# DEMONSTRATING HYBRID CONCRETE CONSTRUCTION PERFORMANCE THROUGH VIRTUAL SIMULATION - A CASE STUDY APPROACH

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**ABSTRACT:** The construction industry continues to face the challenge of meeting up with performance targets such as time and cost based on clients' requirements. Hybrid concrete construction (i.e. the combination of precast and in-situ concrete and other materials) offers the construction industry stakeholders a wide range of benefits. Depending on the appropriate selection of structural materials, the method enshrines an efficient cost and time saving regime in the implementation of construction projects. However, the need to assess these performance benefits prior to (and as a basis for planning) the construction phase of the project is paramount. A methodology of demonstrating performance through the virtual simulation of the key performance indicators of time and cost as a basis for adopting hybrid construction is hereby presented. A typical steel-frame construction project was used as a case study in which the salient aspects of the design, programme/ construction method and progress were captured on–site. Data collated were used to simulate the development in real-time using the prototype of the VR model virtual reality model. Future work entails the generation of alternative hybrid construction schemes and comparing the performance of these against the steel frame alternative.

**Keywords:** Hybrid concrete, performance, virtual simulation, case study

## 1. INTRODUCTION

Time, budget and quality restraints continue to trouble the construction industry in recent years. To this effect, many concepts have been proposed to increase the level of performance management (Savicky *et al*., 2003).

The concept of hybrid concrete construction (HCC) – i.e. the combination of insitu concrete with precast concrete, steel work or other materials - emerged recently as a means of enhancing performance (Mert, 2001). Hence, the term 'hybrid concrete structures' are derived from structures developed based on a hybrid concrete construction methodology.

HCC provides simple, buildable and competitive high-quality structures that offer consistent performance (Goodchild, 2001). Three distinct categories of the forms of HCC are: precast and insitu concrete; concrete and steel work; and concrete and other materials (Xia, 2000). The choice of specific combinations depends on several factors such as type of structure, desired speed and flexibility of construction to name but a few.

The use of HCC has been considered advantageous to the building construction process over the years. The procedure had previously proved advantageous over traditional insitu concrete construction - with enhancements to speed and quality being the most important advantages (Lee *et al,* 1997).

HCC offers its clients the flexibility of choice of elements that may be precast or insitu. Building elements such as floors; beams; columns; walls and cladding; and other units can be incorporated as insitu or precast in any combination that allows optimal construction performance (Glass and Baiche, 2001; Mert, 2001).

A case study approach is used in this paper to demonstrate the potential of HCC performance through virtual simulation. The performance criteria considered are first enumerated and then the aim of the study, its objectives, and methodology are also discussed.

### 1.1 Performance

HCC Key Performance Indicators (KPIs) were divided into two major categories. These are 'hard' and 'soft' performance indicators considered as the high leverage (Oloke *et al*., 2003a; Soetanto *et al*., 2004). They include:

- Hard performance indicators: Speed and Cost
- Soft (evaluative) indicators: Added value.

The 'hard' indicators are currently being evaluated under this research through an iterative analysis of the effects of contributory productivity factors to construction speed and lifecycle costs. Other soft (evaluative) indicators are also being investigated (Soetanto *et al*., 2004).

### 1.2 Aim and Objectives

The aim of this paper is to present a methodology developed for demonstrating HCC performance through the virtual simulation of the KPIs of time and cost using a virtual prototyping tool named HyCon. It is envisaged that results from HyCon simulations will assist decision makers in selecting the most appropriate form of HCC that meets specific performance objectives. The following objectives are thus realised:

- Demonstration of the HyCon system architecture
- Description of the case study and performance criteria database development process
- Presentation of the investigative methodology adopted and a synopsis of the performance analysis results

## 2. THE HYCON SYSTEM ARCHITECTURE

The integrated system architecture for HyCon was developed by Xiaonan *et al* (2004). Figure 1 illustrates the conceptual model upon which the HyCon system architecture was formulated. The system considers the contributions from various users such as clients, designers, construction managers and other stakeholders. Requirements from each user are fed into HyCon in the form of queries (based on the 'what-if' analyses technique) through the graphical user interface (GUI). The system subsequently analyses these requirements by testing the proposed construction alternatives against pre-defined performance criteria (targets). Real-time visualisations of the outputs are then prepared to aid decision-making.

