HyCon - a virtual reality design support tool for hybrid concrete structural frames

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Abstract

Hybrid concrete can provide high quality, cost effective structural frames in a variety of situations when compared to other, more conventional, solutions such as in-situ concrete and steel frames. The key players in the design and construction supply chain process for hybrid concrete are lead frame contractors and design engineers. The use of hybrid concrete, however, is sometimes not considered by contractors and designers during the initial stages of design. This is often because of a lack of reliable and accessible hybrid concrete cost and production time information. Without this information, contractors and designers may disregard hybrid concrete as a design alternative, potentially omitting the most appropriate solution before it has even been considered.

This paper reports on a collaborative research project in the United Kingdom which has developed HyCon - a prototype design support tool which allows contractors and designers at the conceptual design stage to carry out "what if?" analysis in a virtual reality environment to consider various hybrid concrete alternatives against a range of 'hard' and 'soft' performance criteria. The 'hard' criteria allow contractors and designers to assess initial and whole life cycle cost and production duration implications. The 'soft' criteria encourage the whole project team to assess and prioritise the importance and performance of design alternatives against criteria such as physical form and space.

Introduction

Hybrid concrete construction is an important new structural frame technology, and "is essentially the combination of in-situ concrete, steelwork or other materials" (Goodchild, 1995: 1). Advocates of hybrid concrete have long argued that hybrid concrete can produce solutions which are of higher quality, lower cost and faster construction than mono-material frames. Indeed, Goodchild (1995: 1) predicted that "concrete hybrid structures and hybrid elements will become more common as their potential is realized and familiarity grows." However, a lack of information by key actors has been identified as being a principal reason for the narrow diffusion of hybrid, with Goodchild (2001: 4) noting that "… engineers generally lack experience in using hybrid forms of construction and again need high quality readily accessible experience-based information."

Information technology (IT) based design support tools are increasingly being promoted as a means to encourage design engineers to experiment with new technologies and design solutions in a virtual environment to equip designers to consider alternative options. IT design support tools are being developed to stimulate design engineers to the search for, and be confident with, alternative solutions, but no application has hitherto concentrated on addressing the unique needs of hybrid concrete in structural frame design.

This paper presents results from an EPSRC funded project which has developed HyCon, a proof-of-concept IT design support tool to assist design engineers and the wider project team in experimenting with hybrid concrete design alternatives and their performance implications at the critical initial stages of design. Without this type of tool, design engineers might well continue to often disregard hybrid concrete as a design alternative because of lack of reliable performance information, potentially removing the most appropriate solution from the playing field before it has even been explicitly considered.

HyCon design-support tool

The construction process can be divided into three stages: namely, design, construction and post completion. Decisions in the design stages are the most critical ones (Gould, 1997) which have vital implications on the whole project (Baldwin *et al.*, 1998; Idrus and Newman, 2003). The design engineers are the key players in the hybrid concrete supply chain (Goodchild, 2001). Therefore, the conceived focus stage for the use of the virtual prototyping tool is the design stage, more specifically the conceptual design stage.

The conceptual design stage can further be divided into four key sub-stages; namely, the user needs analysis and performance criteria definition stage; the design alternatives stage; the performance prediction and evaluation stage; and, the design solution stage (Figure 1). The main stakeholders associated with the design stage are normally identified as the client and the design professionals, which naturally embraces the architect, engineers, and design consultants (Zhang *et al.*, 2004).

