ANR-06-RGCU-002

COMMUNIC

Deliverables
L1 - Global model

Version 10/12/2010

Collaboration using the Multi-Purpose
Digital Model and Concurrent Engineering

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Presentation of deliverable L1

COMMUNIC: one memo, three deliverables

The COMMUNIC project

The research project is called COMMUNIC, for *COllaboration par la Maquette Multi-Usages Numérique et l'Ingénierie Concourante (Collaboration using the Multi-Purpose Digital Model and concurrent engineering)*. It was selected by **ANR** (Agence Nationale de la Recherche) following a call for proposals in 2006.

This project was approved by the **ADVANCITY Competitiveness cluster.**

The project was **begun in 2007** and lasted 3 years.

Object

Its purpose is to foster the development of collaborative work in infrastructure projects through the use of an information model (IM).

Partners

The project partners are:

- **Engineering**: EGIS and Setec TPI.
- **Contractors** Bouygues Construction, Vinci Construction France, Eiffage TP.
- **Research Centers** and **Academic Partners**: CSTB, the Ecole Polytechnique's Management Research Center, LCPC, University Paris Est, and IREX.

Overview of work done by COMMUNIC

The research conducted under the COMMUNIC research project is the object of this memo, which summarizes the project's progress and results.

To make this thesis more practical to use, we have completed it with three deliverables that:

- describe our work more fully,
- provide unique perspectives on our conclusions.

COMMUNIC project deliverables

The table below shows the 3 deliverables:

Deliverable	Title	Mission	Contents
L1	*Global model*	Describe the **technological and organizational model** which will support collaborative work through a shared digital model	Overall description of the model. Expected values and uses. Structuring of information and its circulation. Adaptations of the organizations. Redistribution of responsibilities.
L2	*Recommendations for implementation of the digital model*	List of **recommendations** for stakeholders.	Tools. Projects. Companies. Construction sector. Change management.
L3	*Functional program of the digital model*	Aimed at software publishers who will have to adapt or create software allowing use of the digital model.	Projects concerned. Proposed system with the expected features, architecture, data model and standardization.

Copy editing and final proofreading was provided by the **Artecomm** company using MRS, l'Écrit Intellisible®.

Content of the chapters of deliverable L1

The infrastructure concerned

The global model described in this deliverable was established by analysis of linear infrastructure projects. It thus relates directly, for example, to:

- roads,
- highways,
- railways,
- canals,
- dedicated urban transport infrastructure
- bridges and tunnels.

Response to specific needs

Compared to the other models we tested, in other, more industrial, sectors, and in building, it meets the specific needs of this type of infrastructure with, for example:

- Major influence of the existing situation (natural ground, subsoil geotechnics, division into parcels).
- Length of the projects, which can reach several hundreds of kilometers.
- Structure of the Public Works sector and its many stakeholders.
- The importance of environmental integration.
- Need for consultation with landowners, residents, and associations.

Note: The model must be easy to transfer to other infrastructure not listed above.

The limitations of the model described

The partners' work led to the development of this model. We tried to test it on a real project. These tests confirmed our belief in the need to move towards this schema.

However we could not conduct all the tests we wanted because we ran into problems of incompatibility and non-interoperability of existing software.

We have developed workaround tools, but this handicap has severely limited testing. It therefore remains to audit the feasibility of the solutions we are considering.

The model is therefore a goal we have identified and believe achievable, rather than a ready-to-use solution validated by experience.

Description of the global model of an infrastructure project

The first chapter of deliverable L1 succinctly describes the global model.

It makes it possible to understand the principle of structuring the **project into objects** that will contain all project information.

It also provides an inventory of the **expectations** of the various direct stakeholders who wish to have an IM for collaborative work on projects.

Finally, it describes the **new processes** that will serve to manage information so as to make it accessible to all stakeholders.

Creation of value by the IM

In the second chapter, we present the **values** and **practices** the direct stakeholders in the IM (clients, designers, builders and operators) want the IM to provide.

We also present a summary of the inventory; a complete version is provided in an appendix.

Structuring and flow of information

The third chapter describes in more detail how to:

- **Structure** a project into elementary **objects** and organize relevant levels.
- **Organize** the **information** and its attachment to the objects.
- **Exchange** and **share** information between stakeholders.
- **Organize** the **validity** of the information and the **quality** of the processes**.**

Adaptation of the organizations

In the fourth chapter, we describe the changes induced by the model on the major missions that constitute the life cycle of the structure.

To simplify, we selected 5 key missions, knowing that other breakdowns would have been possible.

We in this way analyzed the modifications to be anticipated concerning:

- **Management** of the project, which concerns in particular the client and project management.
- Obtaining **external permits,** in other words, the communication, consultations, and approvals needed to steer the project. This mission is primarily the responsibility of the client and project management.
- The **design** of the project, which falls to the designers, and in which all the other direct best football predictions stakeholders must be involved.
- The **construction** of the project, incumbent on the builders.
- The **operation** of the structure, incumbent on the operator.

Redistribution of responsibilities

The fifth chapter concerns our analysis of the new distribution of responsibilities brought about by collaborative work on projects and by the use of an IM for this purpose.

We have:

- compared some **contractual arrangements** implemented on projects (conventional, PPP, D & B, concessions);
- evaluated the **sharing of responsibilities**;
- spelled out the **procedures for approval** by concurrent engineering;
- focused on the **contractual impact** of the use of an IM;
- examined ways to preserve the **intellectual property** rights of the stakeholders involved in the project.

In an appendix

To facilitate the reading of the document, we have attached:

- A table: values and practices expected by the direct stakeholders.
- A summary of the benchmarks.

Reading Aids

Acronyms

The acronyms used frequently in the document are explained below.

Acronym	Meaning
APS	Short preliminary project
AVP	Preliminary project
BE	Design Department
BIM	*Building Information Modelling*
BTP	Construction industry
CAD	Computer Aided Design
GCC	General Conditions of Contract
EC	External control
D & B	*Design and build*
DAO	Computer Aided Design
DCE	Tendering package
GED	Electronic Document Management
IFC	*Industry Foundation Classes*
KM	*Knowledge management*
IM	Information model
MOA	Client
MOE	Principal contractor
MOP	French public building procurement [law]
PLM	*Product Life Management*
PPP	Public Private Partnership
R & D	Research and development
SaaS	*Software as a Service*
SDK	*Software Development Kit*
DBMS	Database Management System
GIS	Geographic Information System
STEP	*Standards for the Exchange of Product model data*
TP	Public Works

Glossary

Definitions (taken from www.wikipedia.fr) of the discipline-specific terms necessary for understanding the present document are given in the table below.

Term	Definition
Benchmarking	**Benchmarking** is a quality management technique that consists in studying and analyzing the management techniques and methods of organization of other companies to draw inspiration from them and select the best.
Building Information Modelling	BIM covers the design data production and management processes through all stages of building design.
Building SMART	The French building industry digital model website. http://www.buildingsmart.fr/
Clash, Conflict, Interference	These three terms are used interchangeably in the deliverables and the memo.
Geolocation	**Geolocation** or **georeferencing** is a way of positioning an object (a person, information, etc.) on a map using its geographic coordinates.
IFC	The **IFC** (*Industry Foundation Classes*) format is an object-oriented file format used by the building industry to exchange and share information between programs.
Open Source	The ***open source*** designation applies to software of which the license satisfies strict criteria established by the Open Source Initiative, namely the possibility of unrestricted redistribution, access to source code and derivative work. Free software is often called "open source" because open source-compatible licenses include free licenses as defined by the FSF. The term *open source* competes with the term "*free software*" recommended by the FSF. The term "freeware" means software that is free of charge but not necessarily open or unrestricted.
Standard	An official **standard** (industrial) is a frame of reference published by a standards organization such as AFNOR, CEN, ISO, OASIS
	A de facto **standard** [...] is a documented common baseline intended to harmonize the activity of a sector.
STEP	The **standard for the exchange of product data**, **STEP** or **ISO 0303,** covers the representation and exchange of product data and is aimed at integrating product design, development, production, and maintenance processes.

A - Description of the global model of an infrastructure project

Introduction

Current developments are leading to rethinking a global model

Current developments in construction practices result from:

- **Technological change** through the introduction of software packages having ever larger scopes and capabilities.
- The establishment of **new contractual frameworks**: Design & build, PPP, etc.

There are no standards applied by all software in the sector

Official and de facto standards for TP-specific data models in modern software programs and databases (ISO-IFC, STEP) have been established in recent years.

Work on these standards (in particular the IFC for technical data) has been under way for over 10 years, mobilizing hundreds of people around the world. Their relevance is no longer challenged today.

Some tools using these standards are already available on the market.

There is very little such standardization of TP tools. To date, the standardized tools are **imperfect**, **barely interoperable,** and, most important of all, very **little used.**

The IM to justify a common standard

The generalization of a standard has a prerequisite: **revision** of certain key stages of the processes, in particular the use of a collaborative IM. This means abandoning an approach based on a simple exchange of drawings.

Three viewpoints of the model: objects, stakeholders, processes

In the analysis of the global model of an infrastructure project, there are three viewpoints:

- An approach based on the **objects processed** and their segmentation into increasingly detailed levels, along with their validation.
- An approach based on the **stakeholders**:
  - **direct** (designers, builders, operators)
  - **indirect** (financiers, suppliers, subcontractors)
  - **influential** (politicians, communities, governments, associations, residents, users, etc.).
- An approach based on the **processes** (design, build, operate) and their detailed **sub-processes,** from the blank sheet of paper to the structure actually built in the field. Each process can be seen as an action that changes the attributes of the objects or creates new ones.

A strategic issue of data harmonization

Given the vast variety of situations, technical data and digital exchanges thereof are **neither facilitated nor secure.** Their harmonization will be the backbone of the new discipline-specific processes.

It is a decisive factor for improvement in terms of **time savings,** of **quality** in the design and construction stages, and of **savings** in the operating stage.

The variety of stakeholders' situations

The construction sector is more **fragmented** and **less hierarchical** than other industrial sectors. In each project, the stakeholders are **new** and partnerships are created in extremely **varied** contractual frameworks.

In industry, there is often a designer-integrator that, for the realization of its products, calls on "first rank" subcontractors that are themselves in charge of part of the product.

Variety of clients and contracts

In the field of linear infrastructure, clients differ greatly in **size** and **organization** (the state, motorway operators, railways, local governments, etc.). They enter into **contracts** of **very different kinds** (engineering and construction, design & build, public-private partnership, concession), transferring all or part of the responsibility for the design, construction, operation, maintenance, and even the financing of their structures.

Organizations profoundly transformed by IM

The emergence of savings, with a positive impact for the community in productivity, quality, and lead times, **results from a change** in practices in the disciplines, with suitable guidance and support.

The experience of manufacturers shows that the introduction of IM-related tools and collaborative work transforms organizations profoundly.

It is therefore time to **rethink the processes** reflecting the workings of our disciplines and the organization of our infrastructure projects.

Lessons from *Benchmarks*

Lessons from *Benchmarks* are described in an appendix.

A1 - Information-bearing objects

The basic principle of the global model

The purpose of this module is to introduce the basic principle of the global model: **share** information about a project with all stakeholders.

It is a very large change from the current exchanges of documents, whether on paper or in electronic form.

Linking information to objects

To organize and locate this information, we decided to attach it to objects. These are a more or less detailed breakdown of the structure built by the project.

We therefore **structured** the project **into objects** carrying information suited to infrastructure. We will explain and justify this in the specific context of infrastructure projects.

Specific needs of linear infrastructure

Compared to manufacturing and building, the construction of linear infrastructure has many specific features, among which are the following.

Linearity and length shape the structures of the projects

By definition, a **linear infrastructure** has a preferred direction. The "project axis" is a fundamental element, not found in a building, for example. Currently, the objects that constitute the linear infrastructure are often identified with respect to this axis (the concept of kilometer point). We must continue to provide this identification, probably backed up by geolocation of the objects.

In addition, the projects are on the scale of hundreds of miles. These **very great lengths** are not found in any other type of structure. The topographic benchmark must therefore be adapted to such lengths. For example, the curvature of the Earth cannot be neglected over a hundred kilometers.

Geotechnical conditions and topography interact strongly in the structure

The existing situation is a preponderant factor in the design of linear infrastructure. Geographic information systems therefore play an important role in the IM.

The subsoil and the geotechnical conditions attached to it are difficult to ascertain. In fact, they vary over the whole length of the infrastructure and are learned only step-by-step in the life of the project. They are in fact never fully known, even after completion of the project.

Similarly, the topography has a much greater importance than for a building on a well-defined site. Variations of the terrain are one of the first issues in the design of linear infrastructure.

The environment has a large and changing impact

The site organization must allow for stronger constraints on the land: gradual release of rights-of-way, relocation of the site (teams and equipment) over long distances. The model must not only represent a finished work, but must also reflect the **successive stages** of construction over time.

Particularities of the objects making up an infrastructure

Having mentioned the specific needs of linear infrastructure projects, we can discuss the particularities of the objects that make up infrastructure, compared to manufacturing.

The objects produced are multi-scale

Automobiles, ships, and planes are all objects on a roughly decametric scale. Buildings and engineering structures often reach hundreds of meters. Linear infrastructure can reach hundreds of kilometers, but the structural details of some of the objects are on the scale of the centimeter or the millimeter, as in automobiles and planes. Management of the scales is therefore a **design constraint**.

The products are practically one-off

The projects are located in sites that are always particular. This makes the objects or products nearly unique or of limited repeatability. In addition to the first point, it requires us to consider, for the same object, the juxtaposition of:

- **Frames of reference**:
  - of the geodesic type
  - "local", intuitive and natural, for one part or another of the structure.
- **Information systems** concerning the geography and structures.

The product is the production shop

With the exception of a few parts precast in factories, almost all of the objects are made on the spot using local materials. The product, during its construction, is its own production shop. This shop:

- is therefore never a controlled working environment.
- moves from one project to another,
- is moved from one part of a project to another, especially in the case of linear infrastructure.

We build more than we assemble

Assembly tasks are **not in the majority** on site. Even if materials are sometimes prepared off-site (concrete, asphalt, ballast), the object is produced on site. A bridge deck is cast in place. In fact, we build, rather than assemble, a bridge or a road.

In addition, the **materials** used **change as they are used**. For example, earth-moving operations add or displace materials that may bulk or subside as a result.

This is why s**imulating** construction is much more **complex** than s**imulating** industrial assembly in a shop.

Control of uncertainties is a necessity

In manufacturing, the problem is to control the **production tolerances** of objects so as to be able to assemble them. The concept of tolerance applied to infrastructure is profoundly different from the one used in manufacturing.

The **local environment** in which the structure is set is not precisely known**.** However, the objects created are linked to this environment. Their definitions must make allowance for this uncertainty and adapt to the evolution of the quality of the data collected. The case of the natural terrain illustrates this problem.

The construction of infrastructure is highly dependent on a number of contingencies. For example, **the weather** is a key factor in the building of earthwork objects. The objects must therefore be able to react to these contingencies and adapt as they change.

The concept of fuzziness must be managed, because an object can be defined only as the design process advances. For example, early in the design process, acoustic protection is defined only in principle. It is not until later that it will be narrowed down to an earth barricade, a noise wall, or noise proofing applied to a building.

The IM will therefore have to be able to support and represent these options (without freezing them).

COMMUNIC definition of the term "object"

In the COMMUNIC project, the term "object" represents a **real component** that has been or will be physically **built** to form the structure. An object occupies a specified volume, is positioned in space, and has its own characteristics.

The advantage of this definition is its real character in the finished structure, making it **easy to understand** what is meant.

When objects share enough characteristics, they can be grouped into a **class**.

Note: This definition differs from the approach taken in computing, where "object" refers more generally to items manipulated by software.

Objects: basic elements of *Project Data Management*

A structure is broken down into objects so that information can be attached to the objects.

These information-bearing objects are the basic elements of the "*Project Data Management"* (PDM) allowed by the IM. The PDM makes **information available** to the various contributors to a project (and lets them modify it) through a single medium.

Exchanges

In the field of linear infrastructure, the move to the PDM is a fundamental change, eliminating:

- exchanges of **physical drawings**,
- duplicate data entry operations.

For this reason, the objects must be defined precisely. The exchange of information between stakeholders in an infrastructure project is no longer "document by document" (drawings on paper) but "**object by object**" (shared virtual representations of a physical object).

Characteristics of an object

An object is characterized by:

- its definition,
- its attributes,
- its links with other objects.

Definition

This means specifying its v**olume**, i.e. its external surfaces or surfaces in common with nearby objects. This volume defines its shape. The object must also be positioned in space. The object so defined is **unique**.

Attributes

These are the **characteristics specific** to an object.

Links with other objects

These are the **relations** the object must establish or satisfy with other objects, on the same or different levels. They are expressed as:

- interfaces,
- associations,
- rules,
- laws.

Project and IM structuring

Structuring the project into objects must be started at the same time as the **project.** This lets you store and manipulate the first information, such as basic data and previous studies.

Structure in levels

To facilitate the handling of information and deal with global issues without getting lost in the details, we propose structuring IM objects in levels.

Starting from the zero level, a single object for the entire project, we can create **increasing levels** (1, 2, 3, etc.) progressively as the objects created describe **finer and finer details**.

This can be regarded as a principle, formulated as:

- The aggregation of all objects of a given level is the overall project.
- An object of level *n* is the physical aggregation of the objects of level *n +1* created by breaking it down.

In general, the objects of the deepest levels are not created at the beginning of the project. They are **created progressively**, as needed.

Do not confuse detail and precision

Levels of objects correspond to **levels of detail**. They cannot be regarded as specific to levels of study. They must first of all, in the first levels, **reflect an economic reality** such as:

- the kinds of functional structures,
- the disciplines involved.

Only the highest levels, where the objects are increasingly detailed, may reflect progress in the design phase.

By contrast, the **precision** of the information attached to the objects **increases as the design process advances,** but this precision is, at any given time, the same on all levels.

The fact that we consider a detail of an elementary object does not mean that more global objects do not share the increased precision that results. The precision of the objects of level 1 increases gradually as you work on the precision of the objects on levels 2, 3, 4, a 5.

Example of structuring

The case described below does not imply any mandatory recommendation. It is just an example, to be adapted to a given project. However, we believe that levels 0, 1, and 2 can be generalized to all projects.

The example is taken from the A28 motorway project.

Representation of the corresponding tree

The positioning of the running section of RN 138, a type 1 pavement (CHT1), in the tree of objects broken down into levels, is described below.

Level	Object of previous level concerned	Object
0	ALIS patrimony	A 28 project Other patrimony projects
1	A 28 project	RN 138 (the project) RN 138 entity Surface of the TN (topography, land ownership, usage, etc.). Streams Conceded structures, networks Existing roads (roundabouts, etc.).
2	RN 138	Engineering structures Earthworks Pavements Drainage Landscaping Equipment
3	Earthworks	Ordinary embankments Ordinary cuttings Fill Borrow
4	Ordinary embankments	Body of embankment Top Drainage
5	Body of embankment	Elementary courses

Level 0

Level 0 represents the object as a **whole** (operation, the project, the area concerned). For the A 28, this means all structures to be built to implement the A28 motorway project.

Level 1

Level 1 represents objects that perform a function, provide a service. For the A28:

Object of level 1	Function to be performed
Motorway	Allow vehicles to travel on the motorway
RN138	Keep the RN 138 open to traffic
Power line	Transmit electric power across the project
Stream	Let the water of the stream flow
Subgrade	Support the project

Level 2 Objects that use a particular type of work, a discipline in the sector.
Diversion of the RN 138:

Object of level 2	Work done by
Engineering structures	Companies specializing in engineering structures
Earthworks	Excavation contractors
Drainage	Drainage contractors
Pavements	Pavement contractors

Level 3 The elementary structure objects that involve similar types of work or disciplines. For the earthworks of RN 138:

Object of level 3	Specific feature
Ordinary embankment	Need for materials
Ordinary cutting	Source of materials
Fill	Storage of materials not used by RN138
Borrow	External source of materials needed for RN138
Adjacent embankment	Nature and placement different from ordinary embankment

Level 4 Objects that use different constructive arrangements.
For an embankment among the earthworks of RN138:

Object of level 4	Specific feature
Body of embankment	Routine placement
Top	Nature of materials and placement specific to the top of the embankment.
Drainage layer	Materials chosen to avoid upwelling

Level 5 Objects that use specifications for placement, execution.
For the body of an embankment among the earthworks of RN138:

Object Level 5	Specificity
An elementary layer	True nature of the materials and associated placement specification

A2 - Project stakeholders

Three categories of stakeholders

By stakeholder, we mean any person, entity, or group of persons having a role in the lifecycle of an infrastructure project (design, construction, operation).

The project distinguishes three categories of stakeholders:

- direct
- indirect
- influential.

Direct Stakeholders

The direct stakeholders have direct **responsibility** for the design, construction and / or operation of infrastructure. They create most of the information and deliver added value to the IM during the whole project lifecycle.

They constitute a special category because their missions are major and require numerous exchanges of information.

Collaboration among them is of s**trategic importance** because of the stakes in terms of cost and completion times.

For an IM to facilitate collaborative work, these stakeholders must be able to use it directly.

Major stakeholders

Four major stakeholders make up this category:

- designers,
- builders,
- operators,
- the client (MOA).

Indirect stakeholders

Indirect stakeholders act for the direct stakeholders. They promote collaborative work. For COMMUNIC, they do not necessarily have direct access to the IM, but go through a direct stakeholder.

The boundary between direct and indirect stakeholders is therefore not defined *a priori*. It is the volume of their contributions and the utility, need, or opportunity to improve flows of information that are decisive.

Technological progress and more extensive use of the IM will probably lead to these indirect stakeholders having more access to the IM.

Major stakeholders

The major stakeholders in this category are:

- lenders,
- consultants,
- financiers,
- suppliers (data on designers, materials)
- the client's service providers (outside inspections, health and Safety, consulting)
- designers' subcontractors (and subcontractors' design departments).

Influential Stakeholders

These are all the other stakeholders, or actively involved actors, who need to know something about the design, construction or operation of the infrastructure. They do not use the IM as such but are informed and persuaded through its use.

Major stakeholders

The major stakeholders in this category are:

- economic stakeholders,
- government agencies,
- associations,
- communities
- software publishers,
- professional associations,
- residents.

A3 - Processes to create and manage information

Management and Development Repositories

Several project management and new product development repositories are available in the scientific and professional literature. However, they are **too generic** and **insufficiently detailed** for projects in dispersed collaborative mode.

Particular context: construction

In the specific context of construction companies, the study of collaborative processes involves:

- analysis of the value chain of the activity to determine the potential gains from collaborative tools
- detailed study of working processes, altered by the performance of digital exchanges.

Does working on a digital platform (= project platform with a collaborative IM) make true co-design possible?

Presumably so, because the stakeholders work jointly on the project, as opposed to practicing "distributed design", a weak form of cooperation in which the stakeholders work simultaneously but not jointly.

The question of conflicts (between disciplines) and of the limits of collaborative engineering (dilution of leadership, nature of the results to be obtained and the checks to be performed less clear, exchange of tacit knowledge more difficult, etc.) underlies this.

Rank-ordered processes

The processes can be rank-ordered into **three levels of increasing detail:**

- macro-processes,
- processes,
- discipline-specific sub-processes.

The three levels

Although they may overlap extensively, each is characterized by a preponderant direct stakeholder:

- **design** → Designer's design department;
- **build** → Builder;
- **operate** → Operator.

