**4D13 Architectural Engineering 2004 Crib (v2)**

**Q1**

(a) Sketches must show load paths. The wind loads are carried horizontally through the floors to the end walls. See notes and articles given out by Dr. Bill Addis, specifically, "The Development of the Cast Iron Frame in Textile Mills to 1850", by Ron Fitzgerald. Plus, see part (b) below.

(b) Answers should draw from lectures, notes and articles give out by Dr. Bill Addis, specifically, "The Structural Engineer in Conservation", by Ian Hume and "Structural Appraisal of Existing Buildings for Change of Use", BRE Digest 366. Answers should include several of the following points:

- There will always be incomplete historical information and general uncertainty about the building, its use, the site, and the materials. Different engineers respond to the state of affairs in different ways.
- Assessing the structural behaviour of an existing structure has a large subjective element.
- Different engineers can conceive of the same structure as behaving in different ways.
- All structures and their behaviour have different states of existence:
    - in the mind of the original designer,
    - during construction,
    - as originally built (completed),
    - at every time in the structure's life,
    - with every modification which affects the structure,
    - with every change or modification to the material,
    - with every change in load pattern,
    - in the mind of every engineer assessing the existing structure, and
    - in the future, maybe after intervention and with new loads.
- There is no way of verifying how an existing structure actually is working as a structure without measurement and tests. Hence, it is difficult to learn from experience (lack of, or poor feedback)
- Assessment of the behaviour of an existing structure must be based on a hypothesis followed by investigations to increase confidence in that hypothesis; i.e. the engineer should not do any tests unless he/she has thought of why he/she is doing them. No investigations can prove a certain hypothesis, and entirely different 'actual' behaviours may yield the same test results.
- An engineer may have a lack of confidence in dealing with uncertainty. They may prefer the confidence which can follow from using a new frame and modern materials.
- An engineer may lack experience and knowledge of the materials, type of structure and construction details.
- An engineer may not make intelligent use of the data available or of new data gathered.
- An engineer may lack imagination in suggesting solutions (e.g. how to create and exploit composite action, how to strengthen the existing structure, how to reduce likely loads etc.).
- An engineer's attitude to old structures may be unsympathetic.
- An engineer may make blind, uncritical and inappropriate application of modern design guidance to an old building, especially concerning material properties and floor loading.

**Q2**

a.) See handout from Prof. Peter Carolin: "Secret Life of a College Library: A Study in Movement"

i.) The two most significant and common types of movement are moisture movement and thermal movement. Moisture movement mostly affects porous materials. Thermal movement affects all materials.

ii.) There are five less significant and common types: deflection of structural members, vibration, chemical reactions, physical changes (ice and loss of volatility in mastics, i.e. silicone seals, due to poor quality) and movement in soils.

b) See handouts from Prof. Peter Carolin: "Secret Life of a College Library: A Study in Movement" and "Cor Ten Catastrophe: A Case Study in Climate and Material Failure".

i.) <u>brickwork</u>- Brick is a porous material. One must accommodate for shrinkage and expansion of individual bricks due to moisture movement in addition to thermal movement. Use expansion joints or lime mortar, which is softer than cement mortar, e.g. as used in the long brick wall on the north, Silver Street side of the Darwin College Library.

ii.) <u>wood boarding</u>- Wood is a porous material so one must accommodate for both moisture and thermal movement. Moisture can be the most significant, e.g. Darwin College Library. One must accommodate for both initial movement and seasonal movement, common to all exposed timber. Wood shrinks across the grain rather than along it. For example, in tongue and groove boarding one must accommodate for movement as they shrink and expand across boards, e.g. Darwin College Library. Sliding joints are one option.

iii.) <u>steel panels</u>- Steel is generally not a porous material so thermal movement is the most significant movement. All Cor ten steel panels used for building facades are designed with movement joints in between them, e.g. Ford Foundation in New York City (USA) and Cambridge Biolab. In the Chicago Civic Centre building one can hear the panels moving as they expand in the morning and contract at night. In the Cambridge Biolab there are sliding joints with stainless steel screws and nylon washers.

c) i.) The flat roof- Across grain shrinkage of timber beams and boards would cause the flat roof to have the greatest vertical movement in the structure resulting in ponding of water on the roof.

ii.) Preventative measures include:

- Make sure that you have equal numbers of contraction points.
- Moisture:
  - Use fully seasoned wood that is fully dry to prevent splitting, warping and distortion.
  - Timber shrinks across the grain so use an adjustable bolt fixing to tighten beams; but be cautious about the loads that will be required for tightening, e.g. Darwin College Library
- Deflection: timber beams that span over supporting columns will deflect most at the

