COLLABORATIVE DESIGN WITH AN INTEGRATED CAD MODEL IN THE PETRA IV PROJECT

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Abstract

The PETRA IV project involves the refurbishment of the 2.3 km PETRA accelerator to accommodate almost 40 beamlines. It also includes the conversion and construction of numerous buildings, including a large experimental hall, with first light planned for 2032.

To support planning and design with a model-based approach, a comprehensive, integrated CAD model has been set up. The model comprises civil infrastructure, the accelerator, beamlines, and infrastructure systems. Serving as a single source of truth, it supports a diverse project team, including civil and mechanical engineers, beamline scientists, and other stakeholders, each with different technical backgrounds and needs.

The fully integrated CAD model is tied to systems engineering processes like requirements management, and supports collaboration across disciplines. Multiple levels of abstraction, a structured hierarchy, and explicit modelling of interfaces help bridge communication gaps. They also reduce redundant work and minimise design errors, all critical for efficient design in collaboration.

INTRODUCTION

A CAD model can serve more than as a design tool in accelerator development. It can also support project processes and create a shared understanding of the project. For the model to become the working basis of all design activities, it must be developed as a comprehensive integration model. Such a model provides the context for the work of all stakeholders. It forms the communication basis for collaborative design. In the PETRA IV project at DESY, fundamental methods have been applied to ensure the model is comprehensive and to enable it to support project tasks such as review processes.

METHODS

Comprehensive CAD Model

A comprehensive CAD integration has been established at DESY as part of the PETRA IV project. This model includes all project-relevant buildings and tunnel systems (comprising approximately 80 buildings) as well as the entire machine equipment along the 2.3 km storage ring and its pre-accelerator complex, represented in different configurations (current state and target design). In addition, the model incorporates user systems, experimental installations and technical infrastructure, including supply routes, escape paths and transport routes. It serves as a single source of truth and provides all stakeholders involved in construction and design processes with a complete and reliable geometric context.

Structure

The model is hierarchically structured with levels designated (from top to bottom) complex, facility, area, unit and component, adapted from the physical hierarchy of the ISA-106 standard [3]. On the “complex” level, the model comprises buildings, accelerator, photon science complex, technology complex and campus. Major facilities are individual buildings, accelerators, the photon science experimental halls. This CAD structure is aligned with the project structure in order to facilitate design processes such as functional and requirements analysis, verification, and reviews. A correspondence to the work package structure ensures that responsibilities are clear. The data integration also includes attaching technical documentation, which is linked to the CAD data and project structure. Together with the modularisation and abstraction principles described below, the structure enables navigation from the overall PETRA IV programme down to the smallest components such as individual fasteners (Fig. 1).

Modularisation

In the PETRA IV integration model, the system is organised into clearly defined modules, each representing a physically bounded and functionally self-contained unit with explicit interfaces to its environment. Modularity is applied consistently across all design levels, from large-scale structures such as accelerator arc to technical subsystems like local media supplies or beamline optics. Even non-technical zones, such as transport corridors or safety areas, are treated as modules to support coordinated planning. This modular approach enables structured integration and facilitates parallel development throughout the entire PETRA program.

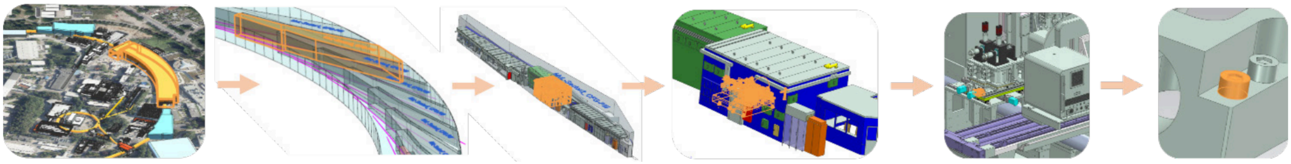

Figure 1: CAD structure allows vertical navigation from the entire program to every individual part.

