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Development of an Automated Design Aid (ADA) for improved Buildability and Accelerated Learning

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Abstract

This research is targeted towards the provision of support for designers in achieving, and measuring, *Buildability* whilst allowing for design *Creativity* and learning. This paper deals with the development of *Skill Models* as an approach to measuring *Buildability* in a CAD produced design. A *Skill Model* is specific to one construction task. A library of *Skill Models* is required for full measurement of a design. Each unique *Skill Model* will result from the combination of *Skill Concept Packages* used in it's assembly. *Skill Concept Packages* supply the designer with construction skill knowledge during the design stage. *Skill* is defined in terms of *Accuracy*, *Competence* and *Rapidity*. Measured in these terms the design will be assessed for *Technical Difficulty*. This will then provide the designer with the opportunity to achieve *Buildability* through *Simplification* of the design.

1. INTRODUCTION

Buildability was originally seen within the construction industry as a tool for improving the ability to construct a building efficiently, without consideration of the concepts of *Function* and *Performance*[1]. Construction product problems were generally the result of designers incomplete understanding of the construction process. Consideration of buildability in the construction process would, theoretically, eliminate product quality problems. However, buildability was no more consistently defined or understood than the construction process itself, as evidenced by the definitions put forward for buildability. To minimise misinterpretation of points discussed in this paper, a glossary of terms is included after the conclusion. Present definitions in this area are generally not sufficiently specific.

The authors suggest that a suitably revised approach to implementing *Buildability* is necessary. A computational method is proposed, taking into account the move towards increased use of automation in construction. A suitable starting point is to put forward a definition for buildability which considers the relationship between design and assembly, without explicit reference to either *Function* or *Performance*, such as that formulated by Illingworth [2]: This definition of buildability, however, does not explicitly address the problem of *Creativity* in design. This paper accepts Lawson's concept of *Creativity*[3]. A suitably revised definition for buildability through *Simplification* is put forward in section 2.

Buildability failed to satisfactorily address product quality problems, as was evidenced by the industry's move to Quality Assurance (QA) systems. QA is now becoming compromised itself. Some companies have rejected QA (in it's BS 5750 guise) as unsuited to the construction industry [4]. Moore[5] suggests that alternative quality standards will fail unless they are able to bridge the divide between design and the construction process. Possible causes for the failure of buildability are explored in section 2. Section 3 introduces the main concepts behind our proposed computational system. Section 4 examines the relevance of *Skill* to the proposed system, and discusses how the system would assess a particular design. Section 5 concludes the paper by suggesting the direction of future development.

2. PHILOSOPHY

Repetition, Rationalisation and *Standardisation* are buildability terms that suggest mass production achieved at the expense of creative individualism. This is reinforced by the use of terminology such as Ferguson's[6] *Variety Reduction*. Buildability in a form which can be seen to impose constraints on design *Creativity* will not generally be accepted by a profession whose main advertisement is the buildings produced from it's designs. Griffiths[7] argues that the contribution of the design process in achieving buildability is paramount. Design led buildability can be divided into two approaches; *Simplification* and *Standardisation*. *Standardisation* is more strongly aligned with the *Variety Reduction* philosophy than is *Simplification*, with its emphasis on avoiding unnecessary complexity. Gray[8] suggests that *Simplification* applied to the "project activity" sequence would provide financial savings greater than could be achieved by application at the task level. This paper proposes *Simplification* at the task level only. The intention is to develop a system for the assessment of *Buildability* which can inform designers of the assembly requirements of their designs.