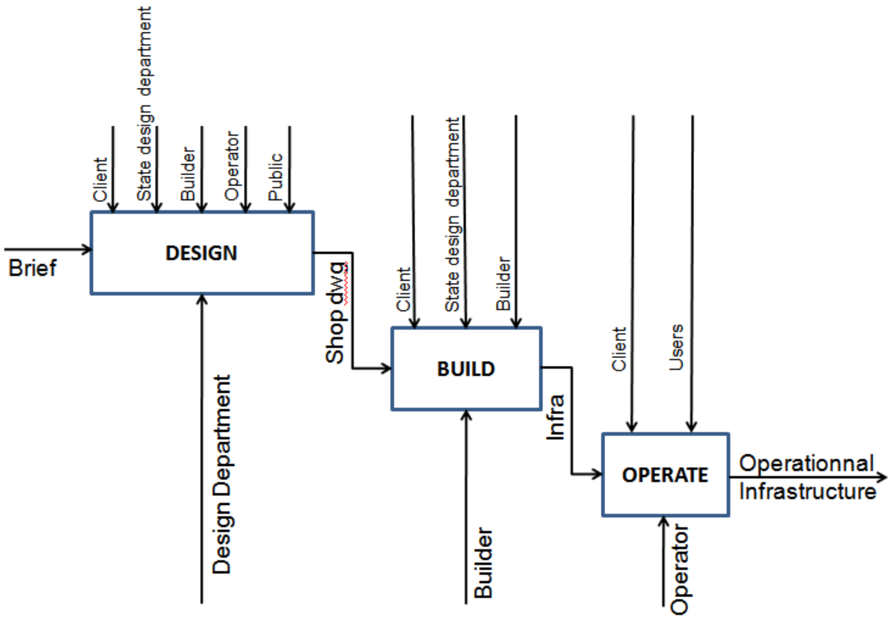

Figure A3 - 1: Global macro-process of an infrastructure project

Breakdown of macro-processes

Each macro-process consists of several processes that complete one another and interact. The introduction of digital tools like the model will tend to **accentuate** the **iterative character** of these processes in the upstream phase (studies).

Note that which process is "master" depends on the type of infrastructure:

Infrastructure	Master process
Road linear	The "study of geometry" process governs the other discipline-specific processes.
Railway	Equipment studies (signage, track, catenaries, etc.) dictate the range of possibilities for the other disciplines.

These master processes can be regarded as:

- **processes,** given their central position;
- **discipline-specific sub-processes**, given their specialized character.

So there is some freedom in structuring the project into processes, and this structuring will have to be decided for each project.

Examples of processes are:

- considering a solution (Figure A3 - 2)
- choosing the reference solution,
- acquiring and releasing the rights-of-way,
- obtaining administrative authorizations,
- preparing the working documents.

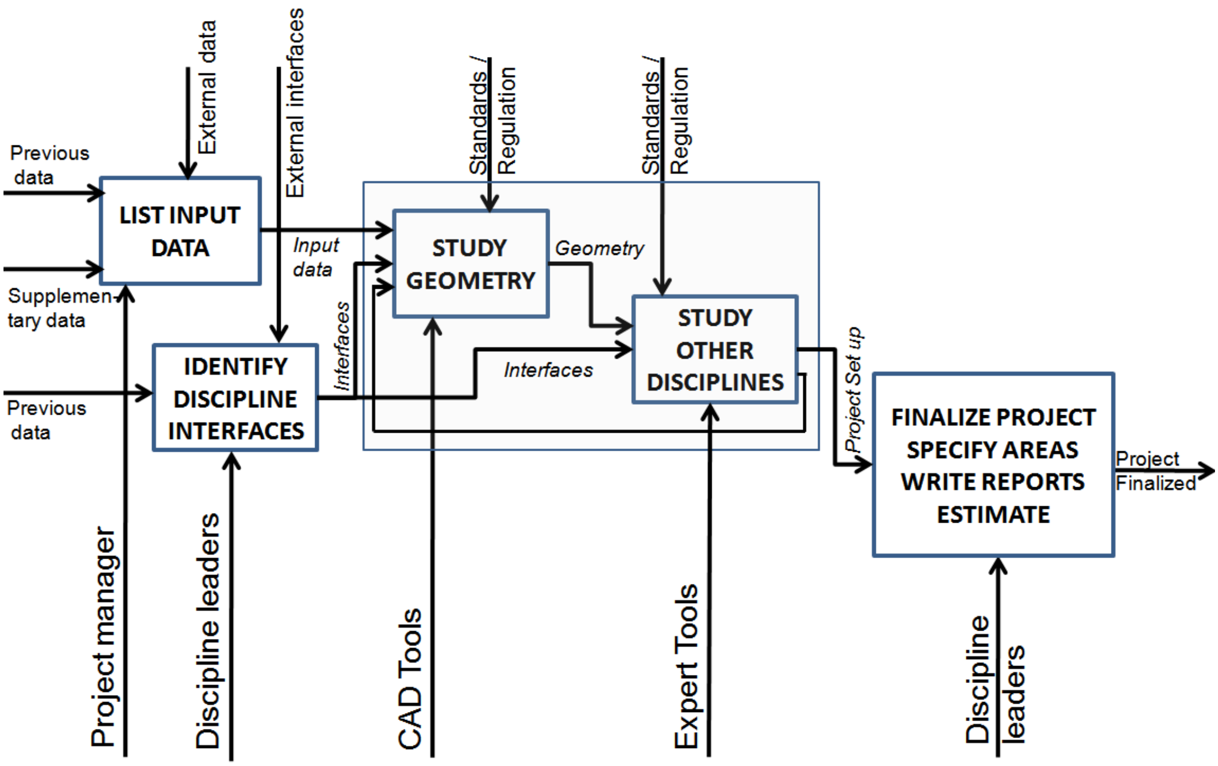

Figure A3 - 2: Example of the "studying a solution" process (within the "design" macro-process)

Discipline-specific sub-processes

Within each process, several disciplines act. These actions are planned by discipline-specific sub-processes that may be, for example, studies of:

- the **geometry** (with the reservation stated above)
- engineering structures (OA)
- hydraulic works (OH)
- **earthworks** (Figure A3 - 3)

When the input data have been set up, these processes are executed rather independently of the other disciplines.

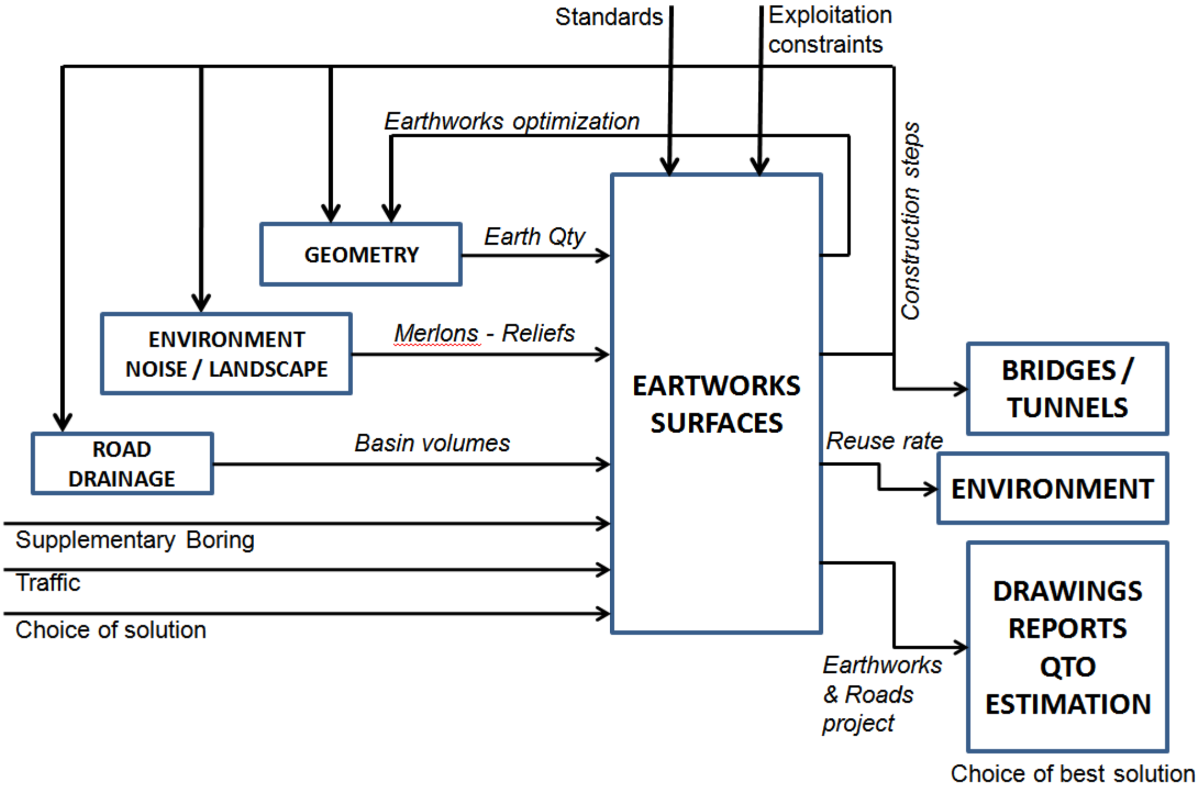

Figure A3 - 3: Earthworks-pavement discipline-specific sub-process within the "considering other disciplines" process

Action by processes on information attached to objects

Reflections on the processes and objects must be compared in order to reveal the action of the various processes on the information in the objects:

Objects are characterized by:

- a **definition** (functional, geometric, discipline-specific)
- **attributes** specific to the object,
- **links** or **rules governing links** with other objects.

Example of information attached to an object

Below are the characteristics of the Type 1 *Pavement* object in a running section of RN138.

Definition	
Discipline	Object of the RN138 that carries vehicular traffic. Pavements are an area of knowledge and know-how.
Geometric	The *Pavement* object is bounded below by the formation level (top of earthworks) and to the sides by the shoulders and drainage. The finished level is determined by the geometry (cross section, vertical alignment, superelevation).

Attributes specific to the object	
Design data (always stored)	Location and definition of volumes (axes, longitudinal profiles, widths, superelevation, etc.). Nature of the pavement courses. Traffic carried. Expected level of service. Characteristics of the formation level. Allowable pavement frost index.
Information stored	Quantities. Estimation frameworks.
Information computable in real time	Costs. Schedules.

Links or rules governing links with other objects	
Geometric	The geometry is linked to the geometry of RN138 (transverse and longitudinal profiles) and to the earthworks (finished grade).
Functional	The pavement structure must: • Bear the expected traffic. • Allow for the characteristics of the subgrade. The allowable frost index must be consistent with: • the expected level of service (need to limit vehicle weights during thaws) • the air frost index. Compliance with standards (concerning adhesion, etc.).
Hydraulic	The pavement geometry must allow water to run off, even during construction.
Environ-mental	Work on roads must comply with environmental commitments.
Execution	Embankments, cuttings and the subgrade must be integrated into the overall earth-moving project (equilibrium of volumes of cut and fill, earth movement, etc.).

The processes must define the information attached to the objects

Based on our analysis, we conclude that the processes are intended to define or modify the information attached to an object or objects. This is an important change, because we used to consider that outputs of processes were drawings, calculation notes, memoranda, bills of quantities, etc.

This change confirms the need for a **central tool** for the storage, management, and visualization of all such information. This is the primary and synthetic function of the IM, the heart of our global model.

The diagram below illustrates an example of how a process:

- retrieves from the IM some information it needs,
- then stores new information in the IM.

Some links, including geometric links, can be **checked** directly by:

- the IM (*clash test* for geometry, check of application of standards)
- discipline-specific simulations.

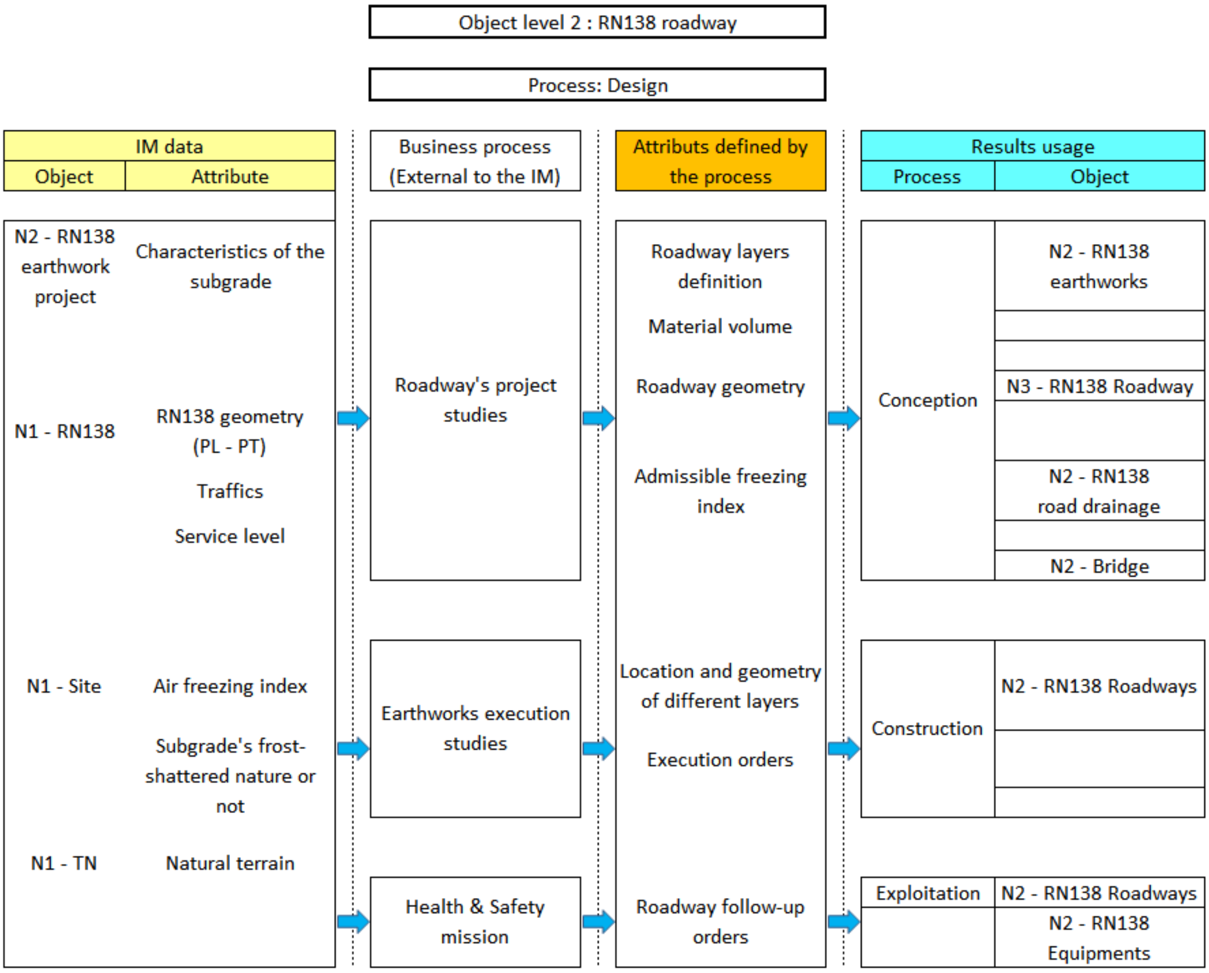

Figure A3 - 4 Example of information processing by processes

Formalization of processes

There are many ways to represent processes. Formalizing processes serves to:

- identify i**nputs** and **outputs** (data exchanged with the IM that the IM must retain; alternatives);
- identify:
  - **links** and **interfaces** between processes (or tasks of the processes);
  - **stakeholders** or groups of stakeholders;
  - **constraints** or **checks** on the execution of the processes;
- include the **time dimension**;
- list the **discipline-specific tools** that must be interfaced with the model (terrain models, design tools, calculation and simulation tools, communication and representation tools, etc.);
- assess, in the longer term, the **value added** by the collaborative work around an IM (making exchanges easy and reliable).

SADT method

The examples presented above are based on the SADT method, with inputs on the left and outputs on the right. The constraints to be observed are listed at the top and the resources to be mobilized at the bottom.

Definitions form

The description of each process can also be supplemented by a form in which the following are defined:

- The **inputs** (and **associated processes**) that determine what information must be found in the model to allow exchanges.
- The **checks** (and external interfaces with other processes) that may be performed by the IM or by specific tools attached to it (check of geometric compatibility, verification of standard).
- **Resources**, meaning both human resources and software. The latter determine the conditions of interoperability with the IM.
- The **outputs** the process must deliver, with the objects concerned and the processes that will use them.

An example of a definition form is presented below. The layout can be tailored to the project.

INPUT DATA

Previous studies
- Before project (adopted solution)
- Client engagement

Others activities issued data

Source activity	Data type
Additional studies requested after the Preliminary Design	Additional surveys

CONTROLS

External control
- Geometric standards (ARP, ICTAAL, ICTAVRU ...)
- Client constrains / owner (type, class of track, abnormal loads ...)
- Road templates
- Traffic
- Networks

Control fullfilled by other activities

Source activity	Data type	Control to do	Impact
Bridges & Tunnels	Slab thickness	Template	Longways profile recovery
Earth moving	Earth volumes	Earth moving balance	Longways profile recovery
Environment	Hearing protection presence (bund...)	Visibility	Cross profile (Side clearance)
Road drainage	Re-establishment	Coverage of Hydro Works	Longways profile recovery
Equipments	Retention	Visibility	Cross profile (Extra width)
Signaling	Signs direction implantation	Respect of distance signaling Panels visibility	Plan geometry recovery

Ressources

Human
- Outline engineer - draftsmen

Softwares
- CAD (Macao, MX, Piste ...)

OUTPUT DATA

General scope
- Plan view
- Longway profile
- Typical cross sections
- Cross section notebook

Targeted

Concerned activity	Data type
Bridges & Tunnels	The most point-binding template Axial elements (plan and LP)
Earth moving	Earth volumes
Environment (noise)	3D models (Project + Natur. Terrain)
Platform drainage	Longway profile's slope, high points, low points. Floor areas and slops
Hydraulic (Natural flow re-establishment)	Hyfro. Works level cut
Equipment (retention)	Plan geometry (internal radius at x meters) Banks heights
Equipment (closing)	Hold (earth entry)
Signaling	Caracteristic points' position (E=1.00m; S=1.50m ...)

Figure A3 - 5: Example of definition form for the "study of geometry" process

B - Creation of value by the IM

Introduction

Contribution of the global model

Before analyzing and organizing the collaborative work based on an IM addressing infrastructure projects, it is important to understand what contribution can be expected from this model.

Initially, expectations often remain focused on a **better understanding** of the project to be implemented and on communication with other stakeholders.

Criteria of analysis

Given the changes necessary, the overall model and the IM must be justified by the **more global gains** we analyze in this chapter.

Our criteria of analysis were:

- What are the **expectations of the direct stakeholders** to which the global model provides a response?
- What **value creation is expected**?
- Can the model help reduce project **costs**?
- Can the IM give the construction sector a **high-tech image**?
- Does the global model give the sector a **competitive advantage** internationally?

These five aspects are discussed in the modules that follow.

What the IM should make possible

The expectations of each actor are the answers to the following questions:

- What **services** does he expect from it?
- What does he want to **find**?
- What **values** could he **contribute** to it (for himself or another player)?
- What **values contributed** by another actor could he take from it?

This is what we have called "Value creation by the IM", which we have clarified in a comment.

For this purpose, it is necessary to identify:

- **Expected uses.** These are all the functions and services a collaborative IM could provide, with their uses and intentions.
- **The value of these uses.** This is an estimate of the importance attached to each use, if possible with the means to assess this value.

For this purpose, we have distinguished the various groups involved in a project, in order to clearly separate their expectations, and also in order to be as complete as possible.

For whom is it a value?

The value expected by the actor in question enables him to **improve his action** vis-à-vis the other stakeholders. We have listed them for each of the values.

The specifications of the IM

Each value is characterized by specifications that the IM must take into account. We have listed them.

Indicators to be defined

Uses and their expected values must be characterized. This characterization makes it possible to judge the **overall quality** of the IM. For this purpose, it is necessary to define:

- one or more quantifiable **performance** indicators.
- the indicators needed to assess the **overall quality of the IM**.

B1 - Inventory of expectations of direct stakeholders

Expectations of all stakeholders

The use of the IM depends on **trust** among stakeholders.

The owner of the IM must be identified

All stakeholders expect clear identification of who the IM belongs to and how their intellectual property and know-how are secured. The following must therefore be stipulated in the specifications:

- the administration of **access rights**,
- the **management** of private and public **data**.

The actual separation between the shared model and the proprietary discipline-specific models will be the performance indicator.

The cost of use determines the entry fee

Before committing to using the IM, the stakeholders must evaluate the direct costs and their breakdown among:

- **setting up**,
- **management**,
- **maintenance**,
- **archiving**.

Stakeholders concerned: direct stakeholders

Among the three major groups of stakeholders listed in module A2, we have worked on the expectations of the various types of direct stakeholder only: designers, builders, operators, and client. These stakeholders create information and, through their know-how, provide added value.

Indirect and influential stakeholders were not taken into account: the study of their uses and values shows that they have little relevance and are often redundant with the tables of those directly involved.

Stakeholder-by-stakeholder tables of expectations

Tables have been established to list the values and uses expected by each direct actor. Considered too large to be included in the text of the deliverable, they are presented in summary form. The complete tables are included in an appendix.

The columns of these tables are presented below.

#	Identification Code
Value and uses	What the collaborative IM makes it possible to do.
Commentary	Amplifies and explains the values and uses.
Vis-à-vis whom?	The value is expected by the stakeholder himself, and sometimes by another stakeholder.
Characterization	The use is reflected in the specifications that follow, criteria of values that must then be quantified.
Performance	Criteria of evaluation of the specifications, performance indicators that are measurable, quantifiable, or can be compared to the values to be reached, critical thresholds, or levels of excellence.

<u>Note:</u> "*client*" refers to the principal in the project.

Use of the results

The results of these tables have in particular made it possible to:

- **Expand**:
  - The structuring of the information.
  - The organization of exchanges.
  - The descriptions of the collaborative processes.
  - The adaptation of responsibilities.
- **Complete** the scenes with demonstrations conducted to clarify the objectives or goals to be attained during the demonstration.

Clients' expectations

We list clients' expectations below.

#	Value and expected uses	Commentary
2.1	**Optimizing the allotment between stakeholders**	Have an overview of the project. Be able to simulate partial projects. Describe the interfaces and links between stakeholders.
2.2	**Be informed**	Monitor project status in terms of: • cost, • progress, • risks • conflicts and disagreements.
2.3	**Control risks**	Identify (organized access to the data). Assess by simulation. Manage and deal with risks by simulation.
2.4	**Follow the schedule** (the project)	View progress by displaying 4D states (delays). Simulate global strategies. Analyze alternatives.
2.5	**Assess the project globally** (impacts)	Have a holistic view. Have syntheses of the impacts that facilitate the consideration of environmental, societal, and economic issues. Accumulate knowledge.
2.6	**Facilitate concertation**	Persuade governments and residents. Popularization.
2.7	**Facilitate approval by the authorities**	Facilitate the examination of the files through a better presentation of the design. Assist in the presentation. View the progress of administrative formalities.
2.8	**Approve the design**	Understand the design better Have a global vision and be able to coordinate. Simulate the consequences of what is to be approved. Be able to validate plans, data, or 3D models. Be able to validate on paper or in digital form. Manage indices: drawing, model, object, attribute. Have a record of the history.
2.9	**Receive the structure**	Obtain as-built documents rapidly Manage and trace reservations. Manage finishing operations. Reveal differences between Model and Reality
2. 10	**Communicate**	Impact of construction on the existing situation (closures, diversions, etc.).
2. 11	**Sell the structure to the operator**	Deliver the "*As built*" rapidly (it becomes the existing situation). Be able to perform simulations of use and operation early. Deliver the history and the parts lists of equipment. Promote early appropriation.
2. 12	**Manage assets**	Have a structured archive of historical and contractual information. Organize effective warranty follow-up.

