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3D CAD ON Qinshan CANDU PROJECT

David Goland 2000-02-14
Atomic Energy of Canada Limited (AECL)

Abstract This paper briefly describe AECL's work in applying computer-aided engineering tools to the Qinshan CANDU project. The main thrust of this paper is to introduce the major CAD software tools and their use in civil design, process design and E I&C design. Other special software tools and non-CAD tools and their applications are also briefly introduced.

Keywords Design, CAE, CAD, 3-D model, Database, Graphic file

1. Introduction

Atomic Energy of Canada Limited (AECL), a long-time user of 3D Computer Aided Design, is currently applying a sophisticated computer-aided design (CAD) System for the design and construction of a two-unit CANDU nuclear power generation station in Qinshan, China. This paper gives a technical overview on the CAD methodology and software tools utilized to accomplish the engineering and the construction of the project. This is the first time that a full 3D CAD system is employed in the design and construction of a nuclear power plant by a Canadian company. Previous use of such a CAD system in Canada was mainly for the design of chemical, petrochemical and other process plants and for their construction in Canada and overseas. AECL has shared its 3D-CAD experience with companies who were involved in some of the non-nuclear projects (notably, the Hibernia Project), by acting as a consultant for a variety of industries. The CAD system drives the engineering work process, assuring consistency, quality and speed in producing engineering deliverables, while other Computer-aided engineering (CAE) tools perform material management, electrical wiring management, document management and various analyses. AECL uses yet other CAE tools for detail design and for mechanical design. A distinction is made here between a new CANDU project and a repeat project, such as the Qinshan project. A portion of Qinshan engineering work consists of adapting the design from a reference plant upon which Qinshan project is based, into the specific Qinshan design. This paper describes project tasks, which are performed through the CAD/CAE system and the challenges which are met. The Qinshan tasks and deliverables include the production of 3-D models, clash (interference) resolution, 2-D drawing extracted from models, text reports, external links to material management, and 3-D visual design reviews.

2. Qinshan Project CAD system

2.1 CAD system Overview

The 3D model is in the center of the system (see Figure 1), with input flowing into it from three sources:

- A Reference Database which supplies information about shapes and dimension of plant items, industry and vendor standards, and allowable item types and ranges according to engineering specifications.

- The human designer who selects items to place in the model, decides where to locate the items in 3-D space and chooses the routing of piping lines.

- An intelligent Process and Instrumentation Diagram(flow-sheet or P&ID) from which the model is fed with information on piping line numbers, specification names, and line sizes, as well as design and operating temperatures and pressures.

The 3-D model consists of graphic files linked to an alphanumeric database.

The software automatically checks the model clashes (interference) while the designers correct the layout until the model is clash-free. Also during the design, the model is viewed through realistic 3-D walk-through software for design review, for layout coordination and for clash resolution.

The completed and checked model is the source of engineering, fabrication and construction documents such as the piping isometrics, general arrangement and layout drawings, bill of materials, piping line lists and weld lists. Other products of the 3-D model are illustrations and movies. Figure 1 below depicts the 3-D CAD system used on Qinshan Project. Figure 2 shows a detail from the 3D model.

Since Qinshan Project design is based on a existing Reference Project, AECL was able to replicate large portions of the 3D model from a pre-existing space-allocation model of the reference project. It has been necessary, however, to enter much data into the model database regarding vendor-specific information and data which were missing from the space-allocation model.

The CAD system hardware consists of several servers, some on AECL's premises in Mississauga and others at a subcontractor's in Montreal and in Oakville. Connected with high-seed data line, the serves appear to all users to be practically at the same location. Multiple copies of the 3-D models are installed at the construction site for viewing with walk-through software.

2.2 Civil Design

Computer-Aided Engineering tools for Civil/Structural Engineering at AECL CANDU are based on the Intergraph Frame Works software. The software is used for the construction of a 3-D model including concrete slabs, floors, walls and holes, as well as steel linear members such as columns, beams and braces. The software also handles steel platforms, stairs and rails. The software creates graphic files which define the geometry as well as a local database which definers the materials and properties of the structural members.