It is therefore appropriate to put forward a definition of *Buildability* specific to our intended approach. The definition of task level *Simplification* led *Buildability* used in the remainder of this paper is developed from Illingworth's definition, and is :

> **"That design philosophy which recognises and addresses the problems of the assembly process in achieving the construction of the designed product, both safely and without resort to *Standardisation* or project level *Simplification*."**

3. CONCEPTS

Yamazaki[9] noted that the present construction system suffers in that basic knowledge about construction technologies is not shared between constructors and designers. The problem of assessment of degree and type of *Skill* required for the implementation of technologies is one aspect of this lack of shared knowledge. The *Skill* assessment problem may be degraded if the design 'system' is accepted as working on the basis of fragment retrieval (Gero and McLaughlin[10]). Fragment information will impact on the development of a given design. In a situation where the fragments retrieved do not contain *Skill* information about the construction process, then *Skill* assessment can not be said to have occurred. Dreyfus and Dreyfus[11] have stated that an individual at a particular stage of *Skill* acquisition can imitate the thought processes of someone at a higher level of *Skill*. However, their performance will not equal that of a more highly *Skilled* individual until they have gained sufficient experience. A design aid which is suitable for assessing *Buildability* will also be suitable for accelerating the process of gaining experience.

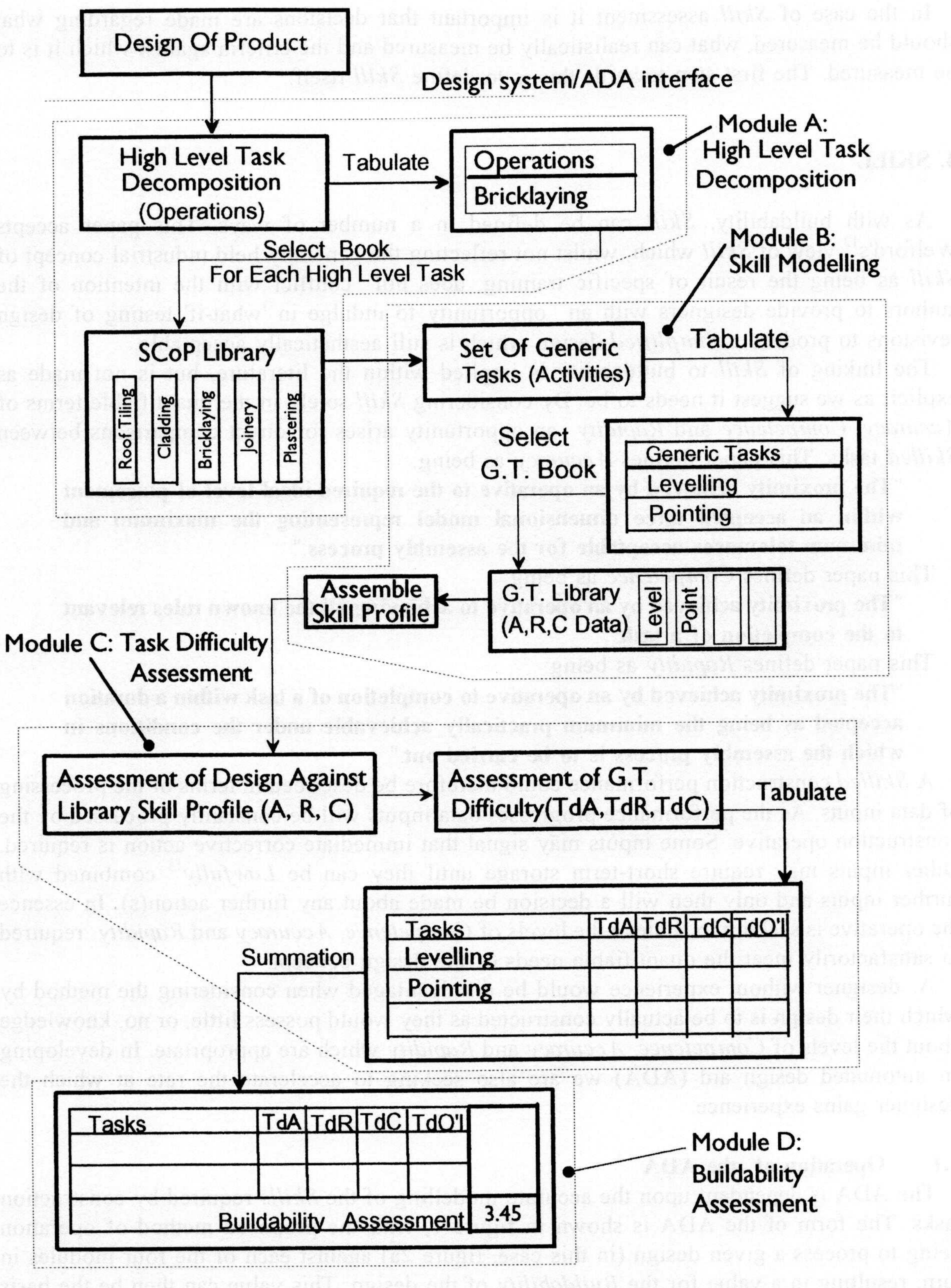

Fig.1. Form and Operation of ADA

In the case of *Skill* assessment it is important that decisions are made regarding what should be measured, what can realistically be measured and the criteria against which it is to be measured. The first step towards this is to define *Skill* itself.

4. SKILL

As with buildability, *Skill* can be defined in a number of ways. This paper accepts Welford's[12] view of *Skill* which, whilst not reflecting the generally held industrial concept of *Skill* as being the result of specific training, does not conflict with the intention of the authors to provide designers with an opportunity to indulge in 'what-if' testing of design revisions to produce a *Simplified* design which is still aesthetically acceptable.

The linking of *Skill* to buildability is implied within the literature, but is not made as explicit as we suggest it needs to be. By considering *Skill* solely in the quantifiable terms of *Accuracy, Competence* and *Rapidity* an opportunity arises for direct comparisons between *Skilled* tasks. This paper defines *Accuracy* as being:

"The proximity achieved by an operative to the required ideal level of placement within an accepted three dimensional model representing the maximum and minimum tolerances acceptable for the assembly process."

This paper defines *Competence* as being:

"The proximity achieved by an operative to achieving all the known rules relevant to the completion of a task."

This paper defines *Rapidity* as being:

"The proximity achieved by an operative to completion of a task within a duration accepted as being the minimum practically achievable under the conditions in which the assembly process is to be carried out."

A *Skilled* construction performance could therefore be described in terms of the processing of data inputs. As the performance progresses data inputs will be constantly processed by the construction operative. Some inputs may signal that immediate corrective action is required. Other inputs may require short-term storage until they can be *Lawfully*[13] combined with further inputs and only then will a decision be made about any further action(s). In essence the operative is seeking to achieve the levels of *Competence, Accuracy* and *Rapidity* required to satisfactorily meet the quantifiable needs of the design concept.

A designer without experience would be disadvantaged when considering the method by which their design is to be actually constructed as they would possess little, or no, knowledge about the levels of *Competence, Accuracy* and *Rapidity* which are appropriate. In developing an automated design aid (ADA) we are also seeking to accelerate the rate at which the designer gains experience.

4.1 Operation of the ADA

The ADA is dependant upon the accurate modelling of the *Skills* required by construction tasks. The form of the ADA is shown in figure 1, with the proposed method of operation being to process a given design (in this case, figure 2a) against each of the four modules in turn, resulting in a value for the *Buildability* of the design. This value can then be the basis of *Buildability* comparisons with revised designs.

Figure 2a shows a design for a brick infill panel suitable for sealing up redundant window openings. The designer does not wish to draw attention to asymmetrically bonded panels. The requirement is therefore added that the panels should be bonded in a symmetrical manner. The revised design is shown as fig. 2b. The designer is, however, unaware of how much more difficult he/she has made the bricklayers job.