Designers' expectations

We list below the designers' expectations.

#	Value and expected uses	Commentary
3.1	**Structure and facilitate the collection of external data**	Have checklists of the necessary data.
3.2	**Have relevant data and constraints, easy to retrieve and consult**	Have access top data that are ordered, explained, and updated at a frequency to be determined. Know the levels of validity of the data. Understand the tolerances. Be informed of gaps and therefore of completeness.
3.3	**Control the interfaces**	Be informed of geometric inconsistencies. Have access to the links between objects, between processes, and between stakeholders.
3.4	**Better understand the constraints of other fields and other stakeholders**	Have explicit representations of the phenomena and therefore better understand the other specialties (other fields) or other stakeholders (builders, operator). Better understand the context.
3.5	**Encourage variants for optimization**	Find ways of optimizing through the view, albeit virtual, of the structure. Encourage a critical approach through access to the data, constraints, tolerances, and updates.
3.6	**From the start, simulate the downstream phases (construction, operation, or maintenance)**	Ensure the feasibility of the design, Verify the possibility of operating the structure. Use the structuring of the objects (data model), from the start, to represent the project as a whole.
	Facilitate specialized simulations	Use the IM to perform and view specialized simulations (direct extraction without re-keying). Represent the results explicitly.
3.8	**Make comprehensive assessments**	Conduct assessments of sustainable development through the availability of consistent data from all fields. Benefit from the structuring of the objects (and data) to assign quantitative attributes or qualifiers to construction processes or operations at any time.
3.9	**Provide data to other stakeholders in design and construction**	Provide explicit results to the other designers. Enhance the design (both a constraint and a value). Deliver the relevant, up-to-date information the various stakeholders need. Share data and results, but not the design (know-how).
3.10	**Facilitate reporting**	Through an explicit vision of the structure, make it possible to share the design with the customer (assumed to be a non-specialist). Make it easier to inform the client (or other decision makers) of the progress of the project (extracting relevant data). Better manage risks and changes in them during the project.
3.11	**Accelerate decision-making**	Provide an overview of the work with consistent data. Answer questions through simulations without waiting for the next files. Have information concentrated in one place and therefore easy to access. Quickly and easily consolidate the data needed for decision making.
3.12	**Facilitate tendering**	Share the design with stakeholders, even non-specialists (explicit vision). Facilitate the monitoring of commitments (by the State). Use up-to-date data in the appropriate formats.
3.13	**Communicate**	Get the public to understand the design (explicit vision).

Builders' expectations

We list below the builders' expectations.

#	Value and expected uses	Commentary
4.1	**Have a complete model** (not just the geometry) **consistent with the program and regulations**	Starting from the object to be built, modelled by the designer: • break down into tasks (planning); • define the necessary resources and facilities; • calculate costs; • optimize tools, the procurement of materials, movements of vehicles; • optimize the schedule according to progress and contingencies; • take construction-related environmental concerns into account.
4.2	**Design construction methods** (vision of the methods manager)	Steer the schedule (discussed above). Handle the points of detail of the tasks. Identify constraints on the object to be built, concerning the tools and their use: inserts, moving and fastening tools, stop joints, 3D reinforcement details, work areas, site facilities, security, evacuation, ergonomics etc.
4.3	**Manage backup plans**	Anticipate contingencies as early as possible. Prepare backup solutions (protective action). Prepare workarounds (repair action). Propose alternatives (for decision making).
4.4	**Manage and verify the availability of the land**	View availability in real time. Simulate for an availability date consistent with the work schedule. Release land used during construction.
4.5	**Make the data reliable**	The IM highlights gaps and thereby ensures completeness. Synchronize data at a specified rate (demand synchronization). Avoid errors in modelling. Ensure that the tolerances are intelligible and defined.
4.6	**Access changes**	Ensure the availability of approved up-to-date information at the beginning of implementation (we can only build what has been approved, we are interested in the object to be built and not the document). Have a graph of the development of Design and Methods documents, with the approvals routing perfectly defined. Track the status of documents. Communicate all information before building (resources and means).
4.7	**Trigger ideas**	Better understand the object to be built and the phasing of construction. Share the same vision early to facilitate its appropriation and optimize its execution. More readily appropriate the final object and better understand the purpose of the object to be built, in order to optimize the required level of quality.
4.8	**Help with decision-making**	Be able to view a summary of simulation in the IM → single, more intelligible vision (no expert interpretation).
4.9	**Share and exchange data**	Provide data to the other stakeholders. Have a neutral exchange format to avoid re-keying in the context of tools and systems that are different and not interoperable. Ensure the absence of loss of data exchanged and ensure accuracy (or acceptable tolerances), thanks to the quality of the exchange model
4.10	**Control risks**	Identify, assess, and prioritize risks: costs, availability of land, availability of materials, availability of resources, quality of the model, accuracy of data, geotechnics (reusability of courses, quality of topographic surveys, etc.), weather and environmental contingencies, approvals and authorizations, supplies, availability of equipment, materials, personnel, etc.

Operators' expectations

We list operators' expectations below.

#	Values and expected uses	Commentary
5.1	**Participate in design**	Stimulate and trigger ideas. Establish the program or check its operation. Assess the cost of the operating program.
5.2	**Access changes**	During the project, track changes in the project and interact with the client / principal contractor to adapt it. Manage operation during the construction phase.
5.3	**Working with up-to-date, non-redundant data**	Establish the operator's program vis-à-vis the designer and adaptation as required by changes in the project.
5.4	**Approve the design**	Verify compliance with the operating program.
5.5	**Anticipate receiving, getting started, and training**	Simulate on equipment and structure. Appropriate the structure Train operating personnel before commissioning (simulator). Help draft specific operating procedures and simulate crisis management.
5.6	**Receive a useful as-built file (including advisories for future maintenance, updated history)**	Order the data: cull the data to shrink the initial base. Update the structures, as built. Archive the data and facilitate access.
5.7	**Chart the life of the structure and maintain it**	Manage the existing assets. Track the warranties of the structure. Have an updated statement of the condition of the network. Prepare the maintenance schedule and optimize it based on scenarios.
5.8	**Share and exchange structured data**	Order the data and facilitate access to them. Retrieve existing structures (managed by other tools, for example) so as to manage the network from a single application.
5.9	**Communicate**	View the condition of the network.
5.10	**Help with decision-making**	Manage crisis situations by generating scenarios for the infrastructure and its environment. Simulate.
5.11	**Geolocate information and consult it on site**	Visualize and locate: • limits of the rights-of-way • interventions. Locate them on the network. Know the infrastructure in detail and access data from the network.
5.12	**Design and optimize future developments**	Simulate (see 4.2 Designers). Provide data to future designers to develop projects (repairs, alterations, etc.). The IM is updated in return.
5.13	**Manage changes during the operating phase**	Define the data model and suitable resources.

B2 - Summary of expected value creation

The IM allows collaborative work

Collaborative work is based on trust.

Building trust

Confidence in the use of the IM is both a necessity for its use and a tool for expanding collaborative work. It is based on:

- the **reliability** of updates of the information it contains,
- **management** of the confidentiality and ownership of private information,
- the **security** and **perenniality** of access to the information,
- the **quality, relevance,** and **user-friendliness** of its functions
- **generalization** of its use to all stakeholders.

Using the IM builds the confidence needed for collaborative work because it can:

- convince each actor of the value of **sharing** information and thereby **optimizing** its own added value
- demonstrate that optimization of the project generates **global gains** that are ultimately shared by all stakeholders.

Four powerful messages

Four key messages emerge from the analysis of these tables:

- Help structure the project.
- See to better understand the project.
- Optimize the project.
- Prepare for the future.

A summary of each of the points is presented below. They are then amplified.

Help structure the project

By providing a tool to help structure the project, the introduction of the IM should lead to:

- Structuring**:**
  - the **project** into sections, lots, objects, systems, etc. ;
  - **information** on the project, making it accessible and reliable.
- Specifying the **roles**, responsibilities, and rights of the stakeholders.
- Managing **successive modifications** to maintain the reliability of the available information.

See to better understand the project

The IM should make it possible to see and therefore to better understand:

- the project,
- the objects that make it up,
- the information it carries,
- phenomena related to the project,

and so have:

- a **global vision** of the whole project, but also each of its components,
- a **better understanding** of the project by all stakeholders (direct, indirect, even influential)
- easier and more efficient **communication** and **concertation.**

Optimizing the project

When a tool to optimize the project in terms of quality, costs, and completion times is available, the following features are expected to contribute to that optimization:

- **Decompartmentalization** between stakeholders through a global approach to the project.
- Enhanced **creativity** of the stakeholders.
- **Ease** and **speed** of the decision circuits through the building of trust between the stakeholders and early resolution of *clashes*.
- **Simulation** of the phenomena and of construction,
- **Evaluation** of project impacts, in particular those contributing to sustainable development.
- Better **risk control** thanks to early analyses made possible by evaluations and simulations, either focused or global.

Prepare for the future

To prepare for the future, the IM should lead to:

- **Archiving** information about the project, in standard formats to ensure that it will be available for as long as necessary.
- Automatically provide the **instruction manuals** necessary for operation.
- **Accumulate knowledge** for the execution of similar projects, by recording the organizations, processes and information related to the project.
- Build more comprehensive models to manage **assets** and facilitate access to location-based information for development and the steering of future projects.

The IM, a structuring tool

The establishment of an IM calls for analyzing the project in detail and defining its components and the rules that govern them.

At the very least, decisions must be made concerning:

- the **objects** that make up the structure to be built,
- the **stakeholders** who will act,
- the **information** we want to store and share
- **processes** to manage the evolution of all these components.

Breaking the project down into objects

For the objects that make up the structure, the sections, levels, and systems must be defined, all while integrating the expected functions, the disciplines involved, the levels of detail and accuracy.

This structuring of the project into objects is described in module C1 below.

Define the profile of each actor

The profiles of the stakeholders must be defined.
Note: The structuring of stakeholders was described in module A2.

Theme	Profile
Category	Direct Indirect Influential
Role	Discipline Field of action
Characteristics	Duties Responsibilities Rights

Define the data model

For the information, a veritable model based on the structuring of the data into objects must be defined. This structuring ensures consistency among the disciplines working on the project or on one of its component objects.

For each item of information, you must:

- **Locate** it in the database.
- Know whether it is **public** or **private**.
- Know who **owns** it.
- Know its **approval level** (shareable, criticized, frozen).

Define management rules for the IM

By nature, the IM evolves continuously with the project. Managing changes and alternatives is a major task in managing a project to introduce collaborative work. These **developments** require:

- precise **rules** for the functioning and use of the IM;
- a shared, standardized **language**;
- **confidence** in the IM and in the stakeholders.

In short, prepare the project

We see then that the implementation of an IM requires careful preparation of the steering of a project.

Future tools for introducing an IM will therefore assist this preparation. The experience of other sectors shows that this preparation also justifies having all stakeholders **work together**. A dedicated physical design cell is desirable; it can last a year on a big project.

The structure proposed for these elements is described in Chapters C, D and E below.

The IM, a visualization tool

Historically, the need to represent a project resulted in the production of physical mock-ups, made of wood or polystyrene.

For fifteen years, infrastructure projects have used virtual models. These were easier to use for communication and concertation. The virtual model, with more or less realistic rendering, could be explored in real time.

The IM proposed allows such use. It is not a simple representation of the finished structure, since it is the **design medium** and contains the 3D objects of which the design is made up.

To see everything...

The IM can be used to visualize:

- the **project** as a whole;
- a **component object**, in isolation or in its environment;
- **information** characterizing an object, a group of objects, or the project as a whole;
- numerical **simulations** of certain **phenomena** or **processes** (eg of construction);
- the **result** of assessments of certain economic or environmental impacts (in the context of sustainable development for example).

It allows all stakeholders to **browse** within the project, to visit it virtually, to know it better and, most important of all, to understand it better.

... and better understand

Each discipline manipulates objects that it used to represent by drawings, diagrams, symbols, and conventions. These do not allow stakeholders from outside the discipline to translate them into forms they understand.

The **3D vision** of the objects eliminates this obstacle. The object becomes concrete, even if its representation is virtual.

Moreover, the actors do not all want to see the same thing in the IM. They are interested in their own disciplines or concerns. The IM allows visualizations tailored to the subject: **highlight a particular problem in the overall context of project; that is what is at stake.**

The IM is thus a valuable tool for:

- Communicating externally, in particular for concertation and approvals.
- Facilitating and accelerating the identification of and response to the data and constraints of the project and of the other stakeholders, saving time.
- Avoiding misinterpretation of the needs and constraints, obviating subsequent reworking or unnecessary tasks.
- Generating new ideas (optimization) using as springboard constraints that are better understood and so easier to work around.

The IM as optimizing aid

The optimization of a project involves several steps. The IM is a valuable tool for each of them.

Step	Action	Contribution of the IM
1	Analyze the project	The IM allows rapid **evaluations** of the project through the sharing of structured and reliable information. These evaluations and **simulations of contingencies** identify the real stakes and risks. Furthermore, this analysis **can be shared** among the stakeholders.
2	Identify areas for improvement	The IM leads to **better knowledge and understanding** of the project. It is a major asset that encourages the **creativity** of the stakeholders and helps them imagine alternatives to the initial solutions. This is because an overall vision of the project leads to a better understanding of the impact of ones proposals on the rest of the project. All of the stakeholders can propose improvements to the overall project when **group work** replaces compartmentalization into specialized parallel designs.
3	Assess areas for improvement	The IM allows the necessary assessment of alternative solutions. This **multi-criteria evaluation** is facilitated by information sharing, the ability to create simulations, and the mobilization of all stakeholders. Even though the expertise of specialists is still necessary for this evaluation,, their mobilization is **faster** and more **effective,** because it is easier for them to understand the context of the project.
4	Make change decisions	The IM helps decision makers understand the stakes, understand the proposed solutions, and assess risks. Decisions are made faster and **costs** and **lead times** are **reduced**.
5	Manage changes	The IM is a **rigorous** and **rapid** Change Management tool to: • quickly **resolve** the ***clashes*** caused by change • **avoid additional design costs** due to late changes.
6	Store compared solutions	The IM makes it possible to: • Manage the solutions studied while they are being analyzed. • Archive these solutions to keep them in memory.

The IM, an archiving and knowledge accumulation tool

Preserving information about a project has always been a difficult exercise. There are many reasons for this, among them:

- **poor circulation** of information during the project;
- **delayed** collection of **information** when the project ends;
- **retention of information** by stakeholders (sharing limited to just what is required by the contract);
- information in **non-standardized formats**;
- **impermanence** of the storage, reading, and processing media.

All of these causes disappear with the use of a shared IM and the collaborative work it allows, if common standards are adopted.

A structured information base...

Upon project completion, the client has a database containing information that is structured, complete, and intelligible to all actors destined to intervene during the operation of the facility, or even its dismantling.

The **instruction manuals** are part of the information given to the operator.

... available to the operators, to manage the structure, ...

The operator then uses this IM to **store** information about the operation of the structure. So complete information on the life of the structure is on hand, for use for maintenance and major repairs.

... available to the stakeholders for knowledge accumulation ...

At the end of the operation, each actor in the project who uses the IM has all the feedback likely to be useful in the context of similar operations in the future. The accumulated knowledge concerns both the organizations fielded and the methods used.

All of the shared data of the project is made available in this way.

... available to the client to manage its assets

The client manages its assets more effectively. Indeed, the formation of asset IMs has been growing for several years, and it is likely that this tool will become more common in years to come.

The **standardization of formats** makes it possible to incorporate the new project in the client's global assets IM, which, thus updated, enables it to:

- manage its assets
- provide an updated database to stakeholders in future projects.

B3 - Impacts on exchanges and project costs

Intensity of exchanges

It is obvious that the use of a collaborative IM has a strong impact on exchanges of information between project partners.

In a **traditional sequential working method**, exchanges are mainly in the form of emails, letters, minutes of meetings and transfers of drawings, associated with document routing slips.

The use of a collaborative IM is based on **real-time pooling** of data on a shared work platform. This modifies exchanges of information, in terms of their number and more especially their distribution over the life of the project.

Four phases

To compare these two working methods, we identified four main phases in the life of a project:

Phase	Duration	Features
Preliminary design (AP)	4 periods	This starts for example at the beginning of a concession or a PPP and ends with the approval of the preliminary design. It includes external concertation.
Detail design (PEX)	3 periods	This is the detailed preliminary design phase (PRO stage of the MOP law), with the preparation of tendering documents and calls for tender.
Work (TX)	10 periods	This begins with the work order and ends at commissioning.
Operation (EX)	3 periods	This covers the start of operation, with in particular finishing work.

Their durations are made up of "periods" on a variable scale. This allows reasoning in terms of the same total duration of 20 periods. Depending on the project, a period can vary in practice between 2 and 3 months.

These values place the duration of the project between 40 and 60 months, which agrees with the current range for infrastructure projects, except for very special projects.

Five groups of major stakeholders

Similarly, to simplify the analysis, we use five major stakeholder groups:

- Client (MOA)
- designers,
- builders,
- operator
- influentials, including governments, communities, other clients, local residents, associations.

Comparing the traditional and collaborative modes

The **intensity** of exchanges has been evaluated in **relative** terms, in which the unit has no special meaning. The factors that can justify this evaluation are the number of meetings, drawings, notes, letters, files exchanged, etc.
Each partner in the COMMUNIC project therefore evaluated the number of exchanges currently made in a traditional project and **estimated the impact** of using an IM on work in a collaborative mode.

The curves below (figures B3-1 and B3-2) evaluate the intensity of exchanges over time.

We considered exchanges with a **constant scope**, meaning that the new way of working with the use of an IM does not generate more exchanges than the traditional mode. This assumption is false, since the addition of such a tool will generate more requests and optimizations, and so more exchanges between the partners. But including an additional parameter, the increase in exchanges, would make it impossible to compare the curves obtained.

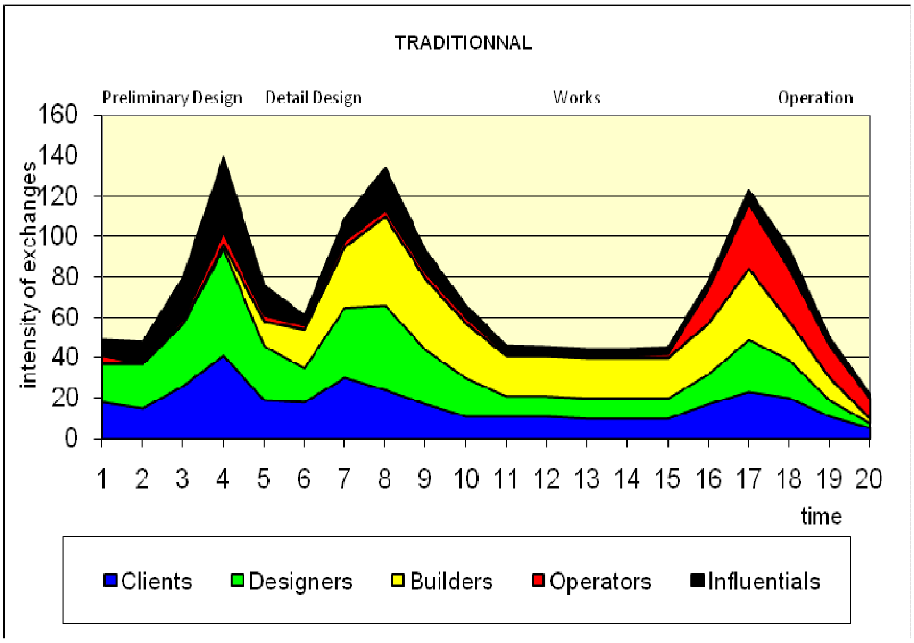

Figure B3-1: Distribution of intensity of exchanges over time in the traditional working mode

We note three main peaks:

Main peak	Features
End of preliminary design / beginning of detail design	The partners involved must work together to finalize the preliminary specifications in accordance with the needs expressed by the client. The selected design departments must understand and take into account the specifications of the preliminary design phase.
End of detail design / start of work	The partners involved must coordinate their actions to obtain a coherent project. The calls for tender necessary for the selection of construction companies to perform the work must be issued. The builder will produce the detail documents for each structure and refine the methods of performing the work.
End of work / start of operation	The builder must produce the as-built file. The operator must understand and take over operation of the project.

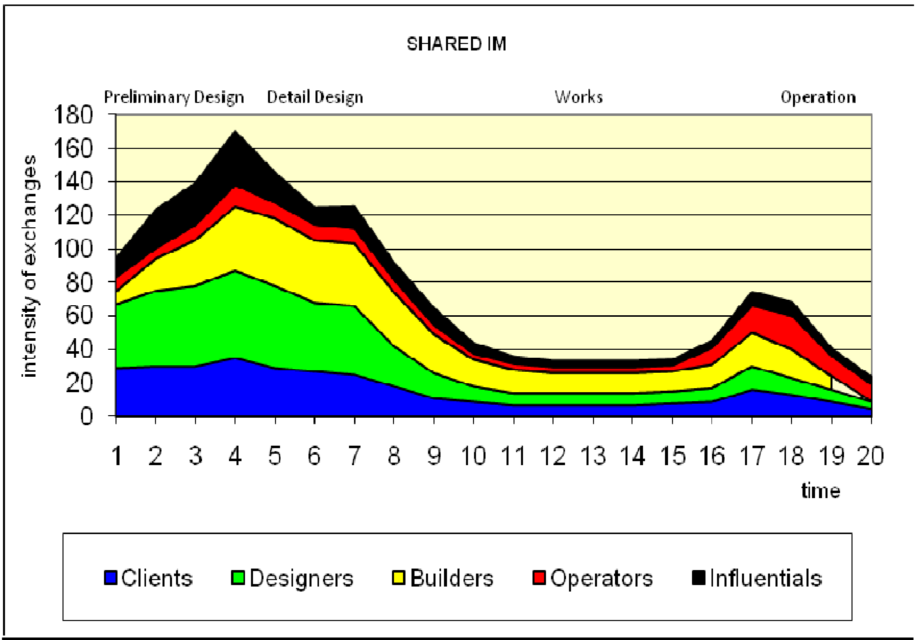

Figure B3-2: Distribution of intensity of exchanges over time in collaborative mode using a shared IM

The 3 distinct peaks on the previous page have given way to a much higher concentration of exchanges towards the beginning of the project.

The exchanges take place **earlier** and are **more intense** thanks to the presence of all stakeholders upstream in the preliminary phases of the project.

The design phase is therefore **denser** and **more collaborative** through better integration of the development, execution, and operating teams.

The phase of taking over by the operator is **more flexible** and **less controversial** thanks to regular updating of the as-built data, consistent with the design data,

The **data** are **up-to-date** in the IM and are not questioned.