Steel Catalogs

Frame Works software uses catalogs of standard linear steel members from many fabricators including China, Europe, USA and Canada.

Link with Analysis

Frame Works is capable of generating input data for STAAD III structural stress analysis software. Rather than employing STAAD III, Qinshan project uses ANSYS and STARDYN for structural stress analysis and design. Future projects will link structural stress analysis with the 3D CAD model.

2.3 Process Design

- **Intergraph's PDS P&ID**

PDS P&ID (Plant Design System-Process and Instrumentation Diagram) is used for the creation of intelligent process and instrumentation diagrams. P&ID stores graphic information in graphic files and alphanumeric data in relational databases. The data includes equipment, piping and instrumentation labels for items and associated design/operating conditions.

In a typical session, the designer places graphics for equipment with nozzles and then connects the equipment items with piping. Valves and specialty items are then placed on the piping lines, followed by the definition of instrumentation loops and the placement of instrument items owned by these loops. The designer then places line attribute breaks, flow arrows, and labels for equipment, piping lines, and instruments.

The next step is propagation. The act of propagation serves to read the text information from the graphic file and to populate the relational database. In this database (called "task database") the data changes often while the P&ID's are developed.

The 2-D reference database (RDB) governs the attributes of the graphics, the symbols, and allowable values for alphanumeric information, as well as format of lists (e.g., valve lists) extracted from the task database.

Another use for the P&ID is the transfer of information from it, into the 3-D piping model. The information consists of piping line information, such as piping specification, size, fluid code, number, temperatures and pressure, which are loaded into the 3-D center-line.

- **PD_Design for Piping Modeling**

A module of Intergraph's plant design system, PD_Design is used to create and modify 3-D models of piping and tubing systems, including in-line instrumentation and support location. PDS Piping stores project layout graphics in graphic files, while the alphanumeric information, linked to the graphics, is stored in relational databases. The data is used for clash detection, drawings/reports extraction, walk-though, and stress analysis.

During a typical modeling session, the designer routes intelligent pipe center-lines which carry data. The data for the center-line, such as line size, specification, pressures and temperatures, come either from manual entry or directly from the P&ID. As the center-line is routed, the designer sees all the models from other disciplines and other designers' piping and equipment models, so the designer is able to visually fit the layout around objects already placed in the plant model and to connect to nozzles on equipment. The designer then calls up valves, and specialty items from the 3D Reference Database, and places them in their proper locations on the center-line. The designer also situates fitting-to-fitting assemblies in the model. Finally, the software places automatically all remaining fittings and pipes, as defined by the specs.

There are three databases for the Piping PDS (plant design system) application:

(1) Piping/Equipment Design Database, which holds all the instances of the model components, such as piping fittings, pipes, nozzles, and the associated data, e.g., wall thickness, material grade, and pressure rating. Each graphic component in the graphic file is uniquely linked to an entry in the Design Database.

(2) Piping Reference Database (RDB), which holds all piping specifications and manufacturer catalog information. In addition to the relational database, the RDB includes information in other formats (ASCII files and Intergraph library files), which contain, among other things, dimensional information, industry standards, project standards for model graphics and messages, drawing labels, and piping component verbal descriptions.

(3) Project Administration Databases, which holds information about the way the Plant model is partitioned into files, their location on the computer network, and the geographical location that the model in each file spans in the Plant. The location and description of models from other disciplines is also stored here, to allow integrated tasks, such as clash check, drawing composition. Also defined in this database, are the isometrics that are extracted, the material reports formats and content, as well as the information on clashes and their management.

- **PD_EQP for Equipment Modeling**

PDS PD_EQP is used for modeling anchored equipment items such as pumps, heat exchanges, and vessels with nozzles which are connected to PDS piping models. This software is used also for modeling equipment for other disciplines such as electrical panels, embedded parts, pipe hangers and cable tray supports. The software defines equipment volumes, for clash (interference) checking , for graphics to be placed in extracted drawings, and for walk-through sessions. The equipment volume may include only the physical volume of the equipment, or also its maintenance and installation envelopes. Access corridors which are not associated with any specific equipment item are also modeled with PD_EQP. The clash checker will identify a “hard” clash with the physical equipment volume, and a “soft” clash with the reserved access envelope.