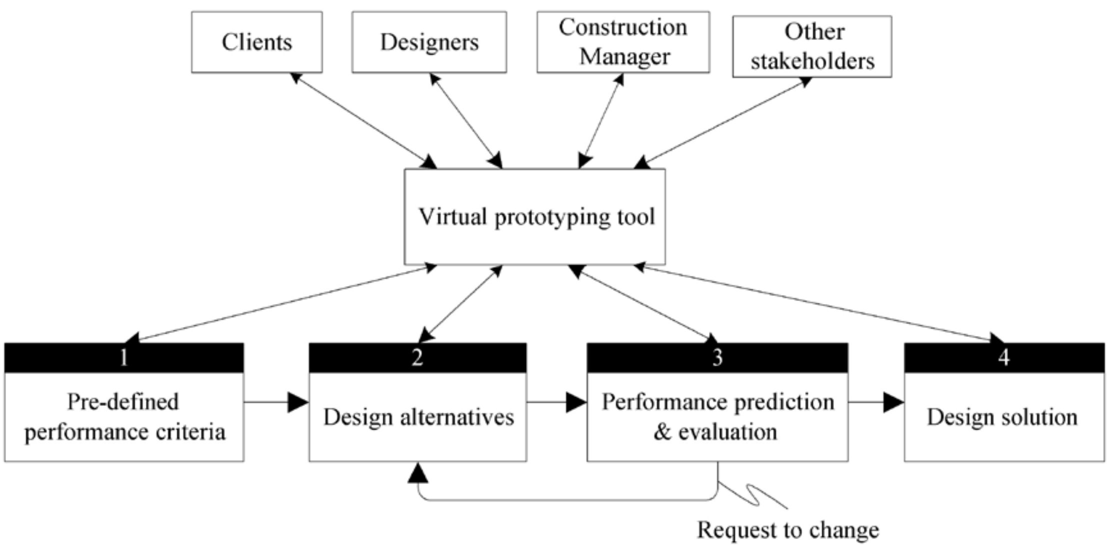

Figure 1. Conceptual relationship among the tool, stakeholders and the process

Informed decisions often require careful analysis of significant amounts of information, especially concerning the combination of available options and the simulation of their performance (Papamichael, 1999). Building design decisions are based on the comparison of design alternatives with respect to a variety of performance considerations. Therefore, one of the main functionality requirements for the decision-support tool is performance prediction and evaluation (Zhang *et al.*, 2003). It has been argued that if the stakeholders can access a tool which dynamically predicts the cost and other performance characteristics of different design proposals, there is going to be a significant increase of the scope of search for good solutions (Petric *et al.*, 2002). These functions can increase the effectiveness of design support environments in at least two ways: “reducing the number of parametric variations a designer may need to explore; and enhancing the users’ understanding of the interactions between various design and performance variables for a given partial design solution” (Mahdavi 1999, p431).

To achieve these goals, users should be able to compare the quality of different potential solutions against performance criteria through the tool. More specifically, the following challenges need to be addressed:

> a) Changeability of design attributes - the user can make a change in a design attribute and observe resulting changes in the design alternatives when one or more relevant performance criteria are constrained (Mahdavi, 1999). This is a way of examining trade-offs among design attributes for a given set of performance criteria.
>
> b) Changeability of performance criteria - the user can make a change in a performance criterion in order to see the corresponding changes in design alternatives (Mahdavi, 1999). There is not standardization in regard to the chosen of key performance criteria as well as the weight of their importance. All these can be varied in different projects.
>
> c) Changeability of structural elements - the performance assessment should work at structural element level, which means all the structural elements like floors, beams, columns, walls could be evaluated separately (Zhang *et al.*, 2003).

The HyCon tool accommodates these functionality requirements.

Performance evaluation is vital for the design decision-making process. Foremost, the two ‘hard’ performance indicators, namely production duration and initial cost, are still the main concerns for the construction industry (Barrett, 2003). According to Goodchild (1995), initial cost is the most influential factor in the choice of frame material. However, in recent years, there has been a call for an industry shift to bring about a more wider range of ‘hard’ and ‘soft’, long- and short- term performance dimensions into consideration - thus, bringing more substantial improvements to the performance of building industry and its products (Egan, 1998; Barrett, 2003).

In the HyCon tool, both ‘hard’ and ‘soft’ criteria have been integrated. It is important to note that the initial cost, whole life cycle cost and production duration of each design alternatives are evaluated only with regards to the superstructure of a building. Each building element of the virtual model has been assigned with a unique identity code which therefore allows users to interact at the element level. This fulfils the ‘changeability of structural elements’ functionality.