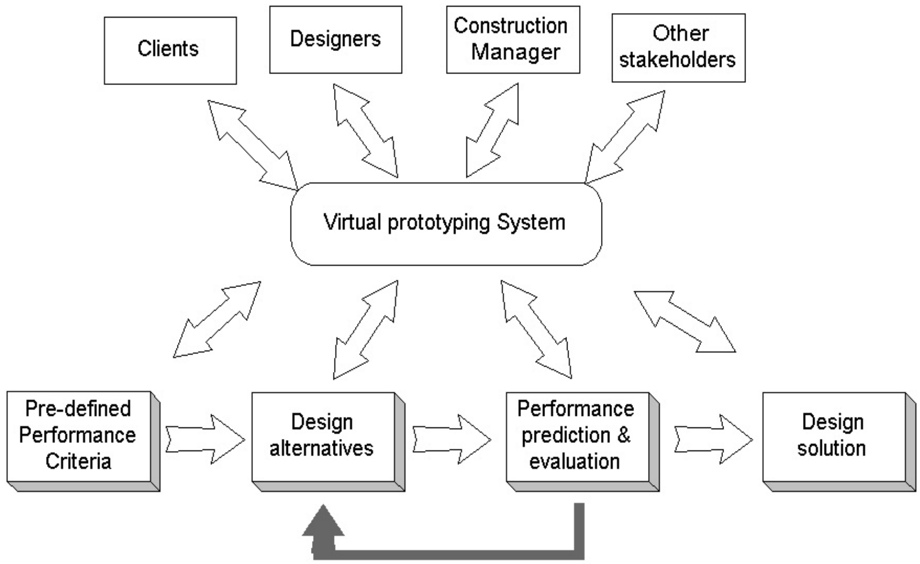


*Figure 1. Proposed Conceptual Model of a VR Prototyping System*
*(Source: Zhang et al, 2004)*

### 2.1 The Development of the Performance Criteria Database

In developing the HyCon performance criteria database, the contributory productivity factors and life-cycle parameters that relate to the speed and cost of various hybrid alternatives were evaluated (Oloke *et al*, 2003b). An overview of the evaluation is as follows.

#### 2.1.1 Speed

Erection methods and rates for precast concrete frames and slabs were used in the case of precast elements (Figure 2). In addition to the time allowed for unloading erection, lining and levelling of frames and grouting of precast concrete slabs, the system is designed to also allow users specify a time for the 'delivery of materials' to site as this variable was observed to vary from site-to-site and project to project. The 'delivery of materials' time will include time for manufacture and/or supply and transportation.

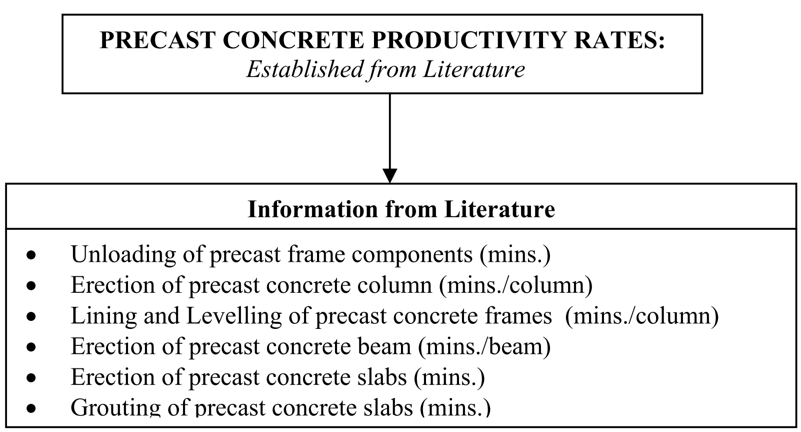


*Figure 2. Precast Productivity Rates*

On the other hand, lifting and placement rates were used as the productivity factors for in-situ concrete for speed performance. Data obtained from the UK Reinforced Concrete Council (RCC) – CONCEPT programme also facilitated the performance criteria database development. These data are presented in Figure 3.