Conclusion: changes are foreseen

Exchanges between the stakeholders can resolve *clashes* and so decide on the changes that advance the design and its validity. This advancement can be called the project **maturity level.** Collaborative work makes it possible to reach a given maturity level earlier. As a result, we know the **project cost** with a given accuracy earlier.

Making changes to the project earlier means that they cost less and **reduces the final cost.**[1]

Impacts on project costs (expected reductions and increases) are spelled out in the paragraphs that follow.

[1] In IT projects, a rule of thumb, the "1/10/100/1000" rule, supports this assertion. This rule states that a change that costs 1 in the overall design phase costs 10 in the detail design phase, 100 in the development phase, and 1,000 in the maintenance (operating) phase.

Lower project costs

The potential savings are numerous and make it possible to consider the adoption of the IM and of collaborative work in the near future.

Optimizing the project design

The IM allows better optimization of projects, thereby reducing their costs. This is because:

- Alternatives are **easier to analyze**, through better evaluations and simulations.
- Project sharing between all stakeholders permits **better use** of the ideas of others and integration of their constraints.
- Concurrent engineering makes it possible to integrate the know-how of the builders in the design to find **the most economical solutions**.
- The **full lifecycle** of the structure is taken into account in the design.
- **Simulations and evaluations** can be **global**.
- Principals visualize the cost of the services requested and so can **limit themselves to their actual needs**.

Lower design cost

The cost of studies is reduced because the rekeying of data is avoided.

In addition, the project is better understood by the designers. This serves to limit the studies to **just the quality** really needed.

There is however a risk that requests for consideration of alternatives will proliferate on the pretext that they are less expensive. This risk must be dealt with by project management.

Early design

The **better understanding** of the project by all stakeholders and their **early participation** make it possible to:

- share the design earlier,
- reduce the number of changes, which always entail cost overruns.

In all cases, those changes that are not avoided are made earlier thanks to concurrent engineering. Since the earlier a change, the less it costs, there is bound to be a **cost saving**.

Optimization of the work

Some contingencies of the work can be studied and simulated by the builders before they start the work. They are better controlled and generate **lower extra costs**.

The methods of execution are considered from the design phase and can be optimized with respect to both costs and completion times.

The organization of the sites and the management of their interfaces are prepared and managed and therefore optimized by the IM.

Preparing the site in advance helps optimize procurement because **competitive tendering** is prepared better and earlier and executed more calmly. This has an impact on costs and completion times.

Shorter completion times and on-time performance

In some phases, shorter completion times are not necessarily considered. On the other hand, completion is more often on time because of **better control** of **risks** and **contingencies**.

Reducing the completion times of a project can:

- **reduce** the stakeholders' **fixed costs** of mobilization.
- allow earlier commissioning, and in some cases revenue collection.

The various costs comprise personnel and equipment costs that are proportional to time and the costs of materials, which depend on the quantities. Shortening the completion times of design and construction tasks reduces the costs of the first two items.

Better management of customer needs

Customer needs are better:

- understood, earlier, through the IM and concurrent engineering.
- justified, because the client can judge the consequences for himself.

These two factors help eliminate work that is unnecessary - either unjustified or simply not requested.

Optimization of project management

Globalization through a **design / build partnership** simplifies the steering of the project and leads to savings.

Risk reduction

The IM makes it possible to carry out more s**imulations** and **global assessments** and to do so earlier. Decisions are better because the ins and outs are better known. The risks are better controlled and costs are reduced.

Costs generated by collaborative work and the IM

Using a collaborative IM may also lead to additional costs. These must be known and understood before this new way of working is generalized.

For the project

There is a risk of increasing **the volume of studies** because more optimization alternatives are desired.

Management of the IM is a **new task** to be budgeted.

The skills of the stakeholders must be upgraded to new technologies and new methods. These **adaptations** have **costs**, at least initially.

Indirect stakeholders with the necessary skills are **fewer** and there is **less** competition among them, at least initially.

The computing **infrastructure** assigned to the project must be **strengthened**.

Earlier interventions by the downstream stakeholders limits competition somewhat and may lead to **higher costs**.

For the company

Companies must acquire **new collaborative software** (the IM).

New employees must be **recruited** (management of the IM).

Training must be provided so that employees know how to use the collaborative software and work with new collaborative methods (sometimes a change of culture).

The existing **software packages** must be **adapted** to make them interoperable.

The **computer systems** must be **completed**. Their **management** must be **adapted** to multiple projects in different partnerships.

For the sector

The sector of activity must:

- **invest** in the development of standards allowing interoperability.
- acquire one or **more** IM **software packages**.
- **accompany the adaptation** of existing software packages to make them interoperable.

B4 – A *Hi Tech* image for public works

The IM, a tool of economic competition

In the most usual sense of the term, economic competition is first of all **within sectors.** For example:

- Renault and Peugeot for cars.
- Google and Microsoft in computing.
- Sanofi-Aventis and GlaxoSmithKline (GSK) in pharmaceuticals.

The competition is fierce and undeniable.

In spheres of influence....

However, there is also competition **between sectors**, at the level of spheres of influence, less visible to the general public.

Public policies are being redefined from top to bottom, caught in a squeeze between the rising costs of new developments and the drying up of financial resources.

This makes it of **strategic** importance for each sector to **position** itself with respect to political **governance** and the public and so enable itself to assert its legitimate demands to be helped by provisions in its favor, for example, policies concerning jobs, exports, training, and, even more important, innovation.

We approach this issue below on three levels: Europe, France, and local operations.

... both European ...

A first example is that of Europe.

The 4th Framework Programme for research and development has seen research programs for construction experience some success. The fifth has turned away from them, with as corollary a **steep decline in aid.**

Themes specific to construction were overwhelmed by very general concerns. This situation changed only after the creation of a **European Construction Technological Platform** (ECTP), which managed to bring together all the professional sensibilities of the sector:

- construction companies,
- research centers,
- SME
- suppliers,
- architects,
- engineers,
- inspection organizations,
- clients,
- principal contractors.

The industry has been able to initiate vigorous **technical lobbying** and **a pooling of the thinking** of all stakeholders on the issues and challenges.

The ECTP has argued that construction has a **legitimate place** in **Research and Innovation** and has had specific themes opened and set aside for it.

The situation of the sector is much improved in the 6th and 7th Framework Programmes, with a *Joint Technical Initiative* for *Energy Efficient Buildings*.

... and French, ...

A second example is that of programs supporting innovation in France.

One important feature of the French research and innovation system is **competitiveness clusters.** These combine public and private research and are supported by the Interministerial Fund.

Of the 71 existing clusters, only the **Advancity** cluster covers **all finalized construction themes**. After four and a half years in existence, it progresses with determination, despite a very undifferentiated and competitive industrial environment.

The fields covered by construction, for all human and economic activities, are those of:

- the **living environment**,
- **mobility**,
- **work**.

Construction has **enormous leverage** on all of these activities in this age marked by the challenges of climate change and sustainable development. The sector as a whole is supported in France by only a single pole. This is not commensurate with the stakes.

... and in day-to-day operations

While **economic tension** is noticeable when policies are being developed, it is also found in the **reconstruction of value chains** between the stakeholders themselves, whether traditional or newcomers.

The technological fields of CAD and CAD/M, knowledge management, and product lifecycles have long been driven by the major manufacturing industries (eg automotive, aviation, machinery). These sectors have developed the corresponding tools, mostly software packages.

The construction field has been a **weak engine** in these developments. However, some publishers have been able, over time, to reach strong **leadership** positions, for example Autodesk and Nemetschek[2]. Twenty five to thirty years ago, a few French construction companies took an interest in this. They suffered many setbacks because of the **immaturity** of the software techniques and of the hardware.

There are, to be sure, digital tools throughout these companies. But they are **not coordinated** around a global model that would enable these tools to create value. In addition, leading software publishers and / or content, data, and knowledge processing service companies have an avowed **strategy** with respect to the construction sector. They are attempting to capture value creation:

- on behalf of **new stakeholders** in a dematerialized economy,
- at the expense of the **traditional stakeholders** in services, construction and engineering.

We will see emerge in coming years **service platforms** whose operators will be able to capture a large share of value creation. They will cover the areas of building, urban and interurban transport, collective or otherwise, urban development, etc.

The COMMUNIC research project, with its goal of **developing a model** around the IM, goes to the heart of this problem.

[2] Publishers of AllPlan and AutoCAD, respectively.

Construction must be an actor in the inevitable, but desired, change

Construction must prepare for this revolution because:

- The **technologies** for it are now **mature**.
- Lifecycle-related **requirements** are greatest in a construction industry that works to serve several generations. They induce a strong requirement of long-term interoperability. Construction will benefit greatly from the creation of digital assets that will be so many memories for future construction and renovation operations.
- The **industrialization of** construction is based on processes, on intangibles, on knowledge. Its products must be **constantly adapted** to specific contexts.
  If any industry is essentially knowledge-based, it is the construction industry, which is international only because it exports its know-how, not its products!

The construction industry must make the **IM the focus** of its lines of action:

- This is for it a s**trategic positioning** in the competition with the other sectors of industry. Without it, they will call its economic model into question.
- Its strength is **knowing how to manage** complex and highly technical processes.
- It alone can **control the** concrete **execution** and the **knowledge**. To hold its rank, it need only turn the digital threat into an opportunity. This presupposes a very high level of mastery of digital tools in order to be able to guide their adaptation to its specific needs.

The IM, a tool to attract talent

The technological image of a sector is a very important factor on attracting and **holding** talent. **Pride** in using and mastering modern design and production methods and tools complements **motivation** by levels of remuneration.

From this point of view, the construction sector does not have this high-tech image. It expects the COMMUNIC research project to change this picture by **developing concurrent engineering** through the use of the IM.

Attracting the best from training organizations

It is no secret that the best from our engineering schools are **turning away from the traditional disciplines** of construction. They are going into careers in finance, or in fields with very modern and progressive images, such as the Internet, space, software, and telecommunications.

For example, successive classes at the Ecole des Ponts are increasingly deserting technology and construction. Only 34% of the 2007 graduates have chosen careers in construction, the environment and transport, research, engineering, and communities.

This trend must be **reversed**.

Spread talents over all the entities of a company and of the sector

The present and future competition mentioned above calls for a strong move into the fields of high technology in order to **attract the best talent** and incorporate it in both research and operational teams.

The knowledge society can indeed find expression only if it is embodied in **brilliant professionals** in construction companies and engineering firms.

The world of CAD, CAD/M, and the IM is a **highly technological world**. It is in constant motion and evolution, driven by large research teams like those of the major laboratories of the INRIA or of the CEA's LIST. Bringing it into companies has the advantage of directly confronting the real world - that of the construction site - and the virtual world.

None of the new entrants can give these professionals as exciting an occupational context. This is an unbeatable asset for those involved in construction.

Trust the younger generations

This **virtual world** is a world very **familiar** to the younger generations. They know more and more about how to handle it. Games, networks, information search processes, and communication tools have made these young people at ease in the virtual world and led them to **share their knowledge** in communities.

They are the **bearers of change.** And so they are attracted to sectors in which they find in the office facilities at least equal to those they have at home.

Promote the sector by communicating about projects

The sector is fortunate to have to communicate with a **wide audience** about projects (public works). Its image is built up through these contacts.

For example, public enquiries give the public a chance to build the works presented "with their own hands". They are an opportunity for the public to grasp:

- the very **modern** character of the sector,
- the "heady" side of a business active in the major works that shape the landscape.

The IM, a tool for "coopetition" within a sector

We now take closer look at construction projects, such as infrastructure development projects. They are always complex operations - adventures we might say - involving many stakeholders.

Competing stakeholders together on a project

The participants in a project are often temporary partners. They do not usually work together, but compete with one another.

Blending competition and cooperation

This competition within a sector is neither pure competition nor permanent cooperation, but a hybrid of the two extremes, competition and cooperation: "coopetition"[3] .

The stakeholders can adopt this attitude because the object to be built is a ready-made "beacon". They can **see themselves** in this beacon, **project** themselves into it, and make it their common or shared **horizon**.

The IM is an innovative opportunity

To address this systemic complexity, the use of a shared IM is the only real solution. Organizations and individuals are so many dimensions interacting in this complexity. They can both play along and compete.

The IM is a **special link between the real and the virtual**.

- It “**models"**, virtually and in advance, both the expected structure and its operation.
- It is an object that is easy to **identify** and can be totally **externalized** in a neutral place for all stakeholders.
- It is both consistent with reality (or at least keeps growing more so) and a **representation** of this reality **ahead of time**.
- It contributes to the **appropriation of the real object,** if properly managed. All stakeholders can appropriate it. Over time, it is the unique and clearly visible receptacle of all work and all individual contributions.

The IM is therefore an **opportunity,** totally innovative compared to design work done using a multiplicity of 2D drawings on paper.

It allows an eminently **participatory approach** between stakeholders. It respects the innovations of **Web 2.0** and the societal changes that accompany it.

The IM, a tool for participation and societal dialogue

Any urban development, any infrastructure, any building makes a **lasting mark on the environment,** shapes it. This environment concerns not only the client but also, and immediately, the neighbor, the townsman, the traveller, the local or national citizen, the general public.

The IM, a tool for societal dialogue

This dialogue has always been **codified** and **organized.** It is increasingly requested, even demanded, by citizens, and is sometimes co-opted by certain lobby groups.

The availability of an objective basis is always the key to an open, calm public debate. The decisions taken are not necessarily optimal, for each party has its own optimum. But they must be understood and accepted as a reasonable **compromise**. Everyone must understand the impacts and the ways to minimize them during the execution of the work and during subsequent operation.

For this purpose, **realistic visualization** and **real-time interaction** to adapt to viewpoints make the IM an essential tool of societal dialogue. It can also be made directly accessible to the public using the procedures of Web 2.0.

[3] Portmanteau word combining **competition** and **cooperation**.

B5 – An asset in international competition

The IM, a differentiating tool in the international market for large, complex structures

The construction market is not strictly speaking a globalized, international market. It is rather a juxtaposition of markets, often regional or at most national.

There is even so an international market that is sizable but focuses on very large infrastructure or building works, from their foundations to all of their technical equipment. This market is a highly visible "**beacon**" of construction activity at its most exemplary, technological, excellent, and emblematic. It is an **attractor** and **model** vis-à-vis the national markets.

French companies international market leaders

French firms have been ***leaders*** there for many years and intend to remain so.

The examples below owe much to French know-how. They are benchmarks for the image of the profession:

- The Bubiyan, Severn, Prince Edward Island, Tagus, Rion Antirion, and Oresund bridges.
- The Yaciretá, Dul Hasti, Xiao Lang Di, and Ertan dams.
- The Fredericton-Moncton and Malaysia motorways.
- The Basilica of Yamoussoukro.
- The Petronas Towers in Kuala Lumpur.
- The Channel and Oresund tunnels.
- High-speed rail lines in Korea.
- Subways in Cairo, Athens, and Hong Kong.

French companies have many competitors (Korean, Chinese, European, and American construction companies) under the control of mostly Anglo-Saxon engineering and project management. They maintain their positions only through their **technical mastery** and their **mastery of construction processes** based mainly on the **control of information flows**.

This is why the IM will be the future **differentiating asset** of our export businesses.

A multi-local and management tool

These complex major projects always involve businesses and **organizations from all countries**.

They are therefore essentially multi-local: **mastery** of **collaborative processes** and modern t**elecommunications** tools is essential.

The IM to understand one another

This mastery of processes and tools is facilitated by the IM.

It is based mainly on the image and visual perception. It is a **"prime" communication tool** for a very natural understanding.

With the IM, it is no longer necessary to translate the texts and words into the languages of the countries of execution to share a question and an answer.

The IM, a promotion and marketing tool

The international market is open to new forms of contracts:

- Design and Build (D&B)
- turnkey,
- concession
- Public Private Partnership (PPP).

Sharing projects with principals

These major projects are won through many qualities, the first among which are **financing, cost,** and **risk management**.

They are also won through the ability to show and **demonstrate the quality** of the proposed structures, and to **share** the content of the functional project with:

- decision-making authorities,
- lenders,
- public authorities.

They want to verify, with all desirable realism - "immersive", one might say -, that it is consistent with their expectations, even their dreams. Again, the IM is a technological response to this question. Indeed, it makes all this possible in all stages of the design process, even far upstream.

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C - Structure and information flow

C1 - Structuring a project into objects

Objectives

Define and organize the digital model that describes the project

Traditionally, a project is described by a forecast list of 2D drawings. Using a shared collaborative IM challenges this breakdown into drawings by using a **breakdown into structured objects** or into an **assembly of objects.**

This breakdown is a modelling technique to define and organize the digital model that describes the project:

Concept		Sector
PBS	*Product Breakdown Structure*	Mechanical
BBS	*Building Breakdown Structure*	Construction
LIBS	*Linear Infrastructure Breakdown Structure*	Linear infrastructure

Breakdown by disciplines, systems, components, and phases

The project can for example be broken down by discipline, transversal system, building components, and phases of the lifecycle.

We must ensure that:

- These **breakdowns** are **consistent** with one another.
- Each partner can **organize** and **view** data as required by its own discipline, without jeopardizing the other breakdowns (e.g. geometrical breakdown and breakdown by transversal system).

Prepare the organization of the project and processes

These breakdowns have a major impact on the organization of the project, on the effectiveness of the work, and therefore on the collaborative processes. They require the partners to **collaborate** and to focus on the same goals, even if they work with different viewpoints and in different disciplines.

The main motivation, the ultimate goal, is to develop breakdowns that are **common <u>and</u> flexible**, and divide a construction project into basic components. This **facilitates** the direct **validation** of objects or groups of objects, as opposed to continuing to validate 2D drawings (partial views of a global model).

Provide an overview

Viewing a transversal system, independently of a geometrical breakdown by zones, must allow:

- **a check of the consistency** of all data in the system,
- **global validation** of the network for the whole project.

Breaking down the structure

We will see below how the IM will help break the structure down into **objects, information**, and **levels.**

The object is physical

The first basic design principle of the IM is to break the structure down into physical objects. They will have (or do have, if the structure already exists) a physical reality. And any player can view them using the virtual IM.

This point is important because software developers understand the notion of object more broadly as any element manipulated by computer.

For example, the *pavement* object is for us **a real object** comprising various layers of materials. It has a top surface on which vehicles roll and a bottom surface that rests on the subgrade. The width of the pavement is not an object but a characteristic of the pavement object.

This basic principle is fundamental to understanding the spirit in which we break down the structure to be built.

A civil engineering work several tens of kilometers long includes a number of objects such that it is impossible to:

- consider them all at the **beginning** of a study;
- represent them all **intelligibly** in a single view of the model.

So **levels of detail** must be **managed**. For this purpose, each object is:

- a **child** object, or component of a more global object;
- a **parent** object, or aggregate of more detailed objects.

Note: Each child object is itself broken down into more detailed "*grandchildren"* objects.

Attach information to the object

The second basic design principle of the IM is to attach all information from the structure to an object. The question the designer of the IM must therefore always ask is which **object** each item of information should be attached to.

To take the example of the pavement, the nature or density of the base layer must not be attached to the *pavement* object but rather to its child object, the base layer. Similarly, the overall structure of the pavement cannot be assigned to the base layer, but belongs to the *pavement* object.

In practice, the physical logic of the **breakdown** (based on real objects, already built or to be built) makes finding the object to which a particular item of information belongs intuitive.

Organize information into three categories

The third basic design principle of the IM is to organize the information attached to an object into three categories:

Category	Purpose	Contents
Identification and geometry	Define the object **uniquely**	The object and the elements defining its shape and its position in space (volume, location, orientation).
Attributes	Provide the properties characterizing the object	Such characteristics of the object as the materials of which it is made, its properties, its cost, its completion dates, etc.
Relations[4]	Know the link between the object or its information and other objects or information.	Links with other objects, whether geometrical or functional, membership in a system, implementation time constraints. These rules are used in particular for the detection of clashes.

Of course, the content of these three categories **varies**:

- from one project to another,
- from one object to another,
- depending on the level of detail, the progress of the project,

but respect for these categories simplifies the design and management of the IM.

[4] This category is especially useful in detecting *clashes* between items of information stored in the IM.

Organizing objects by levels for an increasingly detailed definition

The number of objects in the most detailed level of the structure is such that the objects must be organized into levels for the information they convey to be legible. We can then choose the level **best suited** to the view of the structure we want.

This structuring into levels cannot be defined in the same way for all projects and structures. It depends on:

- the **size** of the structure (hundreds of meters or hundreds of kilometers).
- the **organization** steering the project, its method of **execution,** and its **breakdown** into elementary sub-structures.

It must therefore be **flexible** and **open-ended.** The progress of the project leads to describing certain parts of the structure in more or less detail as the design goes along.

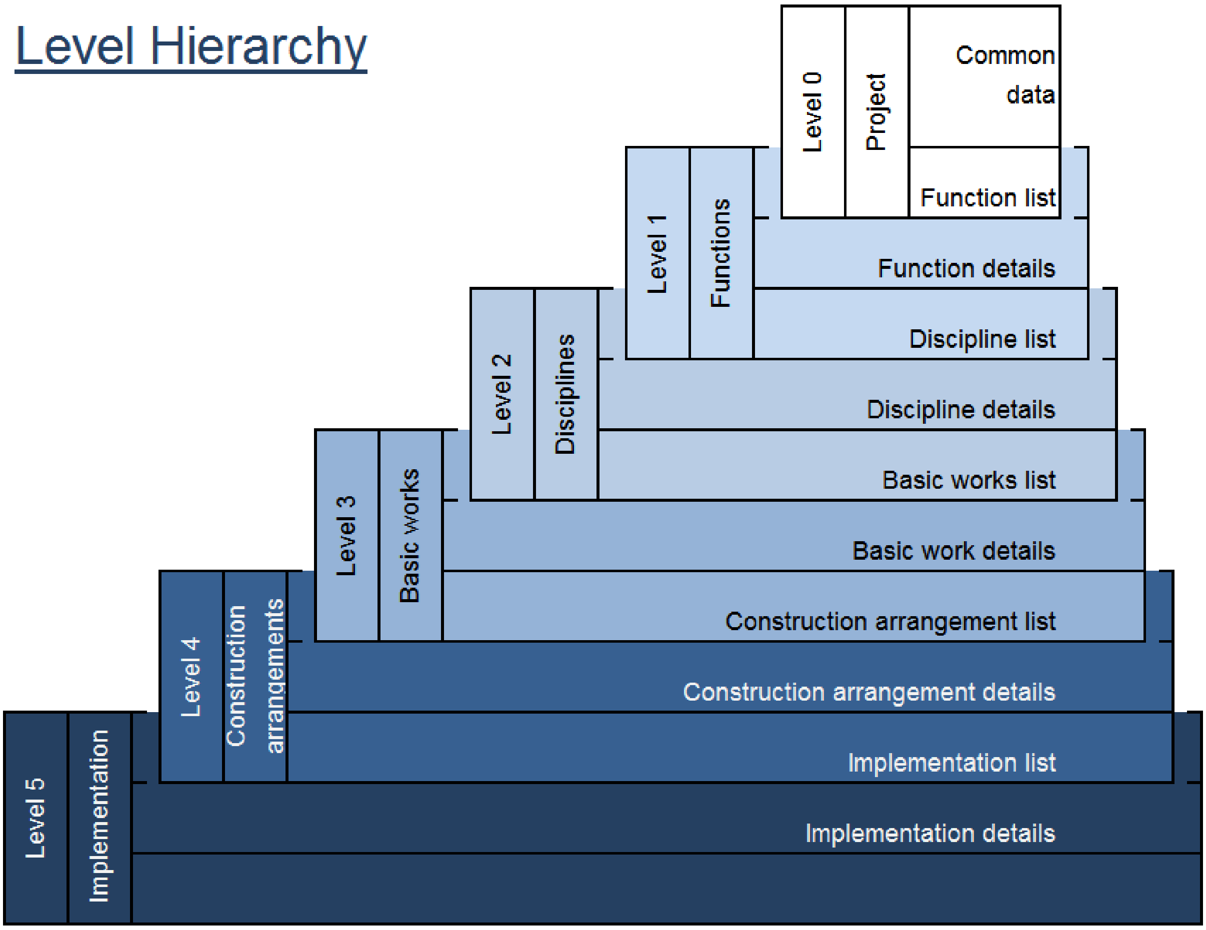


Figure C1-1: Hierarchy of levels of objects

Level 0 corresponds to the whole project

In all cases, the object of **level zero (N0)** must be **the structure as a whole.** All general information about the structure or project is attached to this object. It is organized in a very special way. It forms a database, structured to contain everything that is not characteristic of a more specific object, such as:

- general **data**
- general product **records**
- updated **information** about costs and completion times,
- general contract **documents**.