The HyCon tool has an ‘edit’ functionality to enable the modification of the material of building elements, for example, users can change an in-situ beam to a precast beam. In the virtual environment, users can discern that the texture of the beam changes depending on the material chosen. More importantly, the ‘hard’ performance - cost and production duration - will be automatically recalculated according to the change. Any changes of ‘hard’ performance data will be relayed back to the user through the user interface. The changes are archived, along with any additional notes which can be added by the user to record design decision rationales. This archive can be used for future interrogation, adaptation and reuse, thus providing a clear audit trail for accountability. For example, the design team and client may be particularly interested in the advantage (or otherwise) of some very specific aspect of the design. This addresses the ‘changeability of design attributes’ requirement for the tool.

The user can also access the productivity drivers (Figure 2a.) which have been used to assess the ‘hard’ performance of a design in real time. The user can change the productivity data (Figure 2b.) and assess immediately the performance implications for design alternatives based on the change.

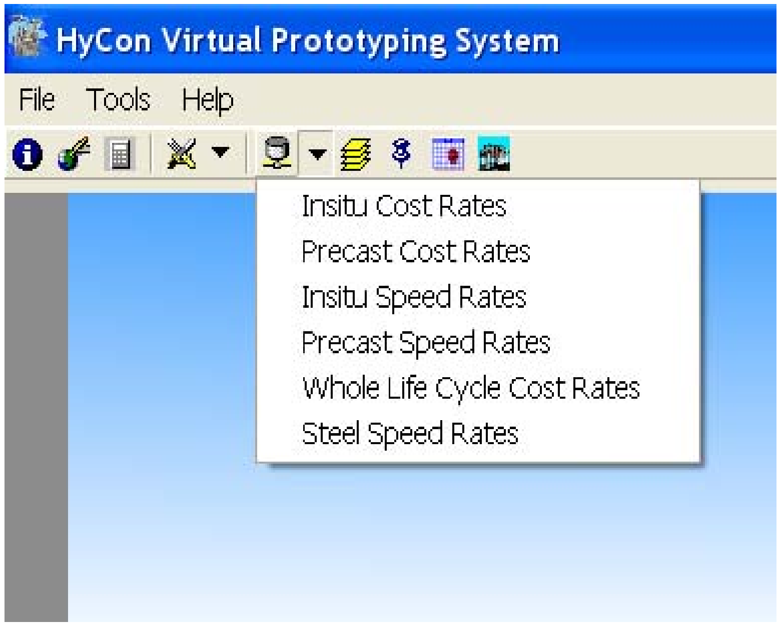

Figure 2(a). 'Hard' productivity data

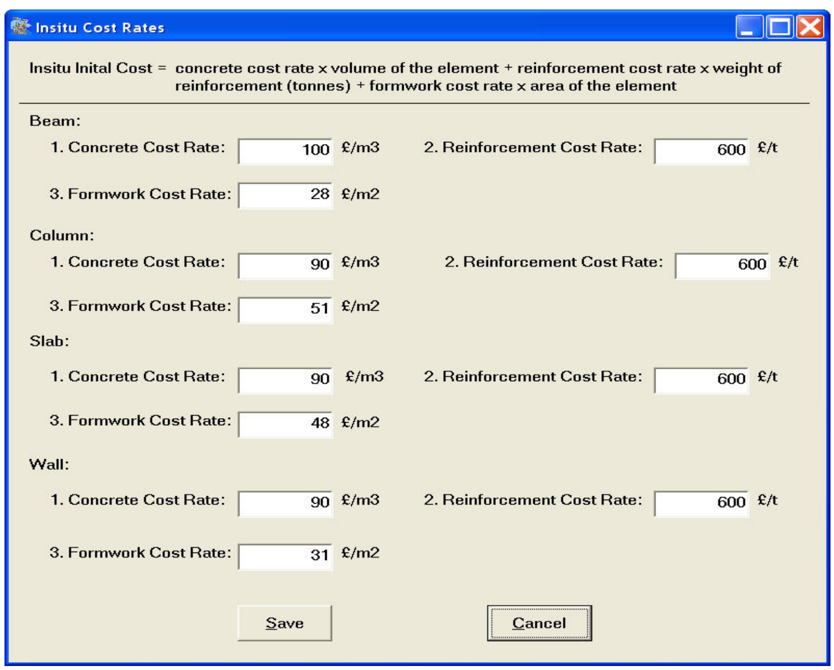

Figure 2(b). 'Soft' productivity data

The production duration and initial cost of each design can be assessed by the simulation function. This function allows users to envisage the progression of the structural frame for given cost or duration variable (Figure 3). Therefore, the designer can simulate the production schedule and budget expenditure implications of design alternatives in a realistic manner before the construction commences.