**INSITU CONCRETE PRODUCTIVITY RATES:**
*Established from Reinforced Concrete Council (RCC)'s CONCEPT Programme and Other Literature*

**Information from RCC Rates (per gang)**

- No. of Columns/day = 4
- Formwork erection (Plain) – 10 $m^2$/hr
- Formwork erection (Ribbed) – 8 $m^2$/hr
- Formwork erection (Waffle) – 6 $m^2$/hr
- Fix Rebar (Slab) – 0.25 Tonnes/ hr
- Fix Rebar (Ribbed) – 0.25 Tonnes/ hr
- Fix Rebar (Waffle) – 0.15 Tonnes/ hr
- Fix Rebar (Beam) – 0.25 Tonnes/ hr
- Strip Forms – 7 $m^2$/hr
- Time lapse for striping forms – 50 hr
- Working Day – 10 hrs
- Placing Concrete Time – 8 $m^3$/hr
- Make 2 phases for building lengths > 22.4m
- Minimum Pours = 3 bays

**Information from other Literature**

- Pour concrete into skip (mins.)
- Lift skip into required location (mins.)
- Pour concrete into shutter (mins.)
- Return skip (mins.)

*Figure 3. In-situ Concrete Production Rates*

Previous research by Emsley and Harris (1993) generated production data for precast erection and steel work using work measurement techniques as shown in the flowchart in Figure 4.

Basic operation times for a given operation were established from: the determination of basic element times for each element of the operation; the determination of basic operation times for contingency work; and the assembly of the basic element time and operation contingency allowance to give the basic operation time.

In deriving the productivity data, the methodology entailed a consideration of precast concrete production data, in-situ concrete production data and steel erection rates. A generalised model was also used to calculate basic times for the work performed in concreting operations (ibid). Separating the basic times for the site transportation of concreting operations into four facilitates the computation of realistic output rates for concrete operations. The four operations are usually cyclical and included time for; (i) pouring concrete into skip; (ii) lifting full skip to the required location; (iii) pouring concrete into shutters; and (iv) returning empty skip. These observations were used to establish precast and in-situ concrete production as well as steel productivity rates.

**STEEL PRODUCTIVITY RATES:**
*Established from Literature for beams, columns and roof purlins*

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**Information from Literature**

- Unloading of frame components (mins.)
- Erection of steel column (mins./column)
- Lining and Levelling of steel column frames (mins./column)
- Erection of steel beam (mins./beam)
- Erection of steel roof purlins (mins.)

*Figure 4: Steel Productivity Rates*

### 2.1.2 Cost – Whole Life Cycle Costing (WLCC)

WLCC was considered as a combination of initial costs and "other costs". Initial costs (also known as first costs) refer to the construction cost estimate, including material, labour, contingencies, supervision and administration (Prasad, 2000).

Initial costs were established from RCC's Concept Programme and Price Books (RCC-CONCEPT, 2003; Landon and Everest, 2001). Such information. Such information includes cost information on concrete, reinforcement, formwork, cladding, etc. A breakdown of the initial cost structure used for the performance criteria database is shown in Figure 5.

**UNIT (INITIAL) COSTS:**
*Established from Reinforced Concrete Council (RCC)'s CONCEPT Programme and Price Books*

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**Information**

- Concrete - £90/$m^3$
- Reinforcement - £600/Tonne
- Horizontal Formwork – Plain - £28/$m^2$
- Horizontal Formwork – Ribbed - £39/$m^2$
- Horizontal Formwork – Waffle - £48/$m^2$
- Vertical Formwork - £31/$m^2$
- Cladding - £250/$m^2$
- Ground floor slab - £30/$m^2$
- Excavation & C/A - £50/$m^2$
- Site Rental - £600/$m^2$/year
- Floor Rental - £250/$m^2$/year
- Variable Preliminaries – 10%
- Finishes & Walls – 21%
- Mechanical & Electrical – 43%
- Cost of time - £0.62/$m^2$/day on gross area
- Foundations - £1.16/kN
- Steel Column Costs (range) – £430 - £480/ Tonne
- Steel Beam Costs (range) - £365 -£435/Tonne

*Figure 5. Unit (Initial) Costs*

The WLCC was, therefore, treated all the costs - in monetary terms – of the design, building and facility management (O & M, support and replacement) of a building throughout its entire service life including disposal costs. To this effect, lifecycle costs were based on recommendations of the GB Tool (2000) in which building costs comprised: predicted total energy costs; annual operation and maintenance (O&M) costs; and other similar costs as illustrated in Figure 6. Similarly, O&M and other financial costs are estimated as a percentage of capital costs throughout the lifecycle of the structure.