The lower levels can be organized according to the use we want to make of the IM, but we believe that levels 1 and 2 may usefully be built on the following principles.

Level 1 to identify functional structures

Level 1 (N1) reflects the breakdown of the overall structure (N0) into functional structures: all parts of the overall structure have functions to perform.

The following examples help to clarify the concept of functional structure:

Structure	Function
Motorway	Allow motorway traffic on a given section.
Diversion	Allow traffic on smaller roads to pass above or below the motorway.
Hydraulic structure	Allow the water of a stream to cross the motorway.
Pipe (water for example)	Continue to provide service across the highway
Power line, overhead or underground	
Natural terrain	Embodies much information about the project environment.
Existing subsoil	In or on which the structure is to be built.

Level 2 to break level 1 objects down by discipline or type of work

Level 2 (L2) reflects the different **disciplines or types of work** that must be assembled to produce each functional structure. Indeed, each of the functional structures of level 1 requires work by specialized trades that design and build parts of it.

The following examples illustrate the breakdown into specialties of a simple functional structure such as a road diversion:

- earthworks (cuttings, embankments, subgrades, etc.)
- engineering structures,
- drainage,
- pavements,
- equipment.

It should be possible to use the structuring principles of the first three levels (N0, N1, N2) as formulated above for all projects. This has the advantage of having, for each of the3 levels, a **set of objects** that constitute the whole structure. Only the level of detail varies. This is a valuable benefit for the creation of specialized partial models, as we shall see later.

The other levels are specific and must be adapted to each discipline

For the subsequent levels, which are more detailed, the breakdown criteria are more diverse. The examples below are for guidance. They make it possible to understand the breakdown process down to the level of detail considered relevant for the intended use of the IM.

Level	Composition	Details
N3	**Elementary structures**	An engineering structure may be the deck, piers, and abutments. Earthworks may be cuttings and embankments.
N4	**Constructive arrangement s**	A bridge pier can be broken down into a footing, a column, and a cap. An embankment can be broken down into a drain, a drainage mat, a body of fill, and a top.
N5	**Specific constituents**	A pier column can be broken down into concrete and rebars. A body of fill can be broken down into elementary layers to specify the different kinds of materials and types of placement.

The structuring of levels N3 and beyond is specific to each job. It is likely that the accumulation of know-how resulting from the use of the model will lead to optimizing these levels.

Structure objects to manage their memberships

The above structuring of the project is based on an increasingly detailed geometrical breakdown of the objects.

However, some objects are members of families that link them transversely. These memberships can be of different kinds.

Classes to identify structures of the same type

The aim is to group objects that have enough characteristics in common.

There are, for example, precast components (concrete drainage culverts, manholes, guardrails, fences, etc.). Individually, these items are clearly identified in N3, N4, or N5, example. However, for the project, we find similar objects in several objects of N1 or N2.

Systems to group structures that are complementary in performing a function

We must also consider the sets of objects that constitute functional systems or disciplines. One example is the drainage network. It consists of a succession of objects whose continuity and coherence are essential to its proper operation. Of course, each of the objects has a link with the adjacent object. We wish to isolate and visualize the network (collection, transport, and discharge) in order to design or check it.

Other networks should doubtless be considered:

- overall system of **earthworks**,
- **toll** system,
- **operating** system,
- **landscaping**,
- **network of communication diversions,** linked with land regrouping.

The structuring into objects is not called into question

In the two cases mentioned above, the structuring of the project into objects is not affected. But it will be necessary to:

- Provide, in the links between objects, a field in which to **record** membership in a **class** / a **network**.
- **Store** (probably at level 0) and **manage the classes / networks** created.

Structuring the IM to create, integrate, or merge, then manage, partial models

From the beginning of the structuring of the project, the question of the size and therefore the user-friendliness (and usability) of the IM will be raised. We accordingly consider cases in which the project in question is not covered by a single IM.

Partial models for large projects in order to handle models of reasonable size

We are led in some cases to **isolate part** of a structure in a partial model. It generally consists of a set of objects of N1. It can be managed **independently**. However, as a **super-object** it has a geometrical definition, attributes, and relations with other objects of the global IM.

The consistency of all these data with the rest of the project is of course managed by the global IM, which knows nothing about the detailed levels of the partial model.

Specialized partial models to facilitate the work of stakeholders in the same discipline

The objects manipulated by some stakeholders are not necessarily of interest to all the other stakeholders. And these objects have few relations with other objects. Finally, it is possible that, beyond a certain level of detail, a specialty justifies a de facto **standard** that should not be shared with other project participants.

This can lead to the conclusion that certain objects of N2 (disciplines) must be partial models. They can be managed **independently**.[5]

The object (eg of level N2) corresponding to the creation of a partial model has a geometrical definition, attributes, and, most important, relations of all of its children objects with other objects of the global model.

The consistency of all these data with the rest of the project is of course managed by the Global IM, ignoring the detailed levels of the partial model.

Partial or duplicate models to study and manage variants in parallel with the basic project

The steering of a project calls for considering, and therefore studying, **variants**. Some parts of the structure may for a time be described by two (or more) models.

For this purpose, we may, for example:

- Identify the **objects impacted** by the variant and extract a partial model from them.
- **Duplicate** the partial model.
- **Study the variant** using this second model.
- Manage the **consistency** of the two models in this study.
- Make a **choice** and possibly **import** the variant model in place of the partial model included in the global model.

Consistency management includes:

- observance of the **external geometry** of the partial models,
- management of **relations** between each of the partial models and the global model.

The partial model **that is not chosen** is **archived** in the project history.

[5] Note, however, that it is still wise to use the IM when **several specialized stakeholders** act on the objects, eg when several stakeholders work on an engineering structure.

Allow viewing of the objects on the selected level

One of the expected features of the model is the possibility of viewing the **structure:** the **objects** of which it is composed, the **phenomena** that concern it.

This visualization cannot be identical for all levels of detail, all scales, and all phases of project progress. When the project is structured, the types of representation of the objects must be defined.

Example: Diversions

For example, a diversion can be represented by:

- a **line** on the Natural Terrain (to identify the function);
- a **tube enclosing** the diversion and the corridor to be cleared;
- an **object with few details**:
  - without realistic textures (for design);
  - with realistic textures (for tendering);
- a set of **highly detailed objects** with differentiating colors (to check specialized detail designs);
- a set of detailed **objects** with realistic rendering (for an operator).

Geometry and texture specific to each object

The various representations in fact tackle two characteristics of each object:

- its **geometry** (details and precision);
- its **texture** (coarse or realistic rendering).

We therefore need to know how to **store,** for each object, a choice of several geometries and several textures for the viewing of the model.

Needs specific to geotechnical objects

We deal below with the integration of geotechnical data into the overall environment of the IM.

It must be possible to integrate expert models in the IM

All geotechnical data share the need to be **interpreted** by the expert, who then interpolates or extrapolates to build a **representative 3D model.**

This is difficult, and a few software packages have been developed to help. It remains to make these **software packages interoperable** with the IM so that it can manage the models.

The IM must be able to manage uncertain information from statistical processing

The **characteristics** collected are generally **dispersed**. They must be processed statistically to obtain average characteristics that can justify the structuring of the model into objects.

Each characteristic of a "*subsoil*" object has an associated uncertainty that can influence the design.

The IM makes it possible to **manage the uncertainties** of the information it contains. The **Management of Geotechnical Uncertainties** is of great strategic importance to a project.

We now take a somewhat closer look at all this.

Geotechnical data are collected gradually, using a variety of means

The characteristics of the soils encountered are determined by reconnaissance campaigns. These can be:

- **boreholes** (linear);
- **tests** (spot);
- **excavations** (volume);
- **visual observations** (surface).

At the beginning of the design phase, there is only a geological map:

- During the design phase, the reconnaissance campaigns gradually provide much information, but no certainties.
- During the work, we discover the true subsoil, but only for the portion of the soil that is extracted.
- Only during operation we can assess the consequences of everything we do not know.

In practice, **we make assumptions and simulate behavior.** Then we check these assumptions throughout the lifecycle, and where there is a divergence we simulate again.

We can see how the features of the IM will be valuable for this.

Geotechnical models differ according to which geotechnical study uses them

Collecting, geolocating, and managing geotechnical data is a basic function of the IM and poses no problem.

On the other hand, modelling the subsurface as homogeneous objects is much more difficult. This is because a geotechnical model will be used for calculations or simulations. Each model is built using characteristics specific to the calculation, as shown in the table below.

Problem dealt with	Major parameter(s) (d*rivers*) of the model
Conditions of extraction from cuttings	Hardness of the materials
Slope stability	Coefficient of friction Hydrogeological network
Foundation engineering	Bearing capacity of the soils
Settlement of an embankment	Water content

For each of these problems there is a model. The same "subsoil" object can well have many, many models. We will have to choose one, and we think the most intuitive to understand is a model based on the **nature of the materials** (clay, sand, sandstone, limestone, silt).

The **more specialized models** can be built by experts from this one and the geotechnical data collected. They use the concept of systems:

- Model of the system of **extraction** of the materials.
- Model of the **hydrogeology** system.
- Model of the system of **reuse** of the materials.

The IM can be used to:

- **manage** many of these models and **make them accessible**;
- have, in the basic **structuring** of the project, **objects** in which the nature of the materials is homogenous.

C2 - Data model

The major challenge: communicating and sharing information

Today, communicating and sharing information have become a major issue, especially in the field of **linear infrastructure:** for this type of project, the volume of input data is too large for the project manager to memorize.

The information attached to objects

We have gone in 15 years from handling drawings to managing computer files, and are now entering the era of *Product Data Management* (PDM).

Managing an item of information and making it directly accessible without going through the documents that have until now conveyed it is a considerable change. This change of scale in managing a project is made possible only by **technological advances** and the **IM.**

Information media

Project information is conveyed by a **variety of media**:

- laws, regulations, or standards to be applied;
- drawings, calculations, files;
- software output;
- multimedia;
- letters, email;
- meetings, site visits.

The IM is a **new medium** that can convey all this information and be used to view it.

The task is therefore to change over from these varied media to the structured assignment, to the relevant object of the IM. This **change** can be accomplished either **automatically** or manually. Given the amount of information to be manipulated, it is clear that manual transfer must be the exception.

The need for a single data model and a neutral exchange format

Two conditions so that this transfer can be automatic:

- The data **model** of the IM must be **defined**, **known** to all, and **complied** with by all of the tools providing the information.
- There must be **only one interchange format** between these tools and the IM.

The principle of the IM is to allow each discipline-specific software package to exchange information only with the IM and to avoid exchanges of data between discipline-specific software packages. This principle leads to imposing on exchanges a **single, neutral format** with which all discipline-specific software packages must comply.

The standardization of the exchange format is **insufficient** to make exchanges of information automatic. The data model must also be standardized and shared by the discipline-specific software packages both for their **inputs** and for their **deliverables.**

If these conditions are not met, it will be necessary to:

- **enter** information **manually** after extracting it from the medium,
- or **store** it in native form in the IM (as an attachment) and **process** it later as is currently done with EDM.

These two constraints, of course, greatly reduce the value of the IM.

Characteristics of the information in the IM

We have already discussed the three types of information attached to an object: identification and geometry, attributes, relations. We now look at other factors characterizing the information contained in the IM.

Parent-child links

Among the links of an object, parent-child links hold a special place. They are obviously among the information to be attached to each object. We distinguish:

Link with	We mean
"**parent**" object	The more global object of which the object in question is a **part,** eg the bridge for a pier.
"**child**" objects	The **higher-level** objects that together constitute the object in question. For example, for the pier, the footing, the stiffener, and the column.
"**cousin**" objects	The class of **similar** objects to which the object may belong, or the system to which the object belongs.

An item of information has its own data

The following must be associated with each item of information:

- owner
- access rights,
- date of deposit in the IM,
- obsolescence date,
- (approval) status
- membership in a system,
- associated uncertainty,
- viewing mode.

All of these data characterize the information (i.e. the data) itself[6].

Documents managed by the IM...

Information can be exchanged directly with the IM. In addition, the IM manages **documents** and the **information** they contain that has been directly assigned to objects.

A few types of documents must be associated with the information model:

- contracts and amendments,
- the regulations and standards used,
- 2D drawings,
- design notes:
  - input data: assumptions,
  - output data: simulation results,
  - complete note with assumptions, results, and analysis of results,
- technical documentation
- letters.

... as in an EDM system

As in an EDM, a search engine is needed to retrieve these documents. Participants must be allowed to classify them according to their own hierarchical structures, depending on their own disciplines.

The documents must be numbered, dated, version changed, indexed, and attached as an attribute to an object of the IM. Information-model change management can then identify the **impact** on the associated documents.

[6] Technically, this information is metadata, because it is data about the (basic) datum.

Organization of the data model

The organization of the IM must be based on the standards adopted by the major stakeholders in the discipline. Some de facto standards are destined to become official standards.

Identify protocols foreshadowing de facto, then official standards

These standards may be preceded by protocols. These are shared by the first stakeholders to employ the model.

The definition of modelling protocols, work charters accepted by all stakeholders, is paramount. It ensures the internal **consistency** of the information. It is therefore a major basis of collaborative work. These protocols are the common basis for all of the software packages, and include:

- The development of file **templates,** for each software package, that contain the basic parameters - colors, textures, fonts, list of attributes and sets of properties.
- A **reference document** describing the organization of the work, exchange procedures, and tips on configuring the workstations and the network.

Once the uses have been defined, the responsibilities and prerogatives of the manager of the information model must be determined.

Define modelling rules

The ideal is to develop common, open modelling protocols that can be exchanged and used by all stakeholders, regardless of the applications used.

A **neutral format exchange** is the goal. More pragmatically, as a first step, a **lighter** and more suitable p**rotocol** can be defined for all stakeholders, or most of them.

The definition of a modelling protocol concerns not only the **data formats**, but also the **common modelling framework**, such as units, origins, structures of objects and their attributes, projection principles, meshing, fonts, and other common parameters.

Draw on existing protocols for 2D drawings

Rules govern 2D drawings. The information protocol should therefore specify, in particular:

- the **organization** of the information into geometric elements, attributes, and relations;
- the **identification** of the information;
- the **naming** of objects, information, systems, documents;
- a **color** convention to facilitate understanding;
- a **geolocation** reference.

All software used must therefore comply with a **common protocol** for all shared information. The **protocols specific** to disciplines can if necessary be kept for private data.

Data models specific to each discipline

Most discipline-specific software packages use their own data models for reasons of **performance** and **effectiveness**. It is therefore essential to **check** that each software package can export data to the IM in a **usable format**.

Clash detection

The designers must create a design free of inconsistencies. For this, there must be a **clash resolution Procedure**, for both **technical** and **organizational** clashes.

So we must specify how to:

- Organize the **sharing** of information on a collaborative platform.
- Develop and schedule **coordination steps** and project **reviews**.
- **Check** the model, detect *clashes*, and **prioritize** before the coordination review.

Visualization of the information

Access to the information can be by discipline ...

Consistent with the development of the information as the project dictates, the information is organized to allow access on the basis of *Model View Definition*, that is to say by discipline.

The visualization need depends on the discipline that accesses the model: coarse for some, detailed for others. For example, the concrete engineer wants to view the reinforcements, while the architect is interested in the short specs registration[7] of the die.

If access is granted only to the objects on which a given participant works (eg the external networks engineer, the geotechnical engineer, or the landscaper) **the IM becomes legible.**

This does not preclude the *Structure* engineer viewing, by request, data intended rather for the architect. He may create links, but cannot modify the data.

... or by interface ...

For synthesis purposes, **access by interface** can also be considered:

- tram platform / surface amenities
- underground station / tram platform
- hydraulic / underground carpark
- signaling / fire safety / power supply.

... while ensuring the uniqueness of the information model

The uniqueness of the model must, however, be ensured. This means access to a single database.

If pieces are carved out of the model (structure, architecture, platforms, etc.), they go their separate ways without necessarily taking into account changes made to the others, and so can no longer be pieced together.

Ownership of and responsibility for the information

The absolute need to protect know-how and intellectual property give rise to two concepts: ownership of and responsibility for the information.

Each item of information must have an owner

We must define who owns each piece of information. The party who created an item of information and deposits it in the IM also defines its nature, in particular whether it is:

- **Public -** visible to all stakeholders, with no possibility of modification, or.
- **Private -** with a possibility of modification by some stakeholders, managed by access rights.

The owner is responsible for shared information

Deposit in the IM means that the owner of the information believes that it can be **shared** with other stakeholders and **takes responsibility for it**. The owner **alone** is empowered to **change** the information, and guarantees its approval status in application of the process described in C4 below.

Note: Before this deposit, the information remains private for the discipline that created it. It is a draft. The owner works on its and checks its accuracy and only then makes it available to the rest of the collaborative environment.

[7] Short specs registration: sketch showing the arrangement of elements having defined shapes to form a pattern or constitute an assembly, from which the number needed to cover an area or fill a volume is calculated.

Implementation of the data model

Choose the object conveying the information

Information must be attached to an object. So an object must be chosen.

This choice is generally rather intuitive. We have not established detailed rules, because there are many special cases that violate them. However, one must generally choose the object of **the most general level** to avoid duplicating information for all its "child" objects.[8]

For example, the height of pier 2 of a bridge is attached to the object pier no. 2. It does not apply to the bridge (the "parent" object), and must not be duplicated in the characteristics of the footing, the stiffener, and the column making up the pier.

The work is hard, but creates value and generates savings

This work of entering data into the IM is cumbersome because it requires:

- **Defining** the complete data model.
- **Checking** the correct allocation of the data.
- **Analyzing**, at times, the information sent, **extracting** from it the data concerning the object, and **creating** the corresponding **attribute**, with reference to the original document.

■ Today: too much time spent at the expense of design

The work of cleaning and digesting data hampers the progress of projects. It is **time-consuming** (selection, printing on paper, display, filing, etc.). It often requires the expertise of the project manager and is of use only to him because it depends heavily on his working methods.

The first data are barely ingested when new data come along and make them **obsolete**. This huge task **cuts into the time** available for **design work that creates value**.

■ With the IM: value is derived from the initial investment

Data entry is probably still cumbersome and time-consuming, but it is **not repeated** for each discipline and each project manager.

The **accumulation of information** on projects can be expected to facilitate defining future data models.

In addition, **standardized formats for exchange** with discipline-specific software packages allow automation that limits interventions by experts to the inevitable adaptations.

Finally, we mentioned **depositing data** in the IM. They are destined to be extracted from the IM to be used by the stakeholders. The time saving is even greater for this task, because **access** to the right information is **direct and easy**.

[8] In the design of an information system, data is assigned to the accurate object for which defining the object has a meaning. For example, if the 4 wheels of a vehicle are identical, the wheel diameter is assigned to the object "vehicle". However, if the diameters of the front and rear wheels are different, the information is positioned on the object "axle".

Set up the data model gradually and adapt it to the expected use

Value creation and the expected uses of the IM were described in Section B. They result from the import and export of information to:

- model objects;
- perform calculations;
- perform simulations and evaluations;
- produce graphic materials;
- view and present the project.

The **uses** expected of the IM impose the precision in **modelling** to be attained and the list of **attributes** to be used and entered for the disciplines involved.

Generalizing the implementation of the model to all fields, with different detailed information, may be too ambitious. It is doubtless much better to define a **reasonable level of ambition** (eg focus on the 3D geometry and a few modest uses) rather than thinking that the IM can meet all needs.

Using the IM to meet **all** stated needs may even be **dangerous,** because nothing will be treated with the required quality. This can be a source of **disappointment** and may even lead to **rejection** of the new way of working.

On the other hand, we must not make the model so impoverished that it becomes **useless**.

Then manage the developments of the information

Once the information has been organized, it remains to manage it during the lifecycle. When the information is modified, it becomes obsolete**. New information** replaces it.

By contrast, the **elements** that characterize the information **evolve** during the lifecycle. They should therefore be:

- **managed** and **updated**,
- **archived** with the information when it becomes obsolete.

This is managed by the IM through the management of changes, approval, alternatives, etc., described in modules C4 and C5 below.

C3 - Exchanging and sharing information

Having described the data organization, we now discuss how exchanges will be organized.

The IM environment

The IM environment is illustrated by the diagram of the functional architecture below.

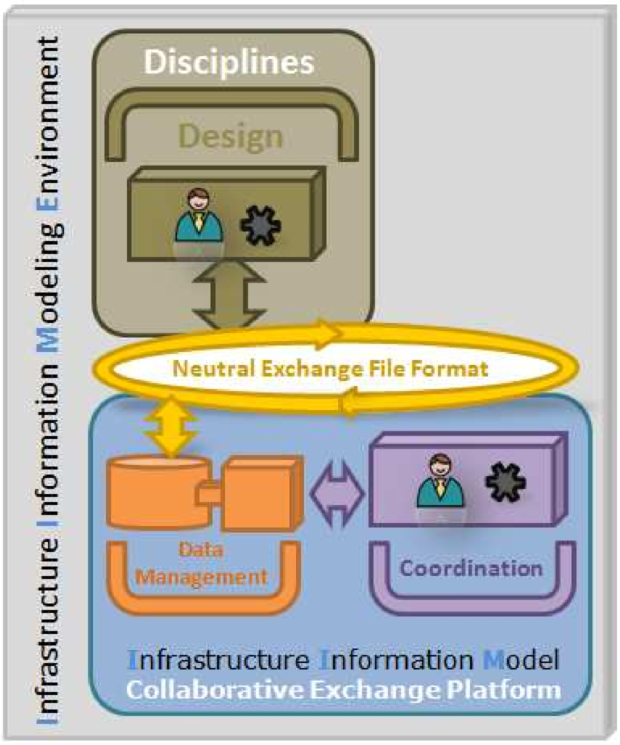


Figure C3-1: Simplified diagram of functional architecture

Discipline-specific functions

The discipline-specific design functions are:

- project **modelling;**
- discipline-specific **simulations**, **calculations,** and **visualizations**;
- the **editing** of documentation.

The tools used to perform these functions are *Discipline-specific software packages*. They take the form of **graphical user interfaces** for:

- **pure entry** (or manual modification) by the tools for integrating data from initial reports and specifications and modellers;
- **loops** (simulation, computation, analysis);
- **pure output** (look-up, browsing, annotation, arbitration, graphic, video, or alphanumeric exports).