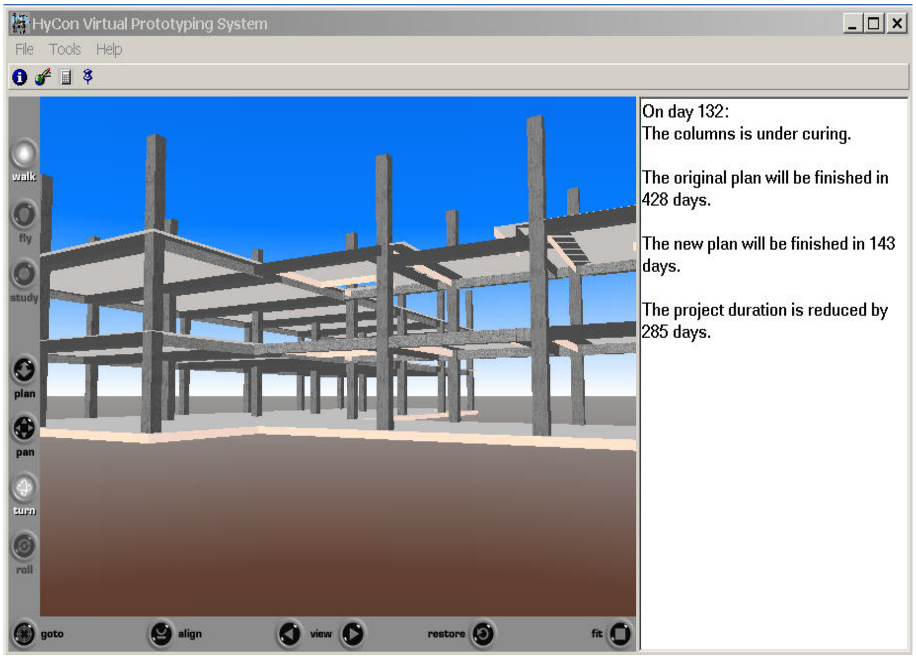

Figure 3. Simulation based on target 'time'

To further clarify the potential of hybrid concrete frame, 'soft' criteria assessment were implemented in the HyCon prototype to allow users to gain a more holistic view of the different design alternatives. By using the 'soft' criteria assessment function, users can evaluate and prioritise frame design alternatives based on weighted soft criteria (Figure 4). In making reliable comparisons, the selection of criteria is important. The thirty one criteria, which have been used in the prototype, were collected through industry wide surveys and workshops (Soetanto *et al.*, 2004).. Users can add new/ additional criteria as well as modify and delete exiting criteria. Also, they can adjust the weighting and score of each criterion to make the overall scores more appropriate for a particular client or project (Figure 4). The accessibility to 'hard' and 'soft' criteria fulfils the 'changeability of performance criteria' requirement.

In associated with the 'edit' function, the HyCon tool allow users to conduct true "what-if?" analysis, therefore adding more value to design decision making process through the exploration and multi-criteria analysis of different scenarios. The combination of 'hard' and 'soft' performance assessment in the prototype can assist project teams in producing balanced design solutions, and thus bringing about better value for the client.

