Note on answers to exam questions. The students have handouts that cover most of the issues covered. The remainder (and much more) was dealt with in lectures.

Q1 *EITHER*

Various innovations in structural and services engineering have been stimulated by the requirements of new types of building. Others have enabled building owners to spend less on their buildings and/or earn more money from them.

Describe FIVE examples spanning the last three centuries that illustrate this. Include in your answer a description of the innovation and its significance. Illustrate your answer with sketches wherever possible.

Answer to Q1 (first option)

Key issues

The main innovations are likely to be among these (covered in notes/lectures)

Structures

- structural use of wrought iron in roofs (from 1780s) and cast iron for columns and beams (from 1790s) as a fireproof structure. Especially for use in theatres (following the theatre boom from the 1760s), warehouses and factories from the 1790s, both after many terrible fires.
- use of wrought iron / steel from the 1850s to make buildings with structural frames. From Crystal Palace to dockyard buildings in the 1850s to high-rise buildings in Chicago and New York from the 1870s and 1880s. The primary benefit was to avoid the need for load-bearing masonry walls which were expensive, labour intensive, slow to build and occupied valuable floor area that developers were not able to earn rental income..
- use of reinforced concrete in flat or curved "sheets" to provide roofs over large spaces such as sports stadia, exhibition halls, market halls, etc.
- use of tensile materials such as woven steel strips, cable nets, fabrics made from polyester or Teflon-coated glass fibre, to create large, lightweight roofs over sports arenas, exhibitions etc.

Services

- introduction of heating and ventilation into factories from the 1730s to ensure some comfort for workers, but mainly to ensure the wool and cotton fibres did not snap in the spinning and weaving machinery
- introduction to of both natural and forced ventilation into ships, hospitals, prisons and theatres from the 1760s to prevent the spread of disease
- introduction of air conditioning into factories in the US in the early 1900s to ensure the wool and cotton fibres did not snap in the spinning and weaving machinery – unlike early heating and ventilation this involved the control of humidity also
- introduction of air conditioning into cinemas and hotels and, later, offices in the US from the 1920s to provide heightened comfort to the users of the buildings.

Q1 *OR*

The owner of a six-storey nineteenth-century factory building wants to refurbish it for use as offices. The building has cast iron beams and internal columns, brick jack-arch floors, masonry load-bearing walls and wrought-iron roof trusses.

Write an outline draft of a report to the owner covering the following issues:
- *the suitability of the building for the proposed use;*
- *the feasibility of introducing modern features such as lifts, additional stairs, and modern building services;*
- *the purpose and the possible outcomes of a detailed investigation of the building by a structural engineer.*

Answer to Q1 (second option)

Suitability
- will be able to carry modern floor loads
- can easily meet modern fire-protection requirements
- can be adapted in many ways without major disturbance to the existing building
- will help preserve the heritage of the local community (by keeping old buildings)

Modern features
- lifts, stairs and services risers can be 'punched through' bays without disturbing the stability of the whole building.
- large floor-to-ceiling allow introduction of raised floors and distribution of modern services

Investigation
- the main purpose is to demonstrate that the building will carry the floor and wind loadings required by modern design codes.
- because the structure is easy to inspect damage or weaknesses can be found easily and remedies provide
- the outcome may be that the structure is satisfactory, nearly satisfactory and can be strengthened, or 9rarely) that the building is unsatisfactory and must be demolished or strengthened using major intervention.
- even if some components are found not to be strong enough to meet modern load needs, the problem can usually be resolved by arguing that design loads can be reduced from the normal ones used today, by strengthening individual structural elements such as the floor or adding new hidden strengthening elements in the floors or walls.
- the engineer's report should outline the sort of remedial actions that could be undertaken, should they be needed to enable costs to be estimated and compared with the value added to the building by means of the remedies.

Q2 (a) Outline briefly four factors that frequently combine to make the process of construction an unusually difficult one.

Answer to Q2(a)

- Most buildings are prototypes
- Most design and construction teams have never worked together before (and never will again)
- Building sites can be wet, cold and dangerous
- Communication in poor light and weather can be very difficult

Q2 (b) Define 'tolerant' and 'intolerant' construction.

Answer to Q2(b)

- C19 century traditional construction was 'tolerant' of inaccuracy Parts of a building were cut to fit on site and components tended to overlap each other and thus conceal any irregularities.
- Mid to late C20 construction tended to be 'intolerant' of inaccuracy. Buildings had become assemblies of highly accurate factory-made components which had to be fitted into openings which were often too large or too small. Joints were rarely overlapping – the space between components was usually exposed and filled with mastic.

Q2 (c) What do you understand by the phrase 'characteristic accuracy'? Describe this in terms of walls constructed out of solid brick, precast-concrete storey-height panels and timber frame.