Gateway

For the *discipline-specific software packages* to be able to interact with the *IM Tools,* it must be checked that the exchange format is consistent with the agreed standard. This check (which may include some conversions) is the *Gateway* function between the two blocks.

Information model functions

The IM functions are of two types:

- **Management** of information to give stakeholders the information they need.
- **Synthesis** providing:
  - a **complete vision** of the project
  - a **check** of its **consistency**.

The tools to perform these functions of the information model are called *information model tools* or *IM Tools*.

Functional architecture

The following diagram describes more precisely the major functions incorporated in the IM environment.

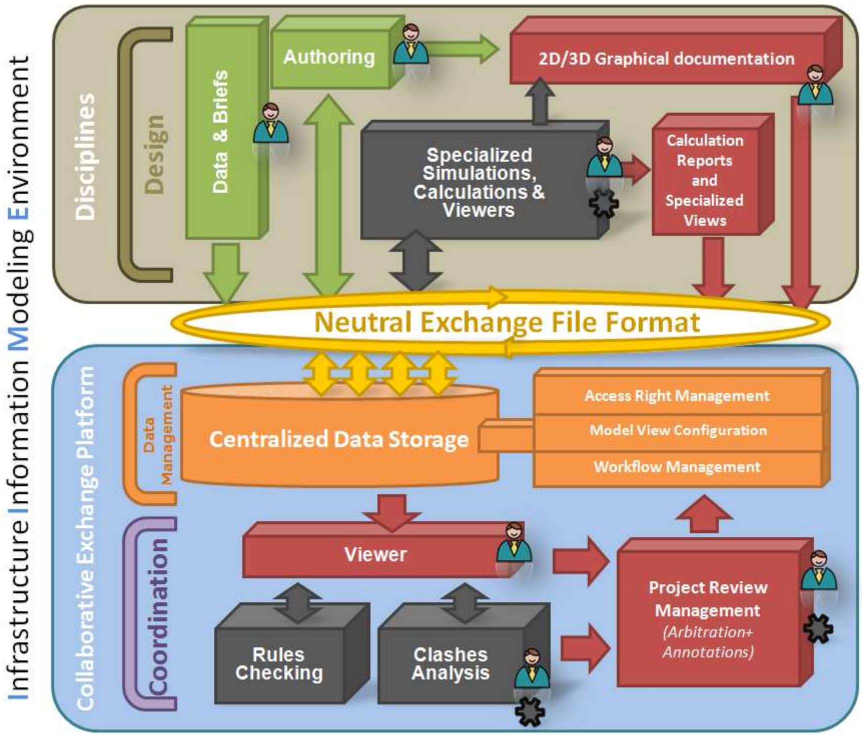


Figure C3-2: Architecture of elementary functions

Elementary tasks are associated with each of the blocks of this diagram.

The processes of the global model result in moves from one block to another as the information is enriched with the help of software (discipline-specific or IM).

Project information lifecycle

To understand the principle, we have drawn below one of the possible circuits, highlighting:

- frequent **exchanges** between the designer and the IM;
- the **strategic passage via the exchange gateway** to ensure that the data are in the standard format.

Allowing secure and **automatic passage** of the information via the gateway is the main point of the COMMUNIC global model.

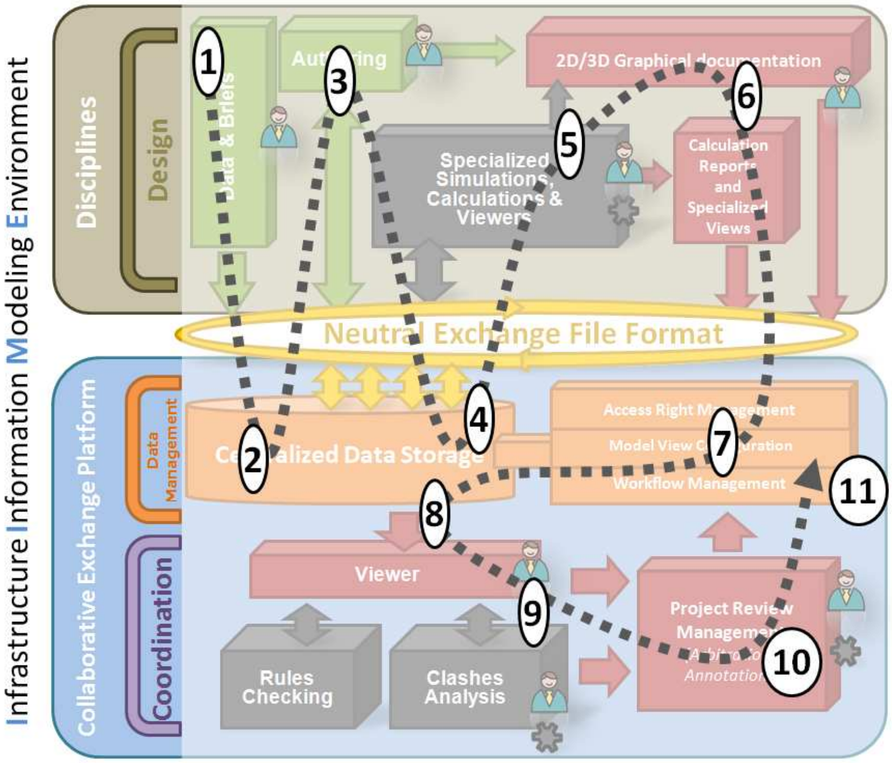


Figure C3-3: Simplified data lifecycle among the tools of the IM Environment

In this example, the lifecycle of the project data among the various software packages goes through the following steps:

Step	Action
1	Client specifications and available data are ordered and classified in the project environment.
2	Data, catalogues, and modelling charters (default models), hosted by the IM, are extracted.
3	A geometric response to the needs expressed by the client is modelled.
4	The model is hosted in the platform.
5	The design is completed by tests, calculations, or simulations.
6	The results of the simulations and calculations are documented.
7	Everything is hosted and managed in the IM.
8	The proposals can be viewed by browsing in the IM.
9	Tests of consistency, integration, and synthesis are performed and analyzed.
10	The design choices may require arbitration.
11	The chosen design is stored in the IM to be seen and used by others.

The collaborative platform for exchanges: the heart of the system

As highlighted by the lifecycle of a datum in a project, the collaborative exchange platform is the heart of the system. It can be implemented **effectively** only if the tools (primarily discipline-specific) that make it up and those that "talk" with it are compatible with a **neutral exchange format**.

Tools making up the collaborative exchange platform or the IM

Like the other tools, the IM is made up of "**software building blocks**" for which we recommend a **logical assembly** as presented here.

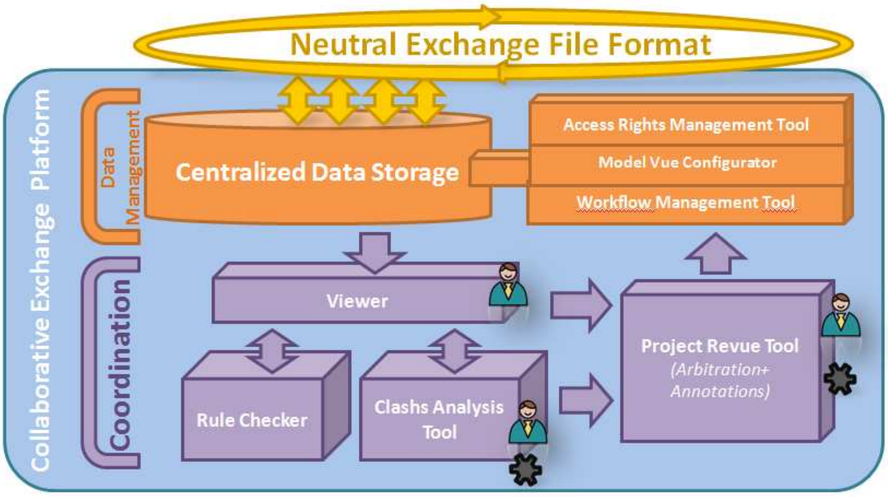


Figure C3-4: Tools making up the Collaborative Exchange Platform of the IM

Software publishers sometimes group these building blocks differently, while performing all (or some) of the functions described in deliverable L2. Most often, they mix the modelling and data management functions but do not really cover the needs stated in the deliverables of the COMMUNIC project, notably in deliverable L3.

The transfer system

Access to the project data is through a "transfer gateway system" that manages the **viability** of the input and output **data**.

The "gateway system" is both:

- a **transfer system** interpreting the data between the user tool and the collaboration platform;
- a **guarantee** that the various tools will **work well** together.

Neutral exchange format

The neutral exchange format is the keystone of the work environment.

It enables the tools to **exchange** design and calculation parameter information.

It provides a **link** with external applications for the creation / modification / editing of objects or attributes. The main functions of the discipline-specific and synthesis tools are:

- the **creation** of data, and therefore of objects and their attributes - both the fields and the values of the latter (upstream);
- the **edition** (modification) of data.

Its principle and structure were explained in modules C1 and C2.

Transfer gateway

The transfer gateway is a data **conversion matrix** between the discipline-specific and synthesis tools and the platform.

■ Interpreting

It **interprets the needs** of the tools in terms of data. It **provides the data** needed for analysis, simulation, and calculation.

In return, it **recovers** the data created or modified by this study process, then **increments** them in the central hosting via the management system presented below.

It therefore ensures **compliance** with the internal formalization.

■ Checking

It checks the **computational consistency** of the input and output data. This helps maintain a level of information quality sufficient to avoid problems of consistency of the model in import-export exchanges with discipline-specific or synthesis software.

It ensures:

- the **consistency** of the **parameters** with one another and of the **links** between objects,
- their proper **translation**,
- the **reliability** and **consistency** of geometric **data**.

It therefore checks the data-processing compatibility and compliance with the formalization of the information accepted (IFCInfra, IFC, etc.).

It orders the data stored in a project tree (for the primary levels) and in the semantic tree (for the secondary levels).

The data management system

The data management system must be even more **secure** because the platform is collaborative. For this, we distinguish **3 types of locks** securing access to the data.

The workflow tool

The first lock is a **regulator** that manages the electronic data flows; its procedures are described in module C4. It controls the flows by recording the creations and modifications of data by each user.

Viewpoints management tool

The second lock is the "viewpoints" management tool (*Model View Definition*). It makes it possible to adapt the view of the model according to the user profile (specialization of the information communicated according to the user's discipline and role).

It **allows or denies access** to the data, in both read and write, to each branch of the project, via the "viewpoint" filter. This filter defines an additional layer of screening of the data that can be accessed according to the user's discipline.

Note: When we mention customization, it means sorting with respect to the user's discipline.

Rights management tool

The third lock on the safe is the management part of the platform. The only parts of the model made available to users are those to which they are allowed access in 4 modes:

- read only
- annotation
- "frozen"
- write / edit,

according to the pair of criteria defining the user's identity within the exchange platform:

- **identity** (name, email address, telephone number… and membership in an entity that is part of the project team)
- **role** in the project (discipline and position within the organizational structure of the project).

Data types

Data storage must be ordered, according to these three types:

Data	Features
Active	These are created, used, and modified by the design process and by the execution of the project, and group all data that are: • **common** to all project stakeholders, • **private** (specific to a user or entity) • **public** (beyond just those involved in the project and potentially available to the general public).
Archived	These correspond to past versions or alternatives not selected for the project and the reasons they were dropped. So the project status of these data is common or private, but not public.
General references	Regulations, standards, laws.

In short

The information hosted is in this way **secured**, **traced**, **checked**, and **formalized** (even standardized but open) in a way that is **centralized**, **accessible,** and **living.**

Any modification of data in the collaborative platform leads to dissemination of the information to the persons impacted by the change.

The project synthesis system

Browser

The browser is a simple **data "viewer"**. It provides access, via the geometry or via a tree, to the data in central storage. A graphic engine makes it possible to browse the model, see the properties of objects, and create weighted multicriteria display requests.

A **weighted display request** amounts to asking the model a question, with as criteria the properties of objects. This calls up a special display of objects that meet these criteria, with a weighting of their importance.

The rules checker

In the design phase, the rules checker can check compliance with certain **good practices**, such as road clearances under bridges or PRM (Persons of Reduced Mobility) regulations in buildings or outdoor areas

The clash analyzer

The clash analyzer is simple in principle. It performs, for all or part of a project, processing to spot **geometrical clashes** between objects. Then it identifies and marks the objects involved in the *clash* so located and generates a comprehensive report customized by authorized user of the IM.

The project review tool

The project review tool is also called the *Project Reviewer*. It is a tool for meetings. It can be used, with the browser, to move about within the virtual project.

The review tool is used primarily to:

- View in graphic form the **results** of simulations and analyses of clashes and compare them.
- Review **critical points**.
- Save the **conclusions** and **arbitrations** reached in a project or coordination meeting in the model.
- Perform passages of milestones and progressive approvals of project data.

Having hosted and addressed the information from these decisions, it is then easy to **disseminate** it in a customized manner and to ensure its **traceability**.

C4 - Approval process

Introduction

In the previous modules, we saw that collaborative work based on the use of a shared IM requires great discipline in organizing and structuring information. This produces the level of quality necessary to ensure trust among all partners.

Steering the quality level

The quality level must be checked in the earliest rough outlines and first contacts with the client. It is absolutely necessary to:

- **structure** the data;
- define with all participants a **common work environment** that is flexible and scalable, and also strict and consensual.

Steering the level of reliability

The reliability assessment of the information concerns the content, that is to say the quality of the study. This requires a **quality process** covering:

- the **checking** and **approval** of the information created and manipulated;
- the **container**, in other words the tools used to create, edit, store, exchange, and share information.

In this module we accordingly explore the approval process, essential in order to:

- make the stakeholders **accountable**,
- underpin **trust** between partners,
- ensure the **traceability** of the decisions taken.

Phases in the lifecycle of a project

We begin by dividing the project into **zones** and **structures**. We then **organize** both the work to be done and the IM around the lifecycle, from the earliest phases of design to operation of the structure.

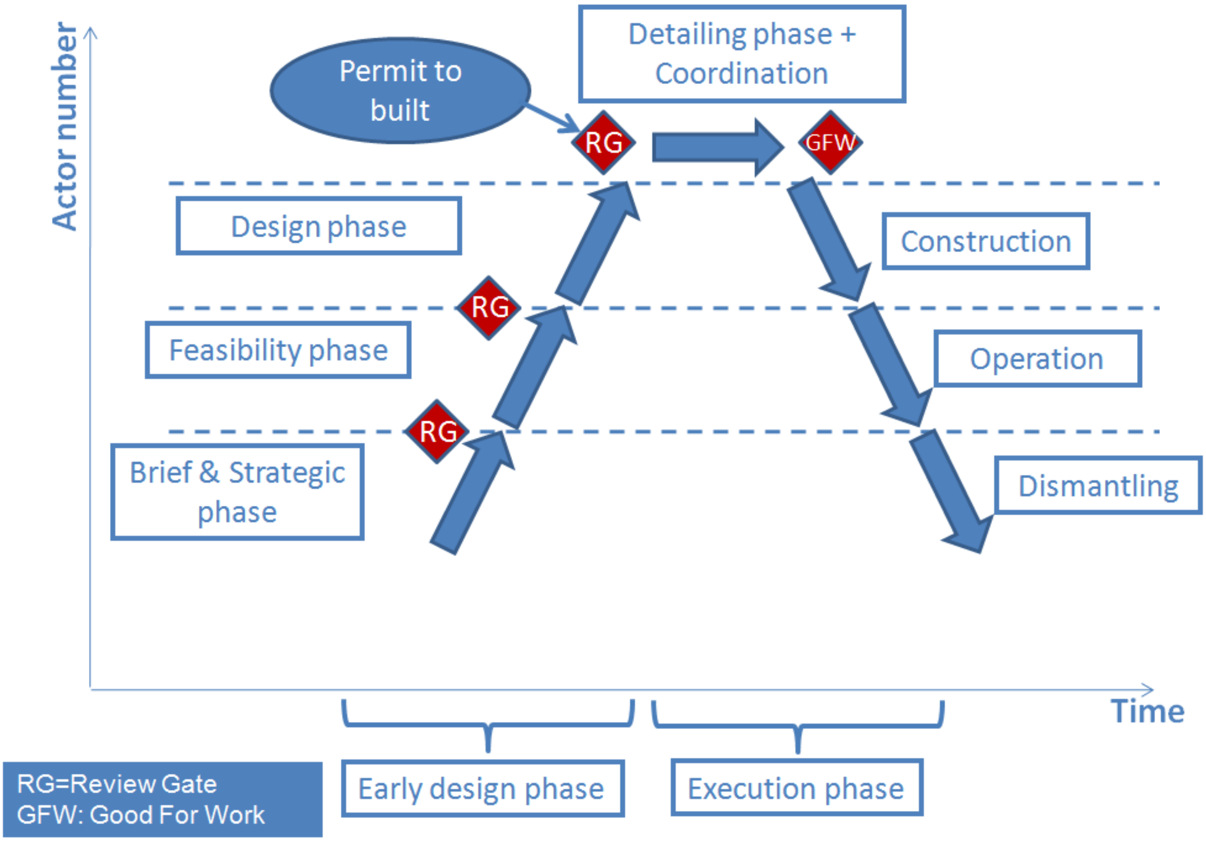


Figure C4-1: Stages of the lifecycle of a project

Phase	Description
Strategic	Initialization of the project and definition of its goals (including the needs of the principal contractor, often vague at startup), the deadlines, the budget to be funded. No IM is available, and little geometric information is accessible.
Feasibility (preliminary design)	Evaluation of technical and financial needs. First envelope alternatives based on administrative, geological, geographical, etc., constraints. Quantities and overall completion times.
Design (detailed preliminary design)	Engineering design and development of alternatives. Quantities and lead times for issuing calls for tender and estimating the exact cost of the project.
Construction	Working drawings and execution. Production of as-built file by updating the IM to reflect what has actually been done on site.
Operation	Operation and Maintenance. Keeping project data that are modified, changed, or replaced up to date. All non-geometric information is associated with the 3D data.
Demolition	Renovation, partial or total demolition of all or part of the project.

Approval, the guarantor of trust among partners

The purpose of approval is to ensure the **existence** and **integrity** of a document or item of information (unaltered and its content accepted).

Approval is used to **freeze a given state.** It certifies that the information is **accurate** at a given time and can be used by others. It thereby establishes trust in relations between the various parties.

Approval process	Objective: To verify that the object designed is
internal to discipline (within the design department in charge of the data)	**compliant** with the requested specifications.
project (outside the design department in charge of the data)	**consistent** with its environment and with the other disciplines that interface with the object.

Today, approval concerns documents

Traditionally, the approvals circuit concerns 2D drawings, calculation notes, and more generally files (paper or digital):

- The **approval** of a document approves all of the information it contains.
- **Non-approval** of a document does not systematically mean non-approval of all of its information. It is accompanied by comments that list the information that is incorrect or non-compliant.

With the IM, approval concerns information

Using a shared IM calls the approval process into question.

What is approved is each **geometric object**, not a particular view of the IM (2D view of a 3D model). It therefore requires approval of all of the component information: **geometry**, associated **discipline-specific attributes**, and **links.**

The geometry and the attributes are the responsibility of **different disciplines.** There is therefore no one authority capable of approving all of the information that describes an object. The object must be divided into sub-objects, by discipline.

In addition, **complete** approval of an object is not always desirable. Indeed, some information is optional, so that the design work can continue or execution of the object begins. For example, the color of paint does not call into question the shape of a concrete column. It can be built even if the "color" attribute of the column is not validated by the architect or client.

This is why the approval process applies to information and not directly to objects.

New process based on tacit validity: shareable information

Many companies in the industry have already implemented this tacit approval process. It is based on a new status accorded to information: "shareable". Once data is **shared,** it is considered **valid** as long as it does not clash or conflict with other data.

Approval is reserved to changes of phase

There are even so steps where the information must be frozen for it to be possible to continue. The most obvious example is the **transition from design to execution**, with the working documents approved for execution. There are other examples, such as the transition from **upstream design to detailed and working design.**

At these changes of phase, the information concerned must be approved and be frozen. The diagram below shows the status of the public (shared) data.

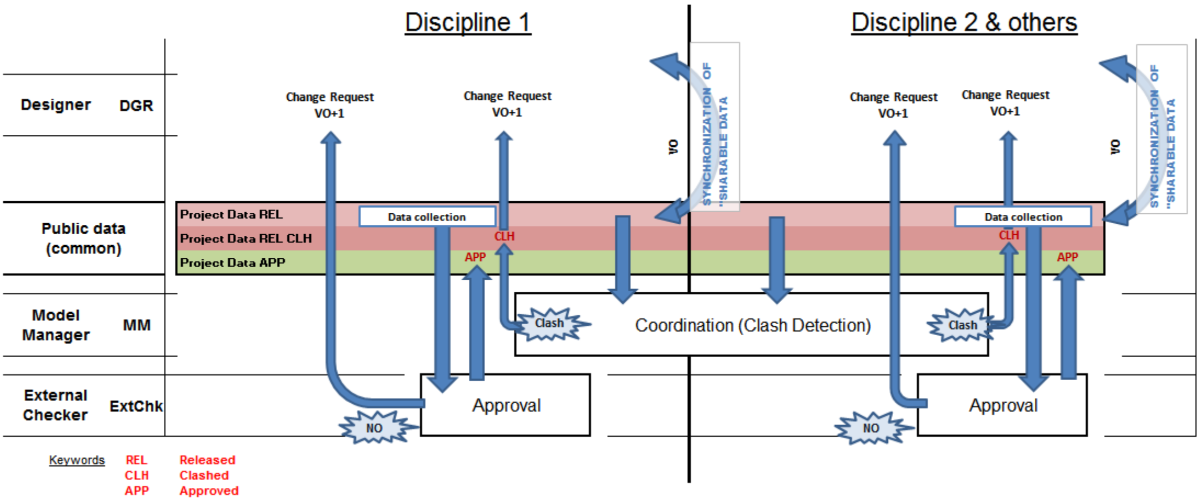


Figure C4-2: Evolution of the status of a datum

Possible approval statuses

In the IM, information can have one of the following 3 approval statuses:

Approval status	Associated processing
REL (can be distributed, shared)	The datum can be shared. It was reviewed by the expert in the discipline that filed it. It can be used by all partners.
CLH (unresolved clash)	The datum creates a problem for another player where the IM manager has detected an inconsistency. The data becomes "CLH." Two options must then be distinguished: • **decision to be taken** (who is responsible for its resolution?, by when?, etc.). • **decision taken** (action by its owner is then expected - request for modification query with an official index VO +1). Note: at the same time, the data can continue to evolve.
APP (Approved)	The External Control (EC) approves the data and allows the transition to the next phase. The APP status is only for data: • that must be frozen for the next phase, • in REL status. If a datum must be modified to be approved (reservation), its status becomes CLH.

Approval workflow

The approval process is essential to ensure the relevance of the IM.

The **complete workflow** must be **defined as early as possible** in the preliminary design phase. The names of the roles and of the decision makers must be specified, as well as the roles and stakeholders who give the version numbers and the status to the data.

To avoid laborious approvals, it must be possible to apply the **status** to a group of data (rather than one item after another). Support tools for modifying the statuses remain to be developed.

Approval is tied to the **maturity level** of the object. The structure will be described in greater detail in each successive major phase of the project lifecycle.

Note: Except in special cases, the EC (External Control) is at the end of the phase only, in particular for the transition to the execution phase.