Equipment models are composed of graphics and from alphanumeric data. The alphanumeric data include the equipment tags and descriptions, as well as the nozzles properties.

During a typical modeling session, the designer places primitive shapes, for example, cylinders, cones and boxes, and groups them into equipment items (pumps, vessels, etc.) The dimensions and weights are keyed in from manual equipment data sheets. Most of the nozzle information (such as flange outside diameter) is read directly from piping specifications in the piping Reference Databases.

2.4 Electrical, C & I Design

- **Schematics**

The suite of software module for the creation of electrical schematics is not advanced enough in its development for use on a project. The production of instrument loop diagrams, one-line diagrams, elementary diagrams is done manually, using drafting software and graphic files.

- **3D Electrical Raceways**

EE_Raceway, part of Intergraph's PDS (plant design system), is used to create and modify 3-D models of electrical raceways, including cable trays, conduits, junction boxes, and air-ways(free cables). The software stores the project layout in graphic files, while the alphanumeric data, linked to the graphics, may be loaded into a relational database.

During a typical modeling session, the designer routes intelligent tray and conduit center-lines which carry data, such as tray cross-sectional dimensions, material, system and unit-weight. The designer can place tray fittings manually, or dress up the center-line automatically with fittings and straight tray.

There are two database for EE_Raceways:

(1) The Design Database, which holds all the instances of the model components, such as fittings, straight trays, conduits and junction boxes. Each graphic component in the graphic file is linked to an entry in the Design Database.

(2) Reference Database, which contains trays and conduit specifications, such as materials, dimensions, and weights. The designer is restricted to the choices which are available from the Reference Database.

These databases must have a common "schema file" with P&ID and with Piping/Equipment to allow the sharing of data.

The software features material take-off and weight/center-of gravity reporting.

The EE_Raceway model is clash-detectable.

2.5 Other Software in the CAD System

The CAD system includes other special software packages as listed below:

- **Clash Checker**

This is a module of Intergraph's PDS software, used for the detection and management of clashes in the 3-D model.

- **Orthogonal Drawing Generator**

PD_Draw, a part of the PDS (plant design system) software, is used for creation of drawings, including plans elevations and sections, as well as isometric views from the 3-D model

- **Isometric Drawings Generator**

PDS Isometric interface extracts and converts PDS Piping data and transfers them to ISOGEN (by Alias, UK). The software then creates fully annotated piping fabrication isometric drawings with the related bill of material.

- **List, Bills and Reports Generator**

This PDS module extracts bills of materials, weight reports and center-of-gravity reports, insulation reports and piping length reports from the 3-D piping models. The users can then generate reports by piping line number, by process system, by construction area, by piping size or class, etc. Types of reports include material takeoff, line list weld list and insulation quantity.

- **3D Walk-Through**

Design Review is Intergraph's software for reviews of 3-D models. It displays the combined model files on a specially-equipped work-station with a large screen and an high-performance graphics card. The display is in fully shaded perspective, with a capability of movement through the model. "Walking" along three global axes and three local axes is possible, as well as rotation of the viewer's virtual head about these axes. In the "encircle" mode, an object of interest is brought to the center of the view, and then viewed from all sides. Alphanumeric information is viewable for each object.

During the review sessions the reviewer can place comments in a special tag file, which can be recalled by other reviewers, or sent back to the designer to take actions for model revision. Periodically, the Design Review Integrator software collects selected information from the databases and then loads it, together with the models' graphics, into the Design Review work-station, for updating the Design Review files.

- **Illustrations and Movies**

During a 3-D walk-through in the model, the images may be stored either as still pictures or as a sequence of frames. Software for movie frames manager (e.g., Adobe Premiere) is employed for the generation of video clips and full fledged movies with titles, special effects and sound.