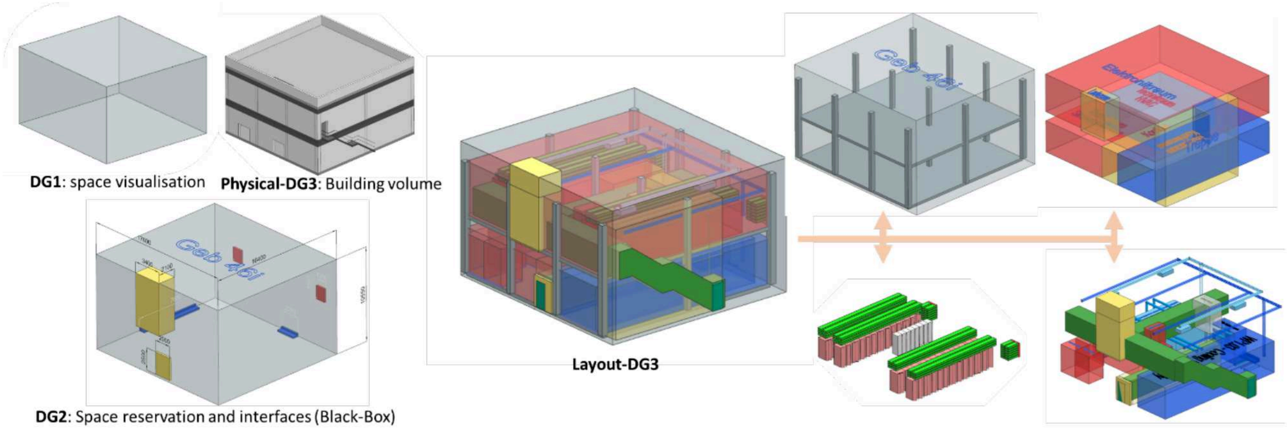

Figure 2: Level of detail in case of a building design. The building is represented in different abstraction levels (level of detail). The layout-DG3 model separates functionally into a construction layout, the room structure, user systems, and technical building equipment.

Level of Detail

To ensure high performance in model navigation and loading, despite the comprehensive scope, a multi-level abstraction strategy is employed across all modules. This strategy enables each module to be represented at different degrees of detail (DG1, DG2, DG3). Each level of detail is tailored to specific technical and coordination purposes (Fig. 2). DG1 models are used for schematic visualisation and depict rough outer dimensions. DG2 models provide a simplified space reservation suitable for collision checks, and include additional clearances for tasks such as maintenance and installation. DG2 models also define all required interfaces. These may include mechanical mounting points or media connections such as power, cooling water or compressed air. When applied to buildings, DG2 representations include transport and evacuation interfaces. DG2 models serve as leading context representations (Black-Box) and are used to coordinate technical planning across systems [4]. Once these interfaces and space-reservations are defined, both the context and the DG3 model of the module itself can be developed in parallel. The DG3 provides the internal structure. The "physical" DG3 representations reflect the full engineering design, with a complete bill of materials, including every individual part down to fasteners. As a possible addition, a logical DG3 model may describe internal structure functionally, without necessarily matching the physical assembly. For example, a magnet may be represented by its functional elements such as coils, yokes and support frames. If necessary, for example in case of building design models, layout-DG3 representations can become more complex. The physical DG3 serves manufacturing and assembly needs, the layout DG3 captures the logical and functional design, the DG2 defines system boundaries and connection points, and the DG1 supports early-stage visualisation. This approach aligns with the RFLP (Requirements, Functions, Logical, Physical) development model of systems engineering [2]. It supports both technical efficiency and interdisciplinary coordination, by allowing fast model loading and early context integration, while maintaining consistency between model development and its integration into the overall design framework.

Context Models

The modelling approach is anchored in one comprehensive and authoritative integration model that contains every artefact of the project. By combining different levels of detail with Siemens NX features such as reference sets and loading options, all design work can be performed directly in the context of this integration model. From the full model, dedicated context models are derived to provide a focused view around a specific system of interest (SoI), for example a building, a beamline, a technical subsystem or an accelerator section. A context model is centred on the SoI, represented in DG3, and includes surrounding elements that are spatially or logically related, such as adjacent buildings, supply lines, or nearby accelerator infrastructure. To ensure good performance, context models are created by selecting relevant elements from the integration model, rather than importing the full model and suppressing content. This requires strict modelling rules, such as the consistent use of coordinate systems across all DG levels and the positioning of subcomponents via defined Base-Orphan Lists (see Ref. [4]). These rules ensure that context models remain consistent even as the full integration model evolves. The approach also enables interface definitions across hierarchy levels. For example, the "support" interface of the accelerator is defined as the sum of the mounting points of all its subcomponents, from arc cells to complete sections. Such interfaces can be frozen and released independently of the detailed subsystem designs, allowing construction tasks like drilling or surveying to proceed in parallel. As long as subsystems comply with the defined interfaces, overall compatibility is guaranteed.

