ Partly

* Interpretation is dependent on which definition of design intent and rationale is applied.