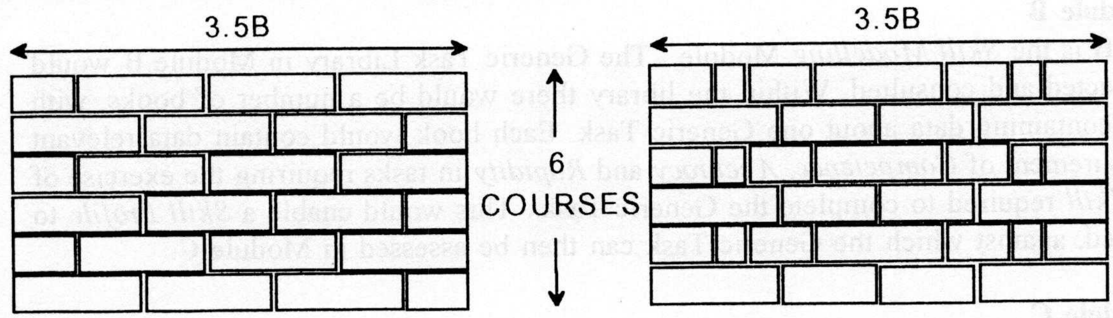

Fig. 2a Original proposal; Stretcher bond

Fig. 2b Revised proposal; Symmetrical bonding

Figure 2. Brick panel designs

Table 1. Quantities: Figs. 2a & 2b

	Full Bricks	3/4 Bricks	1/2 Bricks	1/4 Bricks	Bricks Used	No. Perps
2a	18	0	6	0	21B	18
2b	9	6	12	6	21B	27

	Max. Perps in 1 course	Min. Perps in 1 course
2a	3	3
2b	6	3

A *Novice*[14] designer may be of the opinion that 2b is more difficult to construct than 2a, but may not be able to give satisfactory reasons for this. There are a number of common sense reasons which can be put forward for this increased difficulty. For example; 2b uses more bricks than 2a. This is not actually true. Table 1 shows that there are exactly the same number of bricks in both cases. Rather than continuing examining possible common sense reasons we shall work through the method by which the ADA would assess design 2b.

4.1.1 Module A

Module A is the *Decomposition* Module. Working from the design information generated whilst working in a CAD environment, design 2b would be decomposed in line with Chandrasekaran's[15] Generic Task Decomposition. The first stage would be to decompose the design into High Level tasks, producing a set of *Operations*. The *Operations* would then be further decomposed through reference to the *Skill Concept Package (SCoP)* Library to produce a set of Generic Tasks. Some of these Generic Tasks would be applicable to more than one *Operation*. The Generic Tasks are tabulated in Module B.

4.1.2 Module B

Module B is the *Skill Modelling* Module. The Generic Task Library in Module B would now be selected and consulted. Within the library there would be a number of books, with each book containing data about one Generic Task. Each book would contain data relevant to the measurement of *Competence, Accuracy* and *Rapidity* in tasks requiring the exercise of the given *Skill* required to complete the Generic Task.. This would enable a *Skill Profile* to be assembled, against which the Generic Task can then be assessed in Module C.

4.1.3 Module C

This would carry out a comparison of the task within a design to the *Skill Profile*:

4.1.3.1 *Competence*

By applying our definition of *Competence*, it becomes apparent that the performer requires to develop an organising plan, based around the *Lawful* rules for the task. We suggest that the more *Lawful* rules invoked in completing a task, the more difficult the task will prove to be. In the case of the brick panel this could be developed by the bricklayer referring to memorised information about any similar previously constructed panels and how they were constructed. The *Novice* bricklayer would not have such experience to relate to and, similarly, the *Novice* designer would also be lacking such experience. The book selected from the *SCoP Library* would have to contain such experiential information. In the event of the wrong information being written into the book the remainder of the modelling process will be of little value. *Competence* is therefore of importance with regard to measurement of *Skill.*

4.1.3.2 *Accuracy*

Accuracy would appear to be less problematic, in that within a CAD environment distance measurement and locating of objects in three dimensional space is an essential function. It would, however, be meaningless to take the approach of measuring the design against such criteria as level and plumb. Such criteria would need to be placed within a context applicable to the situation in which the construction work is to be carried out. In the example of design 2b it would be appropriate to consider the difficulty inherent in carrying out brickwork of an acceptable quality within the restrictions imposed by an existing opening. A further relevant consideration would be to assess the design dimensions in terms of the size of the units being used for construction, in the case of 2b this would be brick size. If the opening did not equate to a multiple of brick size *Accuracy* would become more difficult to achieve, as either the joints would have to be 'shuffled' or additional cutting of bricks would be required.