Intergraph's Model View software is used for the creation of photo-realistic pictures of the 3-D model using the ray-tracing technique. The software is capable of repairing and improving the resulting pictures, and it allows their annotation.

3. Non-CAD Computer-Aided Engineering Tools

3.1 Stress Analysis

STARDYNE, ANSYS and PATRAN

These are widely-used software packages for civil/structural and mechanical stress analysis. Based on the finite-element method, they are used for the static and dynamic analysis of structures and machines.

AECL is using mainly STARDYNE on Qinshan Project, primarily for seismic floor response spectra (FRS) calculations. The software is used without any links to the CAD model.

ADIPIPE for Piping

A commercially available nuclear piping stress analysis code, ADLPIPE is the preferred tool for piping stress analysis on new CANDU reactor designs. ADLPIPE has been integrated into the AECL's design software suite.

3.2 Thermal-Hydraulic Analysis

AECL has developed these three software packages for fluid flow, pressure drops and heat transfer calculations. None of this software has links to other portions of CAE.

NUCIRC is used for steady-state thermal-hydraulics

PTRAN is used for fluid flow transients.

ALITRIG is used for Shutdown System 2 transient analysis.

3.3 Detail Design

Pipe Support Design

This software will be used in future CANDU projects. The software performs automatic design of pipe support based on the configuration of pipes and neighboring structural members, loads, allowable stress and deflections, other Code requirements, and available parts from catalogs. The software generates pipe support fabrication drawings and material lists.

Embedded Part Design

Future CANDU projects will use software for managing embedded parts and performing detail design for them. No software is currently being used for the detail-design of embedded parts.

3.4 IntEC-Electrical Cable Management

IntEC is a program developed at AECL in order to computerize via an interactive database, a nuclear plant's cabling and wiring design and management.

IntEC is comprised of three databases:

- The first database contains reference as well as cable specification, conductor and terminal configuration table. These tables contain the data validation and design rules required by other IntEC applications.
- The second database contains the device catalog information, the structures data and all the network file management data.
- The third database contains the electrical project design data which includes all the cabling and wiring data.

IntEC contains all the cabling, wiring and support data required to construct, commission and operate a plant.

3.5 CMMS-CANDU Material Management System

This system has been developed by AECL for the management of construction materials of CANDU Projects.

The material demand from the various disciplines is created as the design progresses, and the material is added up manually (before 3D CAD existed) and then keyed-into the

CMMS. The supply is created as the Engineering Quotation Requests (EQR) are entered manually into the system based on manual estimates from previous projects. The information is entered as stock code numbers and the corresponding quantities. The system produces bills of materials, EQR's, tenders, purchase orders, and reports for planning and monitoring.

Since some of the CANDU design is not done within AECL, not all the material is entered into the system. Structural steel, for example, is handled outside CMMS and outside AECL.

A prime example of software integration is PDS link with AECL CANDU Material Management System (CMMS), which allows mass entry of material demand for piping and cable tray items, from a basic but automatic PDS material take-off. At the same time piping catalogs and specification in PDS are linked to the supply side of CMMS. Other links, such as with stress analysis are being developed.

3.6 Mechanical Engineering

AECL is using outside Qinshan Project, a mechanical design software package which is not integrated with the other project disciplines.

Mechanical design software is used in the mechanical discipline where a tight coupling of detail design, analysis and fabrication is required. The requirements from the software are that is features a parametric solids modeler with facilities for production of solid models, production of finite element meshes, a connection to commercial finite element solvers (such as ANSYS) , drawing production facilities and connection to numerically controlled (NC) machines.

3.7 AIM/TRAK-Document Management System

AIM (asset information management by Intergraph) is the system which controls official project document. TRAK is an additional software that AECL developed to suit the corporate special needs.

All official drawings and reports extracted or created using CAD, as well as non-CAD documents are stored and managed using Intergraph's AIM software.

AIM features capabilities for searching, viewing and tracking revisions of documents through a set of meta-data which describe the properties of the document and it history.