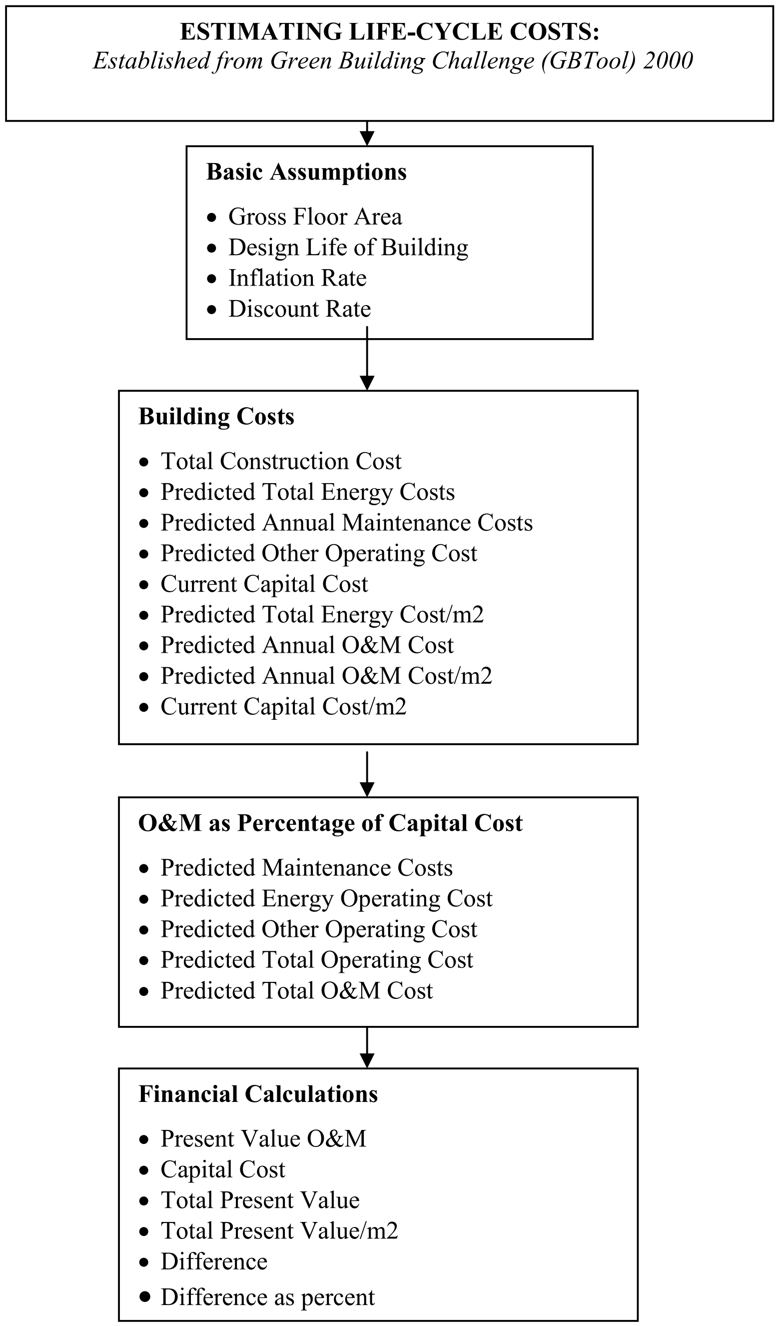


*Figure 6. Flowchart for Estimating Lifecycle Costs Based on the GBTool 2000*

## 3. THE CASE STUDY, ANALYSIS AND PERFORMANCE RESULTS

The case study project is the School of Health building at the University of Wolverhampton main site. The project was designed and constructed by Interserve Plc (one of the industrial collaborators on this project). The project is a three-storey containing a: 200-seater lecture theatre, offices, classrooms, reception area and other associated utility spaces. The structure of the building comprised the following elements:

- Pile foundation
- Precast ground beams and slabs (+ in-situ concrete infill)
- Steel frame (column and beams)
- Metal decking with in-situ concrete infill on floors
- Steel Roof.