Answer to Q2(c)

- Different materials and elements of construction tend to have their own particular degree of accuracy – or 'characteristic accuracy'.
- Brick walls tend to be relatively accurate because their position in plan and section can be constantly checked as work proceeds.
- Precast concrete walls tend to be highly accurate because they are made off-site in a casting yard and can be placed with great accuracy in a single crane-assisted operation.
- Timber stud walls tend to be fairly inaccurate. They are formed by fixing vertical studs to a head and sole plate (which themselves have o be fixed to a ceiling and floor).. Timber warps, can easily get 'out of true' and is fixed by nailing (by hammer or shot-firing). Any of the timber elements may be out of true and the fixing process does not lend itself to accuracy.

Q3 (a) Explain the concepts of hazard, vulnerability and risk, and show in general terms how a risk assessment may be performed.

Answer to Q3(a)

Should give definitions of hazard, vulnerability and risk; and show graphically the relationship between them. Risk assessment involves determining precisely what is at risk; defining the state or states of damage being considered (typically 4 or 5 damage states), defining the measure of hazard to be used (intensity or other ground motion parameter for earthquakes); quantifying the probability of exceedence of hazard as a function of its size; quantifying (using calculation or observation) the vulnerability curves; and then performing the risk calculation, by convolving hazard and vulnerability.

Q3 (b) What contribution can risk assessment play in reducing the impacts of natural hazards?

Answer to Q3(b)

Uses of risk assessment are

- Defining (affordable but effective) appropriate code levels for new construction
- Emergency planning
- Developing retrofit strategies for existing buildings
- Creating insurance pools

Q3 (c) "We must expect more frequent disasters in future" (Munich Reinsurance). Is an increase in the global frequency and scale of natural disasters inevitable?

Answer to Q3(c)

Discussion should consider the impact of global warming on frequency and severity some types of disaster (more storms, sea level rise), but not others (earthquake, volcanic eruption). Should also consider impact of increased populations in poorer countries and where settlements are located (cities often on coasts and/or major rivers). Against this are: better understanding of problem (science), better techniques for countering it (engineering), and rising living standards (ability to spend money to counter longer-term risks). We should be in a position to reduce disasters in future.

Q4 (a) Describe the technical innovations that were first used in the design of:
(i) the Eiffel Tower;

Answer to Q4 (a)(i)

The shape of the structure was adjusted to reduce the surface area of the elements and hence the wind loading on the tower rather than the approach of increasing member strength to take the applied loads as had been the practice up until this time.

(ii) the Sydney Opera House.

Answer to Q4 (a)(ii)

The designers realised that they could take conic sections from a sphere to produce the sails of the Opera House with a clearly defined geometry.

Q4 (b) How have the new digital technologies changed the process of building design and construction? Illustrate your answer using specific technologies and case studies.

Answer to Q4 (b)

See handouts from lectures by Prof.Shea.(titles: (i) A Design Process (ii) A Digital Design Process + Tools)
Conceptual Design -> Rationalisation -> Realisation (Construction)
CAD modelling
Geometric modelling – NURB, solid modelling examples e.g. Eden project.
Parametric modelling – allows shape changes e.g. Waterloo station, Sagrada Familia
Better collaboration between architect, engineer and contractor

Q4 (c) What are the key factors driving the development of digital design technologies? Describe the advantages and limitations that this design process imposes on designers and builders.

Answer to Q4 (c)

Drivers for change:
- architects want to make a statement – ego
- differentiate from others& improve quality
- high-profile
- competition
- globalisation – increased collaboration amongst disciplines, distributed design teams
- enlightened architects are interested in using the new digital processes to push the boundaries and express new forms whose geometry previously could not be expressed and who structures could not be analysed or built.
- availability of fast 3D geometric modellers (software)
- computing hardware advances (speed, graphics cards)
- the availability of computer literate structural and architecture graduates

Advantages:

- express and build phenomenal structures that push the boundaries of what is possible (ego trip for engineers seeking to push the limits)
- work in 3D/visualisation (c.f. conventional 2D)
- optimisation programs allow reduction in amount of material used and allow feasible solutions for complex structures to be found.
- can allow rigorous checking for compliance with codes of practice
- possible to reduce the number of different structural forms and elements
- possible to build unique structures comprising components of all different sizes and shapes e.g. British Museum roof

Disadvantages:

- hard to understand how the structure works and how the loads are transmitted
- complex
- can result in architects pushing for bizarre structures which are not logical
- difficult to check by alternative/independent methods
- difficult to check for compliance with codes of practice – often outside the limits of what was intended in the codes
- difficult to convince contractors and fabricators to collaborate and participate in the process.