This principle is applied not only to technical connections, such as power or cooling water supplies, but also to non-material planning tasks, including evacuation routes or transport corridors, where external networks must connect seamlessly to local interfaces such as doors and gates. In this way, context models establish a reliable and efficient basis for parallel design.

APPLICATION EXAMPLES

The methodological approaches in the integration model are used for various purposes in the project. For the PETRA IV project, a layout design is being created for many new buildings. These are to be put out to tender and detailed externally. As the buildings have very specific requirements, the layout design is being developed in detail in a preceding process involving all stakeholders.

One result of the building layout are transport routes, which are checked in reflection with the actual physical building design (Fig. 2).

Building Layout Design

For the PETRA IV upgrade, around 40 new buildings are planned alongside refurbishments. The most challenging project is the PXW experimental hall, a 600-metre long underground facility for 20 beamlines. Its design requires a structured process in which stakeholder requirements are collected, a functional analysis is performed, and the layout is validated before physical design (RFLP approach).
CAD models are closely linked to the Product Breakdown Structure (PBS) in the PLM system, which connects CAD models with building specifications and supports traceable review tasks. The Layout-DG3 model represents the building's functional structure, distinguishing between room structure, user systems, technical equipment, and construction layout. The room structure defines rooms and corridors, user systems cover installations needed for accelerator and experiment operations like magnet power distribution or monitoring and control electronics. Technical building equipment includes infrastructure essential for the building, such as water or power supply, and safety systems (Fig. 2). System allocation derives directly from requirements, specifying space demands, cooling capacity, or load demands. The review is completed, when stakeholders confirm that all systems are accommodated, operable, and maintainable. The building layout is fully planned in detail, and the tender focuses on the construction volumes.

Transportation Planning

Transportation planning is integrated at all levels of the model. In the vertical structure, it defines transfer points from campus transport routes into buildings and from buildings into individual rooms. Horizontally, it allows collision checks between transport clearances and building structures, as well as installed systems, ensuring that both equipment and personnel can be moved safely.

The planning is based on collected stakeholder requirements, clarifying in the layout phase how many people and which objects (size and weight) must be transported, when, and where. The method of abstraction is applied: the largest items are represented as simple volumes, creating transport envelopes that can be easily checked against available paths (Fig. 3). This approach applies, for example, to technical equipment moved on pallets. Transport routes are also categorized by purpose, distinguishing between operational and temporary construction needs.

BENEFITS

Some key benefits of the comprehensive CAD integration within the project are:

- Shared understanding (vision sharing) and involvement of all stakeholders
- Error reduction in system integration through a common working basis, with context always accessible (single source of truth)
- Time savings through collaborative and simultaneous work and processes
- Support for project processes such as reviews
- Transparency and traceability

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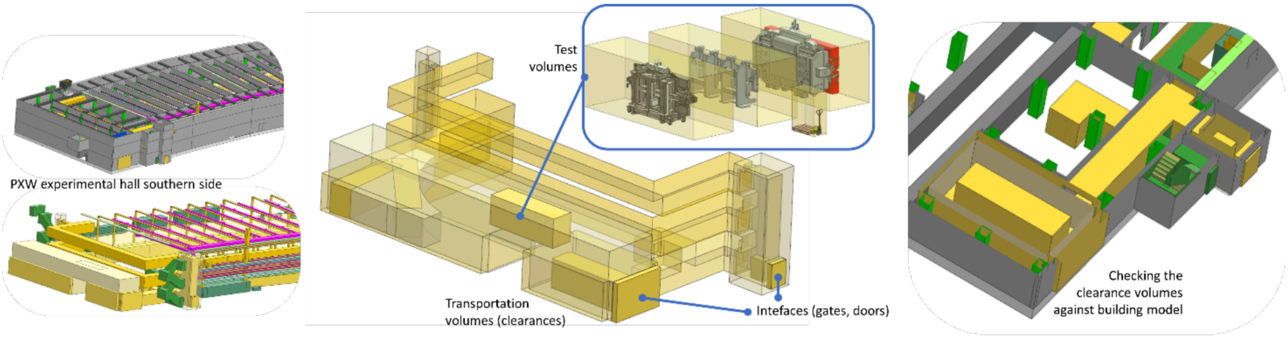

Figure 3: Transportation Planning. Left: detail of a building model and technical building equipment with transport and escape routes, centre: abstract test bodies are tested in the transport network (applicability of transportation concept).