4. Design Process

The illustration (Figure 3) below describes the generic CANDU design process using advanced engineering tools. However, repeat projects, such as Qinshan do not require all the design steps. For example, stress analysis for Qinshan design is minimal, and is usually done by assessment rather than by calculation. Another occurrence which is typical in a repeat project is the minimal requirement for repeating detailed design, such as embedded parts, supports and structural joints and re-bar.

5. Conclusion and Lessons Learned

AECL has procured the plant design CAD system from Intergraph, and then developed and customized it to its own specific needs - in some cases in a unique way which is found nowhere else in the Process and Building industry, and certainly not in the Nuclear Industry. The Plant Design System (PDS) software includes many sub-modules which AECL modified and used to various extents.

AECL has extracted thousands of drawings and lists from the 3D model for piping fabrication and for the installation of equipment, piping, cable tray and concrete-embedded steel parts. The extracted lists include material take-off, piping line lists, weld lists, cable tray length lists, junction box and electrical panel list.

We have established links from PDS to other corporate software systems, thus eliminating re-entry of data and achieving agreement between different deliverables, mainly with CMMS (see section 3.5).

The integration of all the PDS modules enables AECL to produce a quality design with a consistent set of engineering documents, all emanating from the same 3D model. AECL has achieved a high degree of precision in the dimensions of the plant components as well as in quantities of material demand - especially piping material.

CAD has evolved from a mere drafting tool into an engineering tool, and from there into a tool which drives the whole project (see Figure 4).

The first full-fledged CANDU on 3D CAD serves as a prototype for future CANDU projects to be executed with 3D CAD. AECL has learnt some lessons from Qinshan 3D CAD project with regard to work sequence, usage of tools, organization of data, planing and scheduling. New advances in the field of computer graphics, databases and networking will allow us to use 3D even more extensively in the future to achieve better design and more efficient engineering and construction.