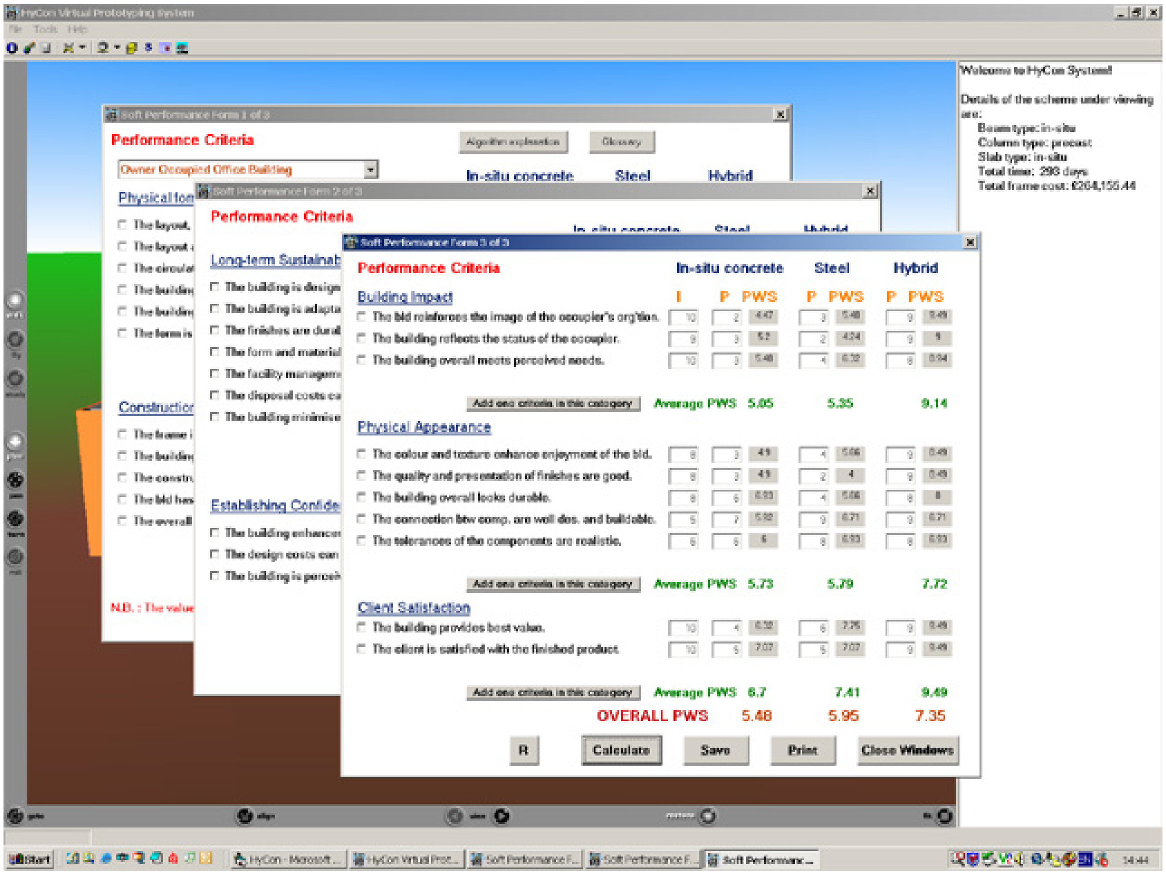

Figure 4. Weighted soft criteria assess

Conclusion

One of the key challenges of structural frame design is the ability to do evidence-based "what if?" analysis which enables different, often conflicting, requirements to be considered in the design process. The HyCon tool addresses this challenge by integrating 'hard' and 'soft' performance criteria into the design decision-making process.

The paper presents key results from the HyCon project. In the project, a design support tool has been developed which fulfilled the three requirements: namely 'changeability of building attributes', 'changeability of performance criteria', and 'changeability of structural elements'. The tool is particularly innovative in that it allows scenario modelling through "what-if?" analysis and knowledge management capability to compare previous utilised scenarios with current practice, enabling continuous improvement. It also allows real time access to productivity drivers (production duration, initial cost and whole life cycle cost) which users can input and continually revise as appropriate.

In future research, this tool can be further developed as an Internet-based tool to support distributed team working. Through this mechanism, the tool could have the potential to capture and evaluate 'hard' and 'soft' requirements in a real-time, virtual environment.

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