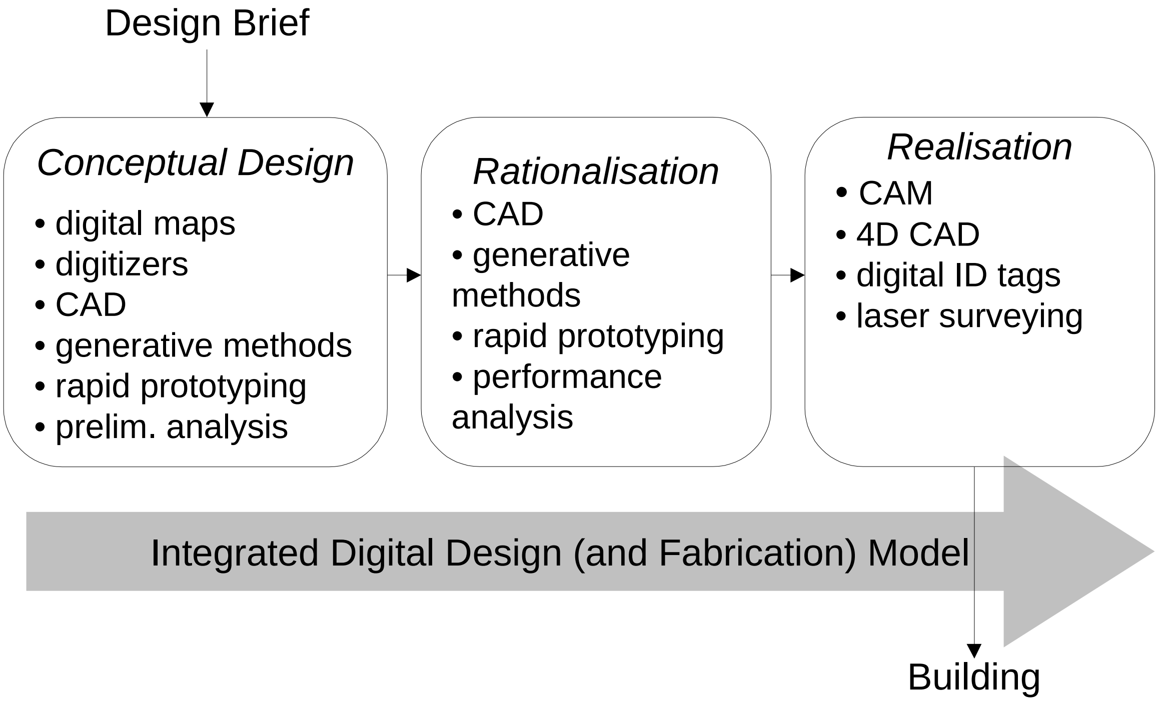
connection with the next beam, possibly at midspan, causing possible waves in roof.

- Interactions: Movements in the timber, in general may impact other aspects of the building, e.g. causing windows to not open which can be catastrophic in the case of controlled environments with automated windows, e.g. Darwin College Library.

**Q3**

See lecture notes and articles given out by Dr K Shea for more information.

a) Answers should include several aspects of the following.




In the above diagram, flow of information generally moves from left to right often with many iterative loops within one stage. For example, geometric data from digitising a 3D model can be used as the basis for a CAD model that is further developed. Generative methods can then be used, e.g. for generating cladding or stone patterns, and the new design in the form of a CAD model is then used as input to rapid prototyping and/or analysis tools both of which feedback on the original CAD model.

CAD stands for "Computer-Aided Design" (not automated or drafting!) and is the critical aspect of a digital design and fabrication process. It has evolved from its first focus on creation of 2D line drawings for the efficient production of construction drawings to now include 3D parametric modelling and provide a basis for CAM. It is now used by most people/offices involved in a building project, e.g. architects, engineers, fabricators and contractors. Increased CAD capabilities for design expression is one driver in the growing complexity in AEC.

CAM stands for "Computer Aided Manufacturing". CAM is the use of computer systems to plan, manage, and control fabrication operations, e.g. computer-aided process planning, computer numerical control (CNC), automated inspection, and robots used in assembly, e.g. welding.

b.) Highlighted projects in lectures included (architect and structural engineer are listed):

1. Guggenheim Museum, Bilbao, Spain, Frank O. Gehry, Skidmore Owings + Merrill (SOM)
2. Disney Concert Hall, Los Angeles, CA, USA, Frank O. Gehry, John A. Martin & Associates, Inc.
3. Greater London Authority (GLA / City Hall), London, Norman Foster + Partners, Arup
4. British Museum Great Court, London, Norman Foster + Partners, Buro Happold

See articles given out by Dr K Shea on these projects for detailed information.