An approval process that builds trust

The approval process improves **confidence in the tool** and **among stakeholders.** It is based on:

- a clear definition of **responsibilities**,
- effective identification of ***clashes***,
- identification of the **disciplines** impacted,
- Collaborative **processing** of ***clashes***,
- **monitoring** of needed changes or improvements.

Reviews

The need for reviews

Today, documents are approved by stakeholders whose mission is to check and approve. These **missions** are performed **inside** the organization (internal checking) or **outside** the organization (external checking).

With the IM, there is always an internal check by discipline that leads to the **sharing of the information** (transition to DIF status).

By contrast, the check external to each discipline is **more collaborative.** It comprises:

- automatic checks (compliance with rules and consistency) by the IM tool;
- the use of the information by the other stakeholders.

Project reviews already exist in the steering of projects. They are mainly intended to discuss the progress of the project.

With the IM, **sharing** project information is the **default.** Reviews can and should become the place where problems are **solved.** Since the principle of the approval process is based on the **detection of *clashes*** and their resolution, project reviews are essential project steering milestones.

Similarly, changes of phase require extensive collaboration between the stakeholders. Approval decisions are taken in reviews that we might call **"Phase reviews"**.

Finally, each discipline sets up an approval process for the tasks assigned to it. This process ends with the decision to share certain information. By similarity, we might call the entity making this decision the **"Design Review"**.

Project reviews at the heart of process

The purpose of project reviews is to verify that **information** contained in IM is **not in conflict**.

They make it possible, in the design phase, to **diminish** the number of ***clashes*** usually encountered during construction.

The growing complexity and shorter preparation times of new projects make **control** of design **coordination** crucial.

In addition, the current method of coordination based on 2D drawings is a tedious process and a source of many errors and inconsistencies. This is because it is not automated and is therefore all-human.

An automatic clash detection tool

Clash detection is a process that **merges several partial 3D models** into one global model in order to **check** for**:**

- **clashes** between the various disciplines involved in designing the project;
- **conflicts** between the design and the regulations in force.

The result of this **automatic verification** is an exhaustive list of *clashes* that is the basis of the coordination process.

This process is constrained by the agreement of all stakeholders to work with the same:

- modelling **protocol**
- progress **schedule**,
- concern for **level of detail**,
- **exchange format**.

It is the tool that provides input to project reviews.

Reviews that are effective...

In order to fully organize a design review, it is necessary to accurately prepare **datasets** and to rank-order ***clashes***. This requires time and the skills of an expert, but the benefits are many.

Project reviews are more effective with the IM because the consolidated model shows the current design. Inconsistencies are immediately understandable.

... save time ...

The IM and project reviews save time because the *clash* detection phase is accelerated. Indeed, inconsistencies are detected automatically.

They are screened and sorted, but they are **identified more quickly** than in a traditional process based on verifying the consistency of 2D drawings with one another.

... and improve quality

The IM and project reviews improve design quality and the reliability of the data. The shared understanding of the project, the time saved in the detection of *clashes*, and better data quality serve to optimize the project.

The effectivity date

The concept of effectivity date is used to define a body of information needed for the approval of an object (the assumptions used in its design).

To design an object and its attributes, use is made of **information from other objects**. At the time of the design, this information therefore includes **assumptions** of which the future changes must be managed.

The effectivity date allows this management. It can be defined as the **filing date** of information that takes account of earlier versions of the inputs that generated it.

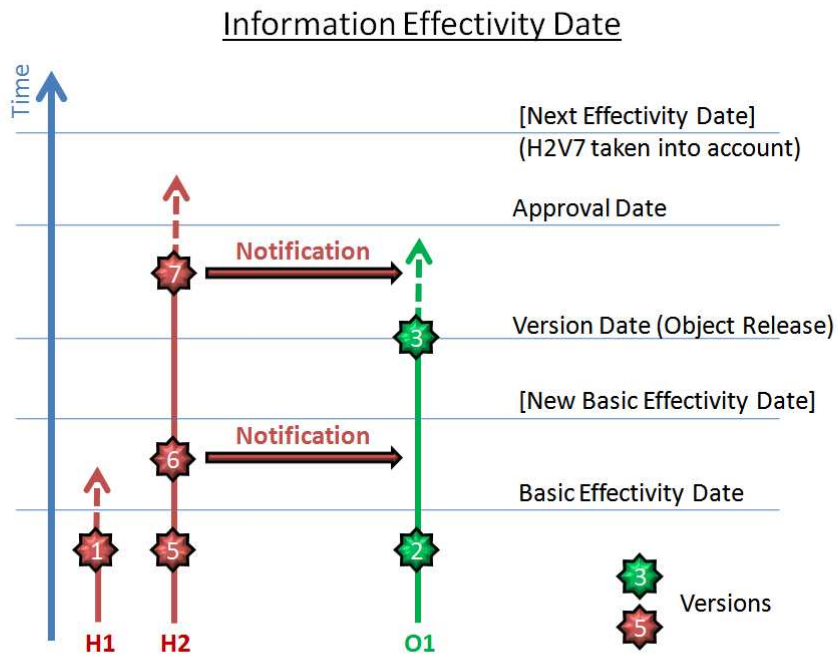


Figure C4-3: Concept of effectivity date

Initial situation

We consider that **object O1** is related to **objects H1 and H2** (eg, a beam resting on two columns):

Object	Index of initial version
O1	V2
H1	V1
H2	V5

Suppose that the designer of O1 receives a change request
(eg change to the section of the beam).

Effectivity dates

When the designer starts his change work, it is the "**basic** effectivity date" of his assumptions that he takes into account.

If, during his work, H2 changes to V6 (eg displacement of one of the two columns), the designer (temporary owner of O1) may receive a n**otification** that informs him of this change.

If the designer takes this new index into account, the effectivity date changes and becomes "**new effectivity date"**. If he does not want to take this new index into account, the previous effectivity date does not change.

Note: In our example, changes made to H2V6 or H2V7 may have no impact on O1.

Index date (dissemination)

The index date is the date of **completion of internal approval** and of the **availability** of the documents to other partners. When the designer completes its work, object O1 changes to index V3. It depends on the versions of the objects linked to the effectivity date in question.

When the request for approval of O1 is sent to external checking, a **complete data package** is associated with the request. This package contains all data used to develop O1V3.
The effectivity date is associated with it, making it possible to retrieve the indices of the objects necessary for its approval (O1V3 associated with the indices of H1 and H2).

Approval date

During the approval of O1V3, the complete **model** is **not frozen**. It can change, and the versions of objects can change (eg, H2 can change to V7).

Despite this, the new indices are not taken into account, and the approver has a comprehensive and coherent package that allows him to complete his task.

Important note: In the ordinary IM, only the latest indices of the objects can be viewed, even if the previous indices are available in the PLM.

In conclusion

It can be seen that the index dates do not tell us exactly which data supported the development of a version.

The only **relevant date is the effectivity date** prior to them. It should therefore be associated with each item of information and used in consistency checks.

Notion of maturity chart

The approval of each step:

- Freezes the **assumptions** to respect (the envelope within which one must operate).
- Is **firm** and **final** (a return to a previous maturity level is a source of complaints).

Stages in maturity to define a stable condition

Each new step enriches the previous one. **Consistency** between phases must be maintained and it must be checked that the initial **needs** are **met**.

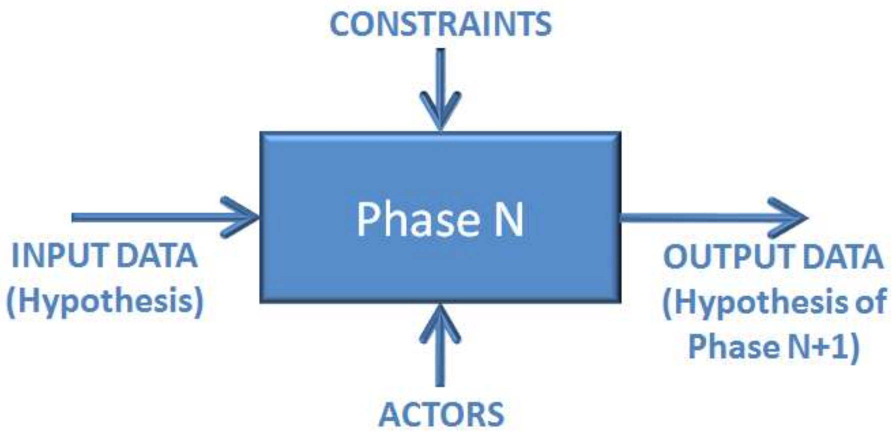


Figure C4-4: Preparation of a Phase of the Project

The highest maturity level corresponds to "Approved for execution"

When the highest maturity level (construction phase) is reach, it corresponds to "Approval for execution" of the object.

We must make sure that all components:

- have reached their maximum **maturity level**
- are **approved**, in order to validate the object as a whole.

In the example below, all working drawings must be approved at maturity level 4 for the pier as a whole to be approved at level 4. An object cannot be built just because it is approved at level 1! All objects in the tree must be approved individually at level 4.

We currently define an exhaustive **forecast list** of the drawings needed for the execution of a project. Similarly, the use of an IM requires us to define from the outset the **list of objects to be designed.** At the most detailed level, these are the components of a global object, as well as constructive methods.

Approval by maturity levels

Approval of components must follow the **construction logic**.
So we need one approval per maturity level:

The pier is approved at:	When the piles, the footing, the pier head, and the supports are approved at:
Level 2	Level 2
Level 3	Level 3, i.e. when the sub-components of the previous objects are validated at Level 3
Level 4 (approved for execution of the pier)	Level 4

<u>Note</u>: It is not necessary to validate **the whole** pier at level 4 before **starting** to make the components.

Example of structural breakdown of the pier

The breakdown of an object must be flexible so that it can be adapted as the design evolves. But it is also very structuring, and should therefore be modified only sparingly.

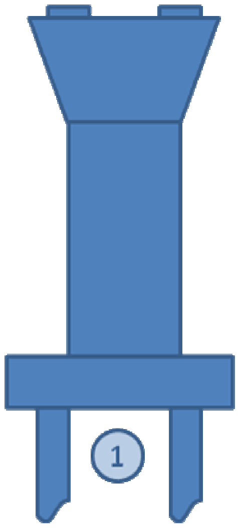
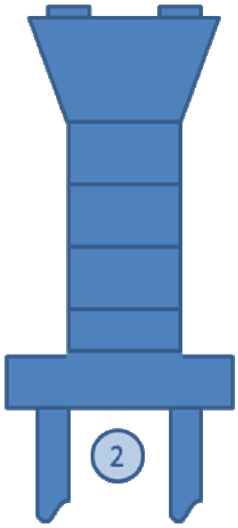
For the pier of the example (level 3), the following breakdown is proposed:

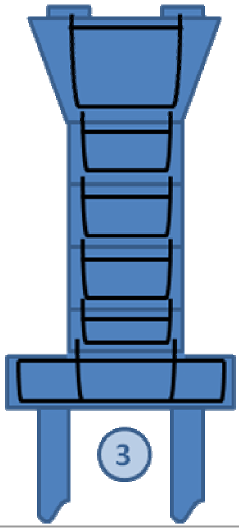
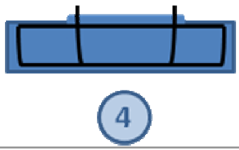
<table>
<tr><th>Level 4</th><th>Level 5</th><th colspan="2">Level 6</th></tr>
<tr><td rowspan="2">All piles</td><td rowspan="2">One pile</td><td>Drilling</td><td>Concrete</td></tr>
<tr><td colspan="2">Reinforcement</td></tr>
<tr><td rowspan="3">Footing</td><td rowspan="2">Footing</td><td>Formwork</td><td>Concrete</td></tr>
<tr><td colspan="2">Reinforcement</td></tr>
<tr><td>Heel</td><td colspan="2">Not applicable</td></tr>
<tr><td rowspan="4">Shaft</td><td rowspan="2">Lift 1</td><td>Formwork</td><td>Concrete</td></tr>
<tr><td colspan="2">Reinforcement</td></tr>
<tr><td rowspan="2">Following lifts</td><td>Formwork</td><td>Concrete</td></tr>
<tr><td colspan="2">Reinforcement</td></tr>
<tr><td rowspan="2">Pier head</td><td rowspan="2">Same as N4</td><td>Formwork</td><td>Concrete</td></tr>
<tr><td>Reinforcement</td><td>Prestress</td></tr>
<tr><td rowspan="3">Support</td><td rowspan="2">Bosses</td><td colspan="2">Formwork</td></tr>
<tr><td colspan="2">Reinforcement</td></tr>
<tr><td>Bearings</td><td colspan="2">Not applicable</td></tr>
</table>

Example of maturity diagram

In this section, we illustrate our point through the management of **the course of approval** of the objects constituting a bridge pier.

This course is also called a "maturity diagram".

Phase	Role	Contents	Illustration
0 - Strategic phase	Architect's sketch	Proposed geometry for the shaft and pier head (deck, etc.). Key Specifications	/
1 - Feasibility Phase	Design department Structure	Layout of the road (principal axis comprising a longitudinal profile, a plan view, cross sections with superelevation) Number of supports Geometry of the deck, to know the soffit of the deck Knowledge of height of supports: definition of altitude Zh of the pier head Definition of the height of the shaft (From Zh to the natural ground) and of the inclination of the shaft (relative to the red axis) Definition of the footing and foundations (depending on the geology), so altitude Z0 of bottom of pier Definition of the concrete, concrete cover on the reinforcements, and reinforcement ratio Proposal of final pier geometry (piles, footings, shaft, pier head, supports): Formwork of structure	 **Figure C4-5: Bridge pier / Phase 1**
2 - Design Phase	Design department	Methods of execution: • of the pier head (number of lifts) • of the shaft (first lift of variable height, following lifts constant) Organization of constructive methods (scheduling and sequencing) Definition of pier head equipment (depending on the type of support) Proposal of final geometry of the pier (heights of pours, positions of rods): Formwork, Methods	 **Figure C4-6: Bridge pier / Phase 2**

Phase	Role	Contents	Illustration
3 - Simultaneous with Phase 2	Design department Structure	Drawings of: • reinforcements: geometry + cross-section (s) • prestressing: geometry of tendons + quantity of prestress	 **Figure C4-7: Bridge pier / Phase 3**
4 – Detail design - Execution	Structure design department	Execution drawings	 **Figure C4-8: Bridge pier / Phase 4**

C5 - Relevance of the information

Reliability of the information

The question is how to:

- Trust the information.
- Ensure its quality and reliability.

A set of information to ensure the quality of the data

The answer depends on a set of information, known perfectly, that certifies that the data can be used safely.

If	Then
The first values are known and the compliance values are positive.	The data is reliable and the quality is correct.

The compliance information can be **automatically checked** by automatic verification tools (*model checker*), provided that they can be expressed as measurable or quantifiable criteria.

This information can be of 4 types:

Item	Characteristics
Identification	Of the **person in charge**. Of the **creator**. Of the **date of issue** or of **updating**.
Consistency	Knowledge of the **reliability** of the assumptions used, by specifying the links to the parent information. Coherence with the rest of the data, in particular with its immediate **environment** and its **interfaces,** by defining **links** to the detection of *clashes* concerning the data.
Compliance	With the **regulations** used, with a link to the regulations used and to the result of the regulatory control. With the project modelling **Protocol**, using a *model checker* capable of monitoring the application of the modelling protocol (eg the SOLIBRI software package). With the **specific needs** of the project (specific contract rules or guidelines), by defining criteria measurable with a *model checker*. With the principal's **requirements** and **needs**, by defining criteria measurable with a *model checker*.
Integrity	Of the **data** (no corruption, voluntary or involuntary).

Maturity levels and degrees of development

Each phase of a project's lifecycle uses **input data** and produces **output data**. The quality of the data expected is therefore described and can be evaluated.

Compliance of output data with expected data

The output data must be compared with expected deliverable data (satisfaction of the client's needs, of the planned level of detail, internal consistency of the data, quality of the 3D IM and of the attributes entered, etc.). When the two match, the next phase can commence.

Phase review and maturity level

It is therefore absolutely necessary when designing a project to precisely define the **end of each main phase**. As noted above, we call this end of phase the phase review or *Review Gate*.

Each phase review marks a level of maturity of the project design. After each phase review, the level of **development** (see this concept below) is made deeper, and each designer adds **increasingly precise data**.

Thanks to this **iterative and progressive work,** the partners do not waste time during the preliminary stages, when there are many data that have not yet been approved by all stakeholders.

Moreover, the level of detail expected in each phase must be scrupulously **respected and not exceeded.** Indeed, defining an object too precisely in a phase of preliminary thinking may distort certain global and synthetic analyses.

Degrees of development

Degrees of development (or degrees of detail) provide a generic definition of the content of the IM. For example, they can be described as follows[9]:

Classification	Characteristics
NDD100	Project functions, envelopes of the alignments, volumes and locations of structures, overall duration.
NDD200	Approximate quantities and cost estimates, planned variants, choice of construction techniques, time needed to complete the structures.
NDD300	Elements necessary for implementing working drawings and simulations, for calls for tender, including details of completion times.
NDD400	Elements necessary for production, for ordering supplies, including the means of production and production methods.
NDD500	Items made on site, including all non-geometric information necessary for operation.

[9] derived from the classification in the AIA's BIM Protocol (E202)

Change management

During the phases of the lifecycle of a project, it is essential to manage changes to objects, in the **design** phase as well as in the **execution** or **operating** phase.

Traceability of changes

The project objects or information undergo successive modifications to:

- correct an error or inconsistency;
- provide information to an object to add detail or complete it;
- make a correction following the modification of a parent drawing or a working hypothesis.

These changes are tracked and managed (traced) so that they can be r**eferred to** and easily **retrieved**, even after the emergence and establishment of newer versions.

An internal version number

As long as the data is not shared, it bears a version number (or **index**) that is internal and unrestricted. It is used internally, in the design department, which is responsible and accountable for it.

Another (external) version number

Once the data is validated internally (data regarded as stable and meeting the specifications), it is shared with the other parties.

It then bears an **official external version number** in accordance with project element naming rules. This number enables all stakeholders to refer to the same up-to-date information.

If there is an inconsistency with other elements, if a modification is requested to correct or supplement the data, the object must be changed and its version number **incremented.**

Dual version numbering

This dual numbering (internal and external) serves to separate the 2 nested information lifecycles and distinguish the following aspects:

- **development**: unrestricted numbering;
- **sharing**: numbering compliant with IM rules.

Alternative management

The management of alternatives is a process **different** from the version management we've just seen.

Alternatives to optimize the project

It has to do with:

- **the search for solutions** to meet a new requirement;
- **the study of alternatives** to optimize a solution or a working procedure.

An alternative management system (or *configuration management system,* in industry) allows **the existence of many alternatives** of a single project under development (design, implementation, or operation).

Different branches serve to make changes, perform simulations, compare results, and merge changes.

Alternatives to take decisions

One of the major challenges facing the IM is to **effectively find the best solutions** using the information available.

The pooling of consistent information makes it possible to optimize the design earlier (thanks to the availability of information generated by all partners) and to study more alternatives.

Each alternative must be treated as a **full-fledged project** based on validated assumptions. For example, it can be used for:

- **simulations**,
- estimates of **quantities**,
- **cost** estimates,
- **scheduling** analyses,
- exploring constructive **methods**
- proposing **options** regarding staging or procedures.

The alternatives must therefore be managed perfectly in terms of:

- access rights,
- identification (naming or numbering)
- documentation
- versions.

When the optimal solution is selected and approved, it becomes the **reference solution** allowing all other stakeholders to build their own designs.

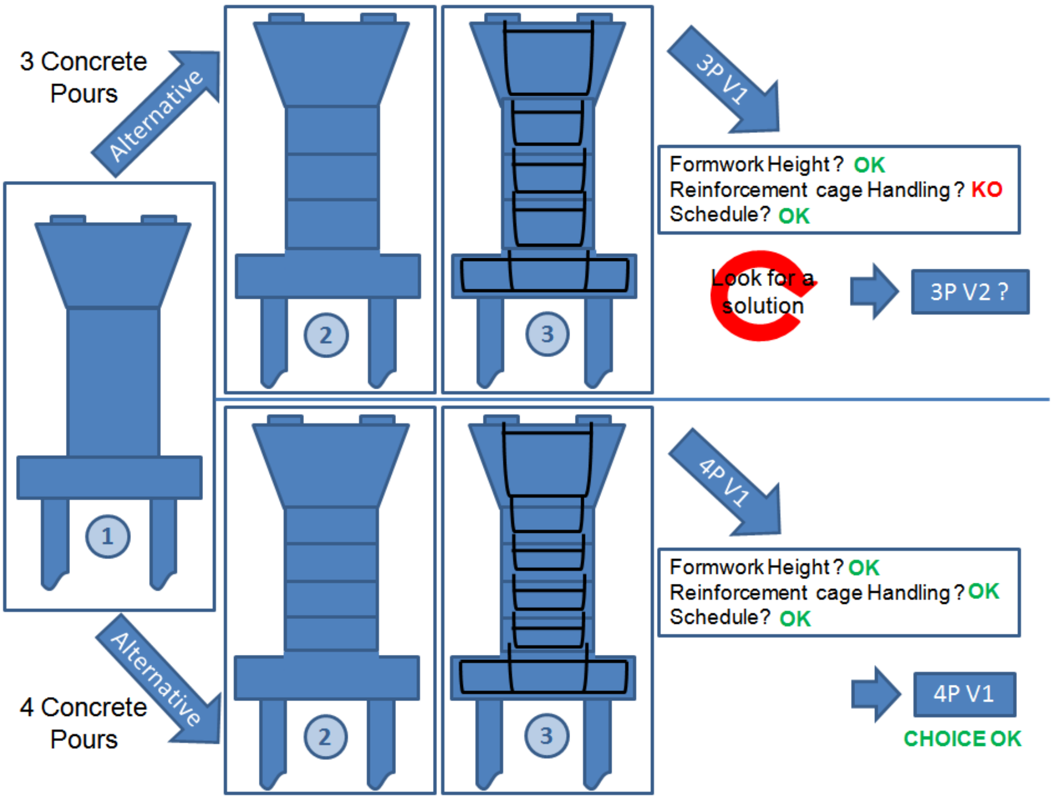


Figure C5-1: Alternative management

Complementary display tools

Alternative management must be completed by tools with functions that can be used to:

- **view** successively the different alternatives of the same object or collection of objects,
- **combine** several alternatives to form an assembly,
- **compare** variants to one another.

Traceability of decisions

One of the major benefits expected from the use of a shared IM concerns the **traceability** of the decisions taken. This is crucial for building trust among the partners. It makes it possible to **understand the evolution** of the design and to make the stakeholders **accountable.** We know who took a particular decision, why, and in agreement with whom or what.

Naturally, all decisions must be made in accordance with the commitments and the needs expressed by the client.

Associated information

The following information must be associated with any decision:

- **Who -** decision-maker.
- **What -** what decision.
- **Based on what -** references used in making the decision.
- **Why -** explanation of the choice.
- **When -** date of the decision.

Restriction

Note that decision management can be a burdensome process. It can **constrain creativity** and **hinder initiative.** We must therefore restrict the traceability system to important decisions or decisions that require action within a specified time.

Management of the 2D drawings associated with the 3D model

Management of 2D drawings must be retained, even in a shared IM environment that is *a priori* composed mainly of 3D objects.

Today and in the medium term, 2D drawings generated automatically from the 3D model remain **the main working tool** of the journeyman on the site.