The case study was used for the performance analysis based on a methodology presented in the flowchart in Figure 7.

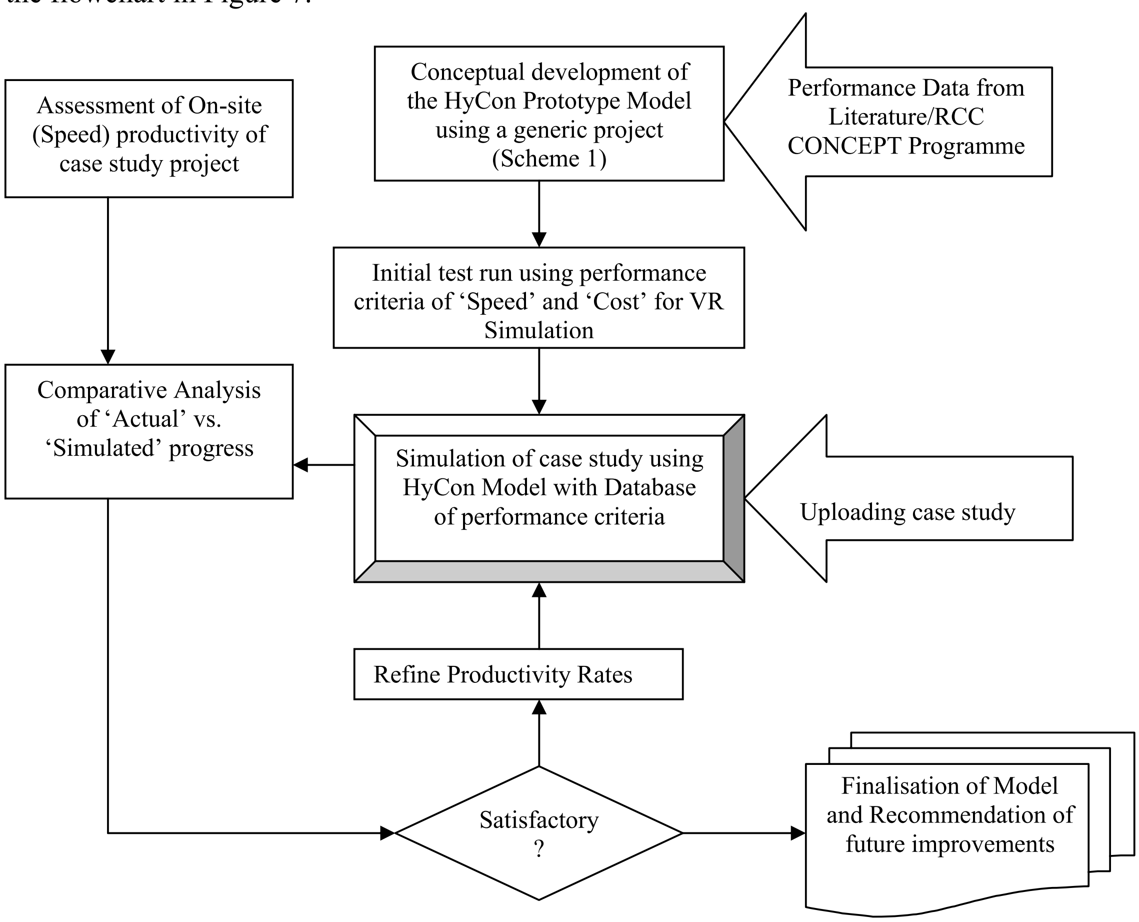


*Figure 7. Flowchart Showing the Methodology used in the Case Study Approach*

The process involved a utilisation of pre-defined performance criteria for the simulation of a prototype model (previously used for a HCC investigation by Goodchild (2001)). The motive behind this was to facilitate the setting-up of the generic performance criteria used to populate the database. Sequel to this, the case study was uploaded unto the system and a 'what-if' simulation of speed and cost was conducted.

Simultaneously, an on-site evaluation of speed of the construction was conducted and the results from this on-site study provided a means of comparing ‘actual’ and ‘simulated’ productivities. This was made possible as a result of a synchronisation of work methods in both the real and virtual environments.