New technologies enabled include (numbers indicate projects above):

- Greater freedom in possible building form (geometry) that can be built (1-4).
- Creation of performance-driven building forms (2-4).
- Design, fabrication and construction thinking in 3D, rather than conventional 2D) (1-4).
- Transfer of large amounts of data/information/models between participants in a project (1-4).
- CNC rapid prototyping tools lead to faster development of tested complex building systems (1-4).
- CNC machine tools allow for large quantities of very different dimension components, e.g. façade panels and structural members, to be fabricated at a reasonable cost (1, 2, 4).
- Laser surveying on-site keeps tolerances of complex building forms and systems in check (2- 4).
- 4D CAD co-ordination models help visualise the construction sequence (2, 3).
- other advantages mentioned in lectures and articles…

Disadvantages include:

- Difficulties of architects to convince fabricators and contractors to collaborate in new ways and think/work in 3D. Guggenheim Museum (1) was a good example while Disney Concert Hall (2) was a bad example of this.
- Handling all complexities involved.

c) Arguments for "paperless" design include:

- Most digital tools enable increased complexity of what can be designed and built, enable communication between participants in a design / project tem, reduce time, and/or reduce cost of complex projects.
- Paperless design is achievable to some point of benefit but should not hinder a design process.
- Physical models are generally not included in the argument for paperless design since they will always be necessary and important to understand a complex form, structure, construction, especially new complex forms. For example, the "Gehry" digital process makes much use of physical models, both hand made and using rapid prototyping.
- A new generation of engineers/architects growing up with computers will impact the take-up of more digital, i.e. "paperless", design.
- other advantages mentioned in lectures and articles…

**Q4**
This question draws from lectures and handouts by all lecturers.

(sketches only)

a)

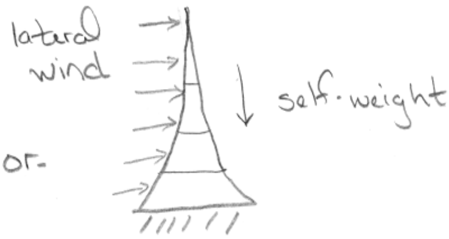
Eiffel Tower

cantilever

-or-

cantilever equivalent of a lenticular truss

-or-

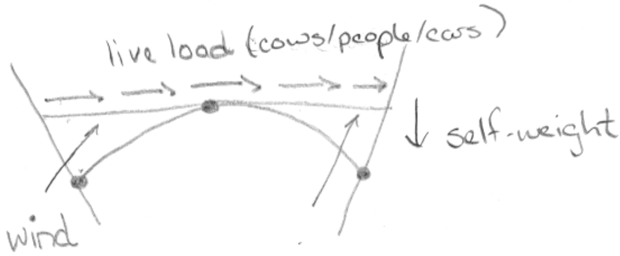



Salginatobel Bridge

3-hinged arch

hollow-box construction

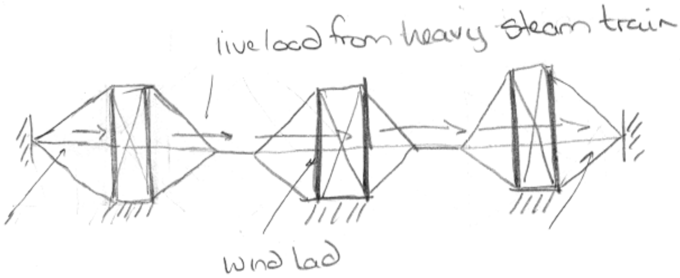
-or- box-arch




Forth Rail Bridge

cantilever

3 cantilever towers




b) Eiffel Tower (1889)-

- The designers wanted to set the record for the tallest metal tower (> 300m), but also produce a lightweight structure.
- The form was derived to efficiently resist lateral wind load.
- material- wrought iron for easier workability at the time and more familiar for a daring structure

Salginatobel Bridge (1930)-

- The shape was derived so that stresses remain low regardless of location/condition of loading.
- To produce the form, Maillart removed material from the sides of a more conventional arched concrete bridge structure since they are in tension anyway, which can produce problematic cracks.
- A new method of construction was developed, called staged-arch construction, that used formwork to build a stable arch first and then the rest of the structure on top of that. This proved cheaper.
- material- steel reinforced concrete

Forth Rail Bridge (1890)-

- A unique double cantilever profile was conceived with large towers and stocky members.
- The structure was designed to be very robust, some say overdesigned, believed in response to uncertainties caused by the "recent" collapse of the Tay Rail Bridge.
- material- mild steel

c) All are landmark structures now. The focus of the answer should be on the excellence of the engineering and should draw from the lectures and writings of Dr Bill Addis.

Individual arguments for include:

Eiffel Tower- Very efficient structure, even now, for a record height at the time; innovative design that removed material, rather than added material, to provide better resistance to wind.

Salginatobel Bridge- At the time the design was chosen because it was the cheapest. Now it is considered as a very efficient, elegant, novel design that used a newly developed, innovative construction technique.

Forth Rail Bridge- It was a new conceptual style developed for a bridge. It held the world record free span (521 m) until 1890. The massive design can be justified due to aftermath of Tay Rail Bridge collapse. Collapses after it, e.g. Quebec Bridge, partially due to the confidence gained through its successful design, justify in part the massive members.

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