Moreover, they are still and for a long time to come the **basis** of the contract documents required by the principals.

Management of drawings has therefore not been neglected in our description of the global model. The specifics of this particular process are spelled out in Appendix 2.

Intellectual property and protection of know-how

Project data and information must be classified into several categories according to their **degree of confidentiality**. In this way, each actor can preserve its intellectual property and protect its know-how.

Private data and public data

We must first distinguish between:

- **private data**: specific to a discipline,
- **public data**: common to the project and to all disciplines.

Confidential and shareable private data

In addition, private data can be of 2 kinds:

- **Confidential.** These concern the know-how of a discipline or a company. Examples include production costs, intermediate results of computations, high-value data and confidential data (such as contracts).
- **Shareable** (Non-confidential). These are relevant to at least one other discipline and must be shared.

Private and confidential data are managed internally by each stakeholder. They are excluded from the COMMUNIC project.

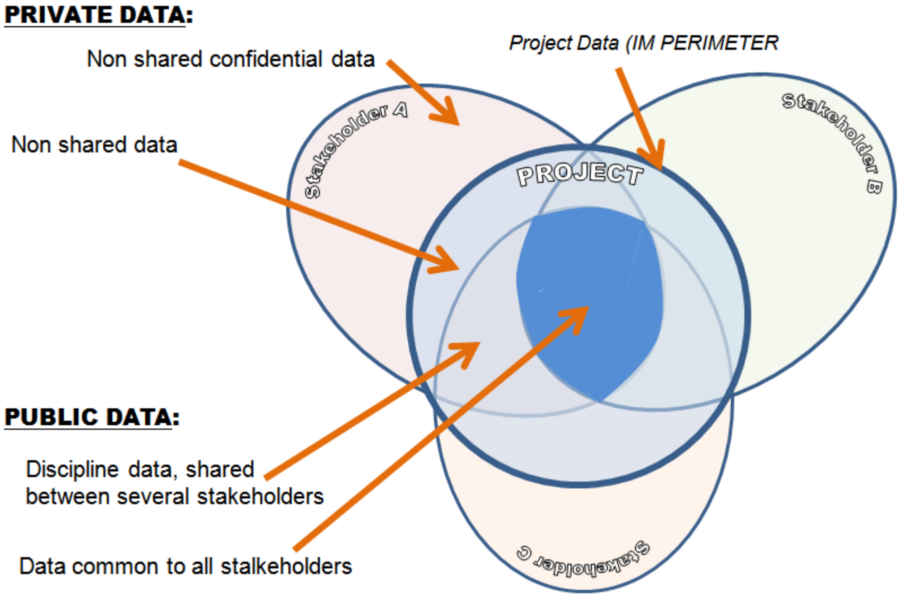


Figure C5-2: Private data - public data

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D - Adaptation of the organizations to implement an IM

Introduction

The IM to work together more effectively

The IM directly **impacts** the **productivity** of each of the stakeholders and of the organizations they set in place.

The global model modifies relations among stakeholders to favor collaborative work

The IM is associated with the adoption of a **new global model** to steer projects. This model is necessary for the IM to work properly.

It is based on the determination of each actor to work with the others on the overall **optimization** of the project. When a project goes well, all players share the **benefits**.

Information sharing in a common IM leads, through practice, to sharing the project's objectives more and more. It therefore promotes real **collaborative work** to attain them.

This change has a **technological and methodological** side and a **cultural** side that is necessarily slower.

We must therefore allow time for the adjustments described below to modify existing organizations.

Adaptations of the organizations

The table below shows the organization of Chapter D.

Module	Title	Contents
D1	**Project management**	Project management must be adapted to work in CE and to the use of the IM.
D2	**External authorizations**	The use of the IM changes the way the project is presented to external stakeholders. They must validate it, grant the necessary authorizations, or approve it.
D3	**Design**	The organization of the studies and the methods used change. This is due to new contractual arrangements favoring CE and the contributions of the IM.
D4	**Construction**	The builders must organize to intervene earlier in the project design phase in CE. Similarly, the IM leads the builders to better prepare the site and to organize it differently.
D5	**Operation**	The IM and CE impact the organization of operation, including its participation in the design process.

D1 - Project management

Introduction to concurrent engineering (CE)

Concurrent engineering, CE, is a new project steering logic that moves certain tasks and decisions forward in order to **delay** as much as possible those that commit major and strategic resources.

Starting further upstream to finish quickly in a "*right first time*" logic, it seeks to **shorten the completion times** of projects.

CE changes everything in depth ...

CE helps:

- Modify the **structures** of industrial organizations.
- Transform the **roles** and the **relations** of the traditional stakeholders in the creation of products or services (marketing, research, engineering, production, etc.).
- Organize new **interactions** and **compromises**.
- Set s**hared global objectives**.

... favors work on a project platform ...

CE also leads to rethinking the layout of the workspace. It systematizes the **use of project platforms** that bring the internal and external stakeholders in a project (subcontractors, partners, etc.) together, physically and regularly, in one place, physical or virtual.

... for co-development ...

Finally, CE has allowed the development of new forms of relations with partners. It calls on their engineering capabilities and brings them together **from the upstream stage of the project** (co-development).

... and finally, a profound change in relations between stakeholders

CE gets the design, construction, operation, and maintenance phases involved from the upstream stage of the project. In civil engineering, it has downstream stakeholders **acting upstream.** Project management must therefore manage the participation of certain stakeholders in phases in which they did **not usually participate**.

The nature and organization of the activity are also modified.

Generalization of CE

The older information systems managed data transmission from one designer to another. Now, the IM is based on the **real-time sharing** of information through simultaneous access to the same object in an evolving environment.

The IM promotes CE ...

Project management is profoundly altered by the use of the IM, in part because it leads to the generalization and systematization of CE.

... and vice versa ...

The IM allows concurrent organization and design. Conversely, the use of **CE requires an IM**. The organization must therefore evolve as soon as the tool is introduced.

... as is confirmed by the manufacturers visited

In the manufacturing industries, the IM has helped strengthen the **cooperation** between disciplines sought through **concurrence**[10] since the end of the 1980s.

Our visits to the aircraft and shipbuilding industries have shown that the development of CE coincides with the development of the IM.

[10] The control of organizations and the definitions the role of each participant depend on the constitution of the concurrent structures.

Teams distributed around a virtual platform

Broadening the concept of CE, the virtual platform or collaborative platform makes it possible to **cooperate** and **synchronize** from a distance around the single IM tool, through an Internet portal.

The collaborative platform allows co-design ...

Working on a virtual platform allows true co-design because the stakeholders **work together** on a project. This is opposed to "distributed design", a weak form of cooperation in which the stakeholders work simultaneously but not jointly.

... synchronous or asynchronous

The IM makes it possible to work synchronously or asynchronously, on a **real platform** or **remotely.**

Physical platforms remain necessary

The phases on physical platforms and direct communication are still necessary, especially at the beginning of the project. The physical platform lets people **get acquainted.** This helps in the later phases when the teams are geographically dispersed.

Cooperation

0

Cooperation on a virtual platform can take place by the following process:

Actor	Action
Project manager	Has a global and continuous view of the whole project. Grants access rights to the IM, for each authorized partner.
Designer	Depending on the space available and based on the geometry available, models the subassembly assigned to him. Has access at any time to the work done and updated in the fields that concern him. Can use the analysis tools to simulate behavior.
Designer and / or **IM manager**	"Publish" the result of his design in the global IM.
Project manager and **IM manager**	Perform quality and consistency tests using the IM.

Project management aided by the IM

The IM must assist project **management** as regards:

- **completion times**,
- **costs**,
- **documents**,
- **risks.**

Better informed stakeholders

The IM enables the various stakeholders to:

- **share** the same information and objectives,
- benefit from an **updated schedule**,
- identify the **role** of each party,
- **position themselves** precisely in the model and in the course of the project.

More ample information

The role of the project manager is facilitated by:

- direct access to information,
- the **motivation of the stakeholders** to provide information of use to him.

Project reviews

The IM was aligned on the concurrent organization and has enriched it. Consider two examples.

New digital milestones

In the project, new **milestones** will emerge: **digital** milestones. In industry, they have already appeared in projects that use the model. For example, Renault has since the early 2000s been using the *Digital Mock-up Design Review* (DMDR).

The IM reinforces the importance of project reviews

Project reviews should be at **shorter intervals** than today.

In addition to sharing the project's progress, they are **the *clash* settlement forum**. The very principle of sharing information and the new approval process are inherently sources of *clashes*. There must be **regular** reviews to resolve them.

New roles in the project

A new job, IM manager, to assist the project manager

The role of civil engineering project manager already requires the qualities it takes to lead a large interdisciplinary team spread over several sites.

With the IM, the interdependencies between objects take on greater importance. The project leader must assume a new role as IM manager to resolve problems:

- assignments of **rights**,
- parameterizations of **software packages**,
- read-write **access** *clashes*,
- leading project **reviews**
- **parameterizations** of the IM.

The preparation phase on the platform can be rather long

This role is particularly strategic at the beginning of the project, in the IM **preparation phase on the project platform**: parameterizing of software, choice of coordinates, and checks of interoperability.

This phase can **be rather long.** In an industrial case, seen during the visit to the *benchmark,* it lasted a year.

The importance of coordination of zones or systems

Our benchmarks have shown us that the project must often be **divided into zones** (eg at Airbus, the *Digital Mock-up Integration tool*). Similarly, there are **systems** that cut across these zones.
Zone or system **coordination** functions are therefore needed.

The current infrastructure projects already have these coordination functions. Independently, CE and the IM are going to reinforce their importance.

Organization	Type of coordination
Sequential	Hierarchy of disciplines
Concurrent without IM	Project (*Heavy Weight Project Managers*)
Concurrent with IM	Project and integration of model

These functions provide an **additional** level of project **coordination** compared to discipline / project coordination.

The IM adds to the functional breakdown a **spatial vision** of the project: it allocates to the designers spaces like a virtual 3D geometric shape representing the volume constraining the design.

At Airbus and at Gehry Partners, projects start as large volumes of space assignment (*Mock-up Space Assignment*). Within each volume, disciplines interact.

A flexible and pragmatic project organization

Using the IM should not restrict management to a single type of organization assumed to be efficient. Management must **adapt the forms of organization** to the types of projects managed.

In other words, the organization changes according to the project. The IM can be adapted to the organization without changing the expected functions.

D2 - External authorizations

Internal authorizations: not dealt with

The steering of infrastructure projects requires several kinds of authorizations. Some authorizations are internal to direct stakeholders in the project, for example, those of:

- the **client -** Design approval, change of phase, acceptance of the work.
- the **designers -** acceptance of outsourced services, signature of working documents, conformity of the work to the project.
- the **builders -** acceptance of subcontracted work, quality control.
- the **operator -** Acceptance of the work, operational records.

These authorizations are not dealt with here. They enter into the approval process considered elsewhere.

External authorizations

Other authorizations, which we call external authorizations, must be obtained from **external stakeholders.**

Many and varied

They are many and varied, as shown by the examples below

Entity issuing the authorization	Type of authorization
Government agencies	Compliance with specifications, with laws and regulations, with laws on water, air
Concessionary authority	Compliance with specifications.
Funders	Risk management, justification of loans.
Local authorities	Alignment, fit with the environment, various impacts.
Other clients	Impacts on other structures they own and / or operate.
Residents and **Associations**	Project impacts and remedial measures.

Various media to justify them

Apart from certain government agencies, the stakeholders are not specialists in the technical aspects of infrastructure.

The current means for obtaining authorizations are based on:

- **files** containing documents they approve;
- **presentations** based on drawings, photo-montages, virtual movies, physical or virtual models;
- explanatory **meetings.**

Paper to record authorizations

Paper documents indicate the scope and content of approvals or authorizations. They serve to record and manage them.

Inputs from the IM for external authorizations

The IM facilitates external authorizations in two ways - preparation of documents, pedagogy – with no need to change the authorization process itself.

Aid in preparing documents

The IM automatically establishes the **documents appropriate** to each interlocutor. The structuring of the project and the data model make it possible to:

- **sort** the information,
- **extract** it from all the other information that might pollute it.

An outstanding tool for explaining and getting to understand

The IM is structured and can be used to **reassure** concerning the rigor with which the project is steered. Its 3D visual representation **makes it easier to understand** the project.

The association of the information with physical objects that the interlocutor sees and understands **answers** his questions in more and more detail.

The IM is thus a unique tool for explaining and getting to understand.

Without changing current processes

The authorization process must not be changed, even if precautions are taken to ensure proper understanding of what is shown.

Anticipated developments

The contributions of the IM are immediate and require no major changes in the short term. On the other hand, technological and cultural developments are changing and will continue to **change the relations** between stakeholders, whether direct, indirect, or influential.

Dematerialization

For about a decade, there has been a trend towards paperless exchanges. They are established for example in **procurement/tendering** and are **being tried out** for **notarized instruments.**

Article 56 of the **government procurement code** defines the conditions of this dematerialization.

As a continuation of dematerialization by file sharing, it is likely that within a few years, information exchange will be by exchange of IMs. We must therefore prepare for the transition from paper documents or files to exchanges of IMs.

The new communications technologies

New technologies such as the **Internet** have significantly altered the means of communication with influential stakeholders.

For public surveys, a **site** is often provided for residents. They can **look up** documents that explain the project. They can **comment,** and the client replies.

It is likely that the IM, or more precisely a **public extract** thereof, will be accessible. Citizens can thus access complete information by real-time browsing in the IM.

The culture of sharing: Web.2, networks

The spread of Web.2 and of networks may also lead to associating **residents, citizens,** and even **future users** with the preparation of the project.

This allows **enrichment** of the **design** and of the **construction**. However, the impact on the project steering processes is considerable, and COMMUNIC was not aimed at this. COMMUNIC is limited to **collaborative work** by the direct stakeholders, which is already a very significant change.

Prerequisites

See below some prerequisites to using the IM for external authorizations process.

Interoperability

For modern and future communication technologies to be able to use the IM, they must be interoperable with it. Therefore the **exchange formats** and **data models** are **standardized**, de facto or even officially.

Integrity

The integrity of the information exchanged must also be guaranteed. In particular, an external actor must not be able to change the published data. Today, the **PDF** format ensures this integrity for written documents and drawings. There must be a **comparable format**, one not allowing changes, for the IM.

Access management

Access to the IM must be managed by rules and monitored by the IM manager.

The general guidelines for interoperability (RGI) provide rules

The French government has already issued an interoperability baseline, the General Guidelines for Interoperability (RGI), o*rdinance No. 2005-1516 of 8 December 2005 on electronic exchanges between users and administrative authorities and between the administrative authorities*.

The GRI imposes **interoperability rules** on the administrative authorities for their information systems. It defines an interoperability scope for exchanges between:

- administrative authorities;
- an administrative authority and a business;
- an administrative authority and a citizen.

It addresses:

Interoperability	Contents
Semantics	Design of exchanges Specification methods Semantic resources
Syntactic	Data encoding Data formatting
Technical	Browsing technologies Multimedia Web services Infrastructure Network protocols

The RGI must be completed by the IM's exchange tools and formats

The RGI deals with the tools and formats currently in use. For example, the PDF format covers a significant number of exchange situations.

It must be completed, as anticipated in its updating process, to meet the specific needs of IMs.

Limit requests for alternatives

The IM facilitates the study of alternatives through the provision of information, the interoperability of tools, and synthesis functions.

Even when made easier by the IM, the study of alternatives costs something

Even though the study of an alternative is facilitated by the IM, it must still be done and then managed. There is therefore a **direct cost** and an **indirect cost** of management and of the size of the IM.

CE cuts the cost of alternatives

CE lets stakeholders **participate** in the design process **earlier**, beginning from the quality studies, by spelling out possible options and actual choices. This builds trust in the stakeholders and limits requests for unnecessary alternatives.

It must be possible to **check** various options in the **initial phase**, so as to limit the risk of having to do it in the downstream phase. The **cost** of studying alternatives is **reduced** in this way.

Study fewer alternatives earlier

Altogether, then, optimization must be accomplished by:

- looking at major alternatives **very early**;
- **sharing** the analysis and the acceptance of the choices;
- then being **firm** in not calling these shared choices into question.

D3 - Design

A new context

Linear infrastructure projects mobilize a **growing number of stakeholders** who must organize themselves in **collaborative mode**, especially during the studies phase.

The IM will lead to associating more and more stakeholders in the design process.

Some examples of this evolution

In a Public Private Partnership (PPP) contract, traditional principal contractors (engineers, architects, urban planners, and landscape designers) now associate with **construction companies** from the design phase.

The strong support of clients for the sustainable development movement is leading to the involvement of new stakeholders, **engineering firms** specializing in the new "green" technologies, **"managers"** of the environmental issue.

The **operator** can now also act early in the project.

In PPPs and concessions, **financiers** want to track the design to control their risks.

Exchanges of more structured data

The intensification of exchanges of data requires **reinventing the decision-making process**. The IM comes along at just the right time to centralize data and organize exchanges.

The **breakdown** of the project into building blocks, the "breakdown structure" industrialists are fond of, associated with the **digital encoding** of objects, make it possible to manage complex projects involving a large number of stakeholders.

CE: earlier and more collaboration

Through its targets of reducing completion times and working more collaboratively from the beginning of the project, CE requires:

- **Designing in parallel** rather than sequentially.
- Revising the production and design approval **processes**.
- Tailoring **design software packages** to make them interoperable with the IM.

IM facilitates multisite production

IM allows the development of multisite work. This trend to a multiplicity of production sites results from:

- shorter lead times, which means that more teams must be mobilized to do the same work faster.
- action by more and more stakeholders whose grouping on the same platform cannot be justified economically.

Access to the IM via the Web is an expected function that will **facilitate** exchanges with the IM and thereby the sharing of information. The IM's information management and use functions can be used to **check these** parallel **uses** of data.

Three profound changes in the study process

What will be the **consequence** on the organization of studies? How can this new tool be **controlled** to deliver only benefits?

The paragraphs that follow focus on three aspects of the change:

- redefinition of the **sequencing of tasks**,
- the **virtualization** of exchanges,
- the pooling of **tools and skills.**

They attempt to identify possible impediments to progress.

Redefinition of the task sequencing

The first aspect of change in the study process is the redefinition of the sequencing of tasks.

Increasing the level of detail in lockstep is no longer an ironclad rule...

Until now, the progress of the tasks was based on a **steadily increasing level of detail** in the project. For example, Section 87-9 bis, "*Construction and appointments of concessionary motorways*", gives a **definition of study phases** based on the width of the "strip" impacted by the project:

- 1 km for the preliminary study of the feasibility stage.
- 300 m, for the feasibility stage itself.

The preliminary design, for its part, situates the project precisely. The text adds that "*studies of any kind [...] must be of a uniform level of detail*".

However, collaborative work using the IM implies that some stakeholders from downstream **participate in upstream design.** They contribute a more detailed vision that may lead to revising the upstream design. The homogeneity of level of detail within a phase is not necessarily preserved.

... implying adaptation of the texts

We know the famous **bell-shaped curve** which shows how, in the construction field, working in the IM has the effect of moving up in time the "effort" required for the project. To apply this model to linear infrastructure projects, we must **adapt the texts** defining the tasks (MOP law).

Benefit from the concentration of exchanges at the beginning of the project

The principle of collaborative work is to **share** information and postpone its approval to changes of phase. This approval means that the information is **approved** by the stakeholders.

The later an approval decision, the more **shared** and **mature** it is. It is therefore less likely to be questioned later.

For example, it is useful to delay approval of the choice of an **alternative alignment**. You want to **know everything** about the two solutions before choosing one. And this is where the IM, which allows the sharing of information **upon deposit**, is an asset. The intensification of exchanges at the beginning of the project makes it possible to group **maturation** sequences, which often extended up to the start of the work.

Management of uncertainties is an issue in IM

The management of uncertainties in part of a project is a mandatory **constraint** that is difficult to deal with. The IM is a tool for this management.

For example, it is decided to provide a noise barrier along the infrastructure. This information is then **immediately** placed in the IM and taken into account by all stakeholders. However, this arrangement is **defined vaguely**, because we do not know whether it will be a wall or an earth barricade. The IM associates this vagueness with the object and the other designs take this into account.

The choice concerning this vagueness may be even be **deferred** to a later phase if it does not interfere with the other designs or even construction operations.

The current definition of sequencing with a uniform imposed level of detail can therefore **be relaxed**.

Easier assessments, in real time

One strength of the IM is undoubtedly the possibility of quantifying a project based on well-chosen indicators (volume of cut / fill, cost, environmental impacts, etc.). Today, it is difficult and time-consuming to collect the information needed to generate them.

With the IM the data are structured and accessible at all times. It is not necessary to mobilize teams specifically for these cumbersome tasks (eg at the end of the preliminary design phase or for the awarding of contracts).

Missions are no longer justified in CE

In a PPP, for example, the collaborative work of the designers and builders in all phases of the project makes the "**Project"** mission (PRO) and the "contract assistance" mission (AMT) unnecessary.

There is no reason to retain an **intermediate step** between the preliminary design and the working design. Moreover, responsibility for the **working design,** now the builder's, can be transferred to the designer.

New references for stakeholders

These considerations indicate that the basic tasks of projects can be expected to change radically. The stakeholders will therefore have to find new "references".

Virtualization of exchanges

For the design of a large infrastructure project, the stakeholders (engineers, architects, landscape designers, alignment specialists, many draftsmen, etc.) can be **physically brought together** on the same project platform.

This organization is suited to CE without the collaborative tool to:

- facilitate **interdisciplinary** coordination,
- avoid **multisite** coordination.

The IM allows exchanges without a virtual platform ...

The IM makes it possible to share information around a **database** and 3D **visualizations** of the current project. This calls into question the organization of the work.

The performance of the web and of communication tools allows **rapid exchanges** of files, even very large ones. In addition, they make it possible to work together on the **same shared document** (eg WebEx). Collaborative spaces (Build Online, BSCW instance) are powerful tools for sharing.

The development of remote collaborative platforms makes it possible to consider, in the near future, sharing a **design** in **real time,** by a freehand sketch, between geographically distant teams (example of the "Collaborative Digital Studio" in the "CoCr" project, PI3C, etc.).

Multisite work and CE can be envisaged **with each stakeholder** remaining in his office, or even at home.

... but the physical platform is essential to starting the design work

Contrary to what one might expect, greater opportunities for sharing digital data are not necessarily accompanied by **effective communication** between project members.

Motivation, the will to communicate, starts with **physical contact,** relations between people.

The *benchmarks* we have conducted with other sectors confirm that it is **essential** to make provision for these physical encounters, in particular to:

Phase	Then
Project kick-off	Structure the project and the IM. Define the rules of operation. Discuss, get to know and understand one another.
Certain project or phase reviews	Resolve *clashes* and make decisions. Meet when it is necessary to discuss, make sure of understanding one another, and deal with any misgivings distance might conceal.

The virtual still has its **limitations**!

Pooling tools and skills

Working in the IM also raises the question of pooling skills around a common object, and by extension pooling software resources.

Imposed and / or interoperable software packages

A first configuration requires the use of one or more common software packages, to the exclusion of any others. However, This fairly common solution penalizes stakeholders with specific expertise, or even in-house software.

A second configuration requires interoperability and the use of standards for exchange of files, so as to leave the choice of tools to the designers.

The choice of one configuration or the other is a **decision** for project management to make. It must **suit** the project and its context.

The sharing of employees' skills must be controlled by the design process

In addition, the new work organization has more subtle consequences. Even more than the pooling