4.1.3.3 *Rapidity*

Rapidity could make use of information generated during the *Accuracy* assessment of the design. The multiple of unit size would effectively give the number of joints required (subject to further processing of the data against any relevant rules, such as bonding requirements) and this, in turn, would be one factor in assessing the time required to complete the design. Such information could be utilised on the following basis.

Reference to Table 1 shows that in design 2b the number of vertical joints ('perps') is 33% greater than in 2a. Design 2b also has a greater variance in the number of perps on alternate courses. Such circumstances would reduce the rate at which a person of a given skill level could carry out the work. *Rapidity* would therefore vary with the nature of the design and the levels of *Accuracy* and *Competence* required.

Having assessed the design against the library *Skill Profile*, the resulting information would be further processed to arrive at an overall *Task Difficulty* rating for each Generic Task. By evaluating the difficulty for each Generic Task individually the designer would have available a range of data to enable selection with regard to which components of the design, if any, to revise. For example, the design may be such that it is evaluated as being particularly poor in the context of *Task Difficulty* with respect to *Rapidity*. The designer would then have the opportunity to concentrate his/her efforts in this area first.

Raouf et al[16] describe one approach to assessing *Task Difficulty*, which suggests that asymmetrical activities of a nature such as are required to construct design 2b, would be of greater difficulty than those required by design 2a. A consequence of this would be that 2b would take a person of a given skill longer to construct than would be the case with 2a.

4.1.5 Module D

The final module deals solely with the processing of the tabulated Generic Task difficulty values to arrive at a *Buildability* assessment for one complete High Level task or operation. In the case of a design which can be decomposed into a number of High Level tasks, a Buildability assessment would be calculated for each operation.

5. CONCLUSION

The authors are aware that the proposed system is a hypothetical one and that there are a number of areas which are still effectively generalised concepts. Our intention is to expand and clarify the knowledge in such areas. It is suggested that it is important to return *Buildability* to the design process agenda, in order to place greater emphasis on problem prevention within the industry rather than on problem solving. To achieve this a change of emphasis from *Standardisation* to *Simplification* is required. This will allow and encourage design *Creativity*, thereby reducing a present disincentive to designers considering *Buildability*. The emphasis on *Simplification* may prove to be of benefit in the achieving of greater automation in the construction process in two ways. Firstly, by adopting a design phase tool which is itself automated. Secondly, by encouraging *Task Difficulty* within the construction phase to be reduced, automated means of construction and the use of robotics could both be increased.

Use of an automated design aid would allow the designer the opportunity to compare and evaluate various designs on the basis of common criteria. In this way the designer could be directed, either by process or, more appealingly, through computer software to technically difficult aspects of a design prior to construction commencing. Such aspects can then be further simplified on a 'what-if' basis, using a knowledge based system approach for example. By placing the *Skill Modelling* system within a CAD environment a design/re-design facility can be supplied in a convenient form. This may then enable *Buildability* to be considered as an aid to *Creativity*, rather than a restriction.

The authors are currently progressing this research to further explore the theories of *Skill Modelling*, viewing *Skill Concept Packages* as fundamentally knowledge-based processes, in order to develop intelligent tools for *Buildability* assessment.

6. GLOSSARY

Decomposition - the action of identifying the sub-tasks required to complete a given task. *Lawful* - within the rules recognised by the process of decomposition. *Production Tasks* - those tasks required to execute a design on site, as identified by decomposition. *Rationalisation* - the minimisation of the number of materials, components or sub-assemblies. *Repetition* - the maximisation of use of the minimum number of materials, components or sub-assemblies. *Simplification* - the minimisation of complexity within a design or project to that which is actually essential. *Skill Profile* - the representation of the generic task skill data related to one decomposed high level task. *Standardisation* - a design philosophy requiring the designed product to be produced from those materials, components and materials remaining after rationalisation has taken place.

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