### 3.1 The Performance Analysis Result

Using the construction materials, methods and techniques proposed for the execution of the project, a real-time simulation of the progress of the development can be visualised.

Figures 8a and 8b show the ‘simulated’ and ‘actual’ site works progress respectively as at week 15 of the construction work. Comparing the two developments revealed that although the frame installation rate was accurate, the work method for the simulation needed to reflect the installation of roof elements prior to the slabs. This modification was subsequently effected and the simulation results became more satisfactory. Such a comparative performance analysis (carried out during various stages of construction work) enabled a refinement of the productivity rates as part of an iterative process.

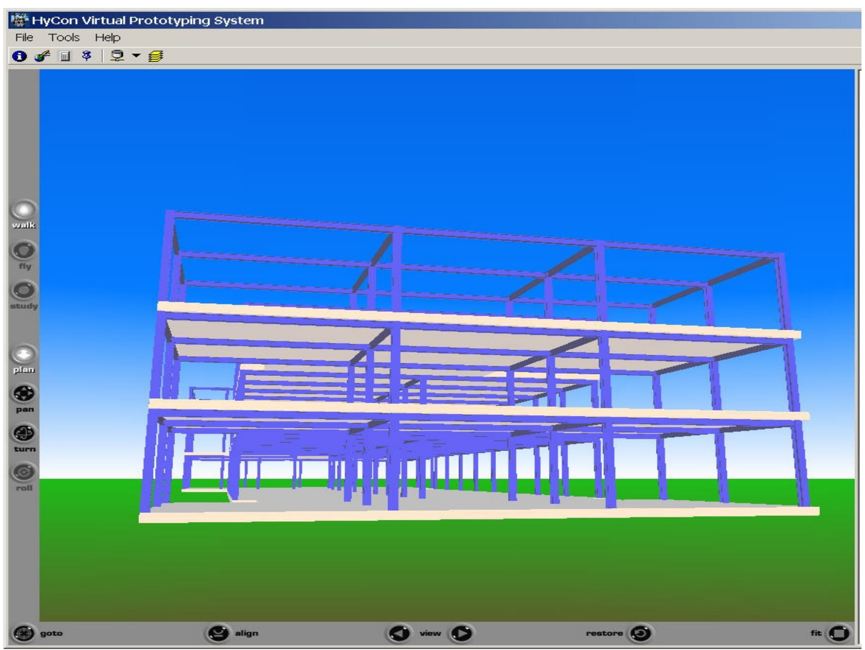


*Figure 8a. ‘Simulated’ Progress of work on the School of Health Project at Week 15 of mobilisation to site (First Simulation) (Source: Zhang et al, 2004)*

*Figure 8a. 'Actual' Progress of work on the School of Health Project at Week 15 of mobilisation to site*

## 4. CURRENT STAGE OF DEVELOPMENT AND FUTURE WORK

Current work involves the finalisation of the 'cost' simulations. This is by the simulation of the development based on budgetary provisions for phases of work for initial costs and projected budgetary provisions for the whole lifecycle maintenance of the project.

Similarly, the RCC - CONCEPT programme is being used to establish alternative forms of structure/construction methods. This procedure seeks to evaluate the feasibility of a full precast/insitu frame structure for the project. Preliminary results indicate the adoption of a waffle flat slab (no beam) solution on precast columns as feasible option. Further work will be required to simulate this option using the HyCon tools and compare the results with the generic form. It is proposed that the final selection of a form of structure/construction method should be based on the configuration with the most acceptable performance.

## 5. CONCLUSION

HCC offers the construction industry a wide range of benefits including satisfactory achievement of performance objectives of speed (time) and cost. The procedure had previously proved advantageous over traditional insitu concrete construction - with enhancements to speed and quality being the most important advantages.

A methodology for demonstrating HCC performance through the virtual simulation of the KPIs of time and cost using a virtual prototyping tool named HyCon is hereby presented. In developing the HyCon performance criteria database, the contributory productivity factors and life-cycle parameters that relate to the speed and cost of various hybrid alternatives were evaluated. A case study was then used for the performance analysis. Comparing the 'simulated' and 'actual' site works progress enabled the refinement of the performance criteria used to populate the HyCon database.

Current work involves the finalisation of the 'cost' simulations and the investigation of alternative forms of structure/construction methods.

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