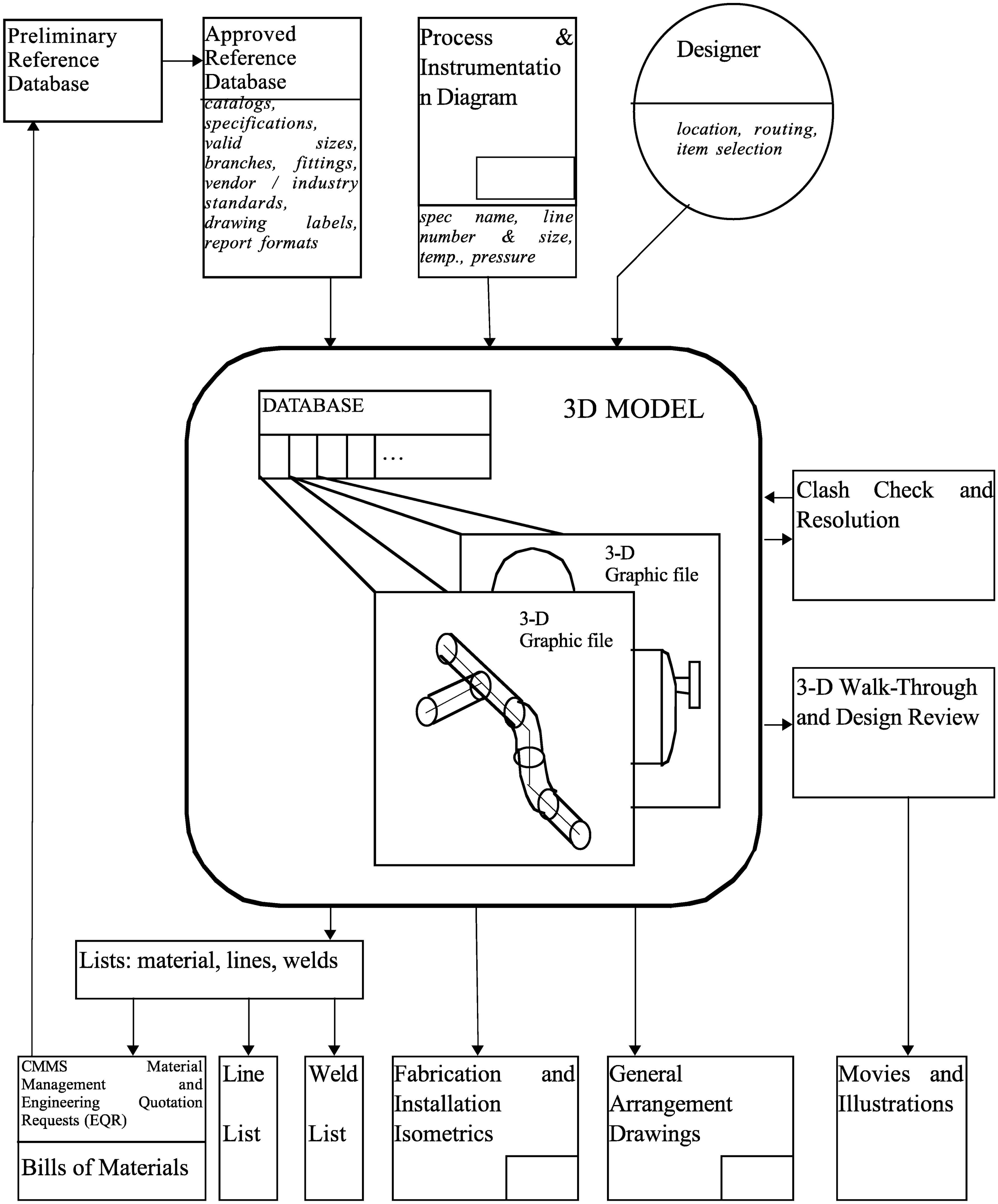

Figure 1 **3D CAD SYSTEM: QINSHAN CANDU PROJECT**

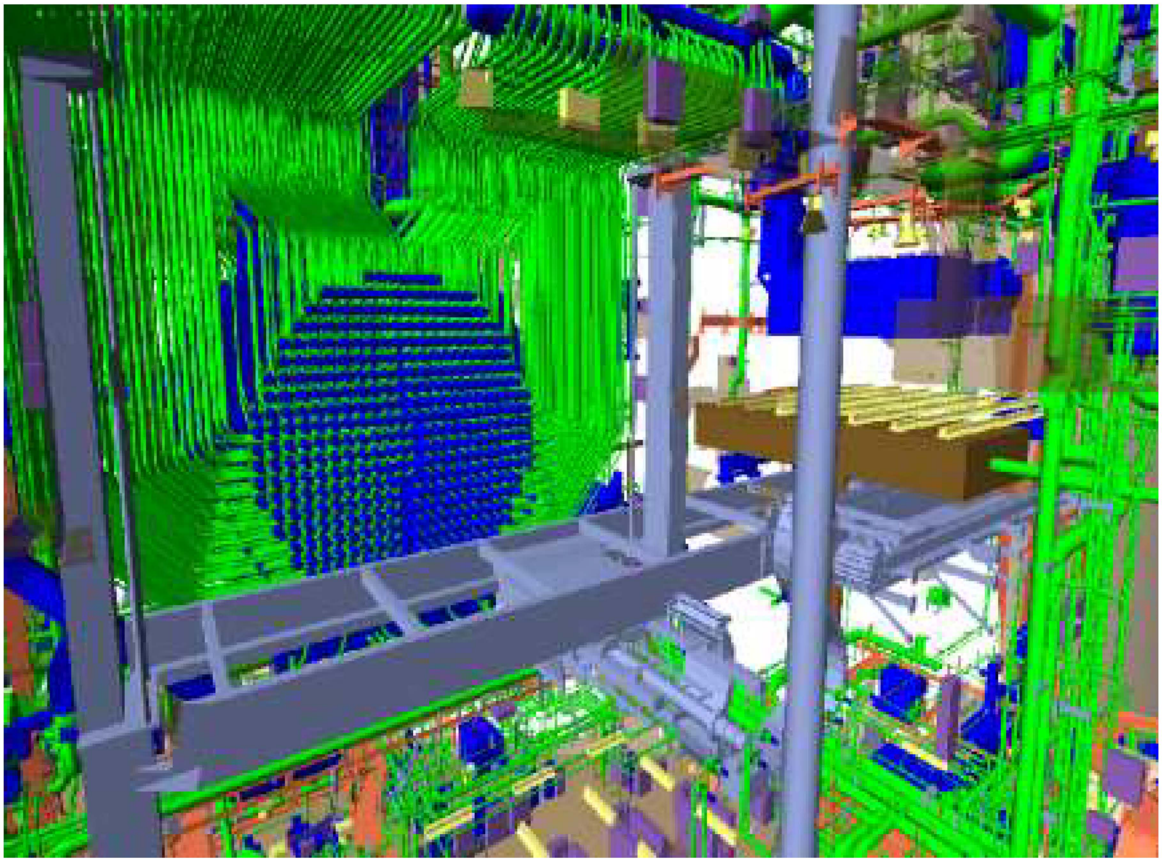

Figure 2 **3D CAD MODEL: DETAIL**

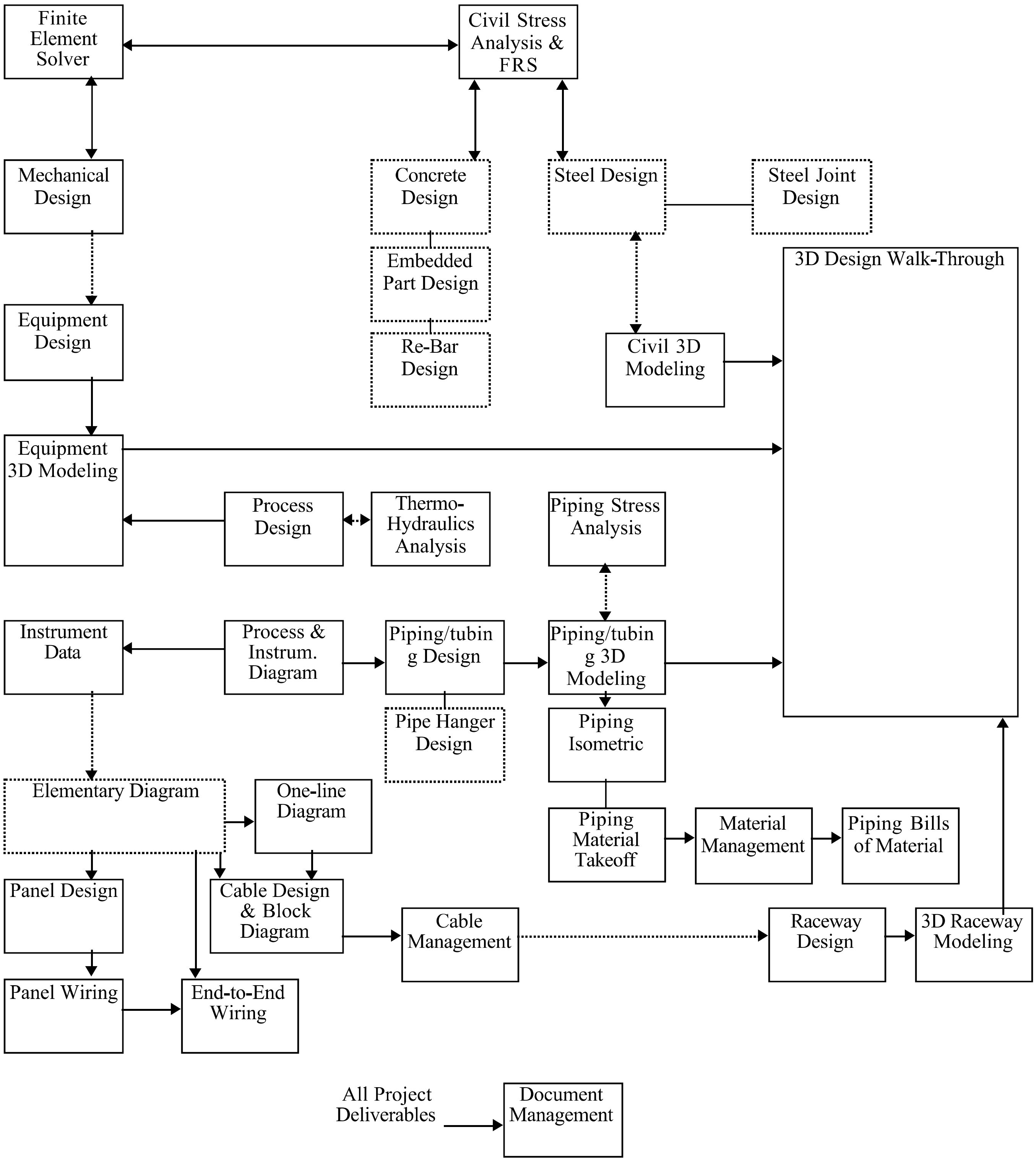

Figure 3 **CANDU Project Design Modules**
(Note: Software modules and links not yet integrated into the overall system are shown in dashed lines)

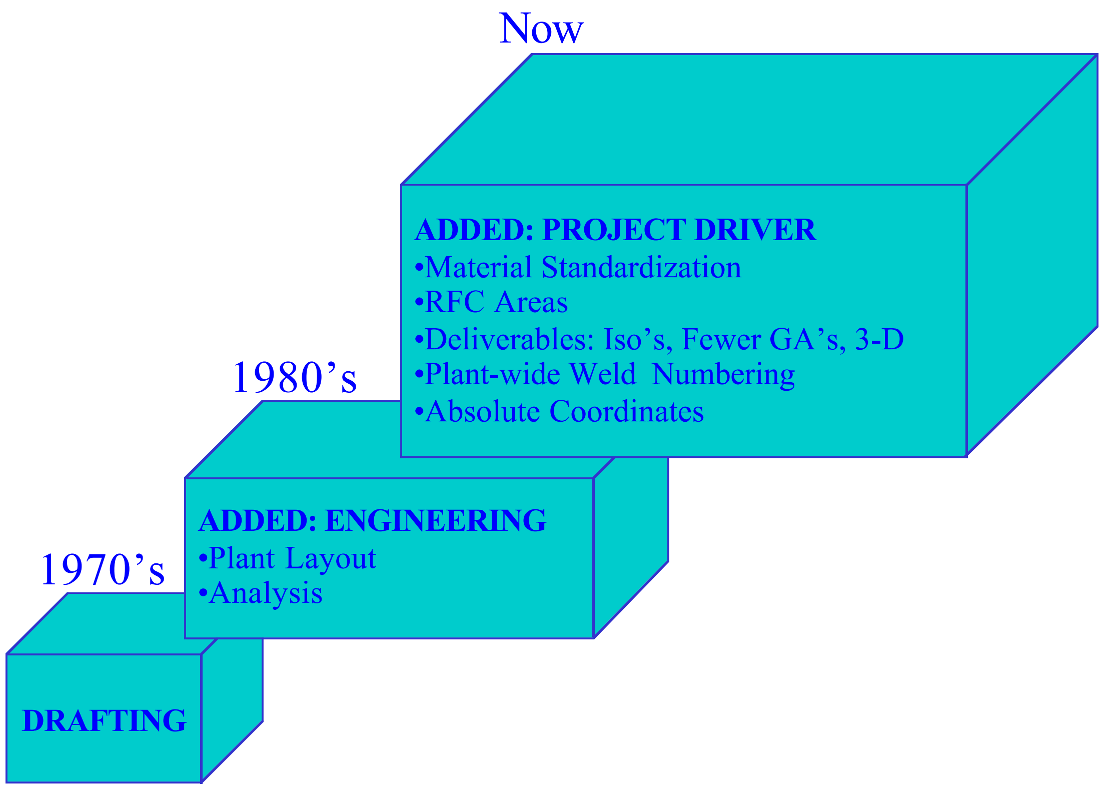

Figure 4 **Evolution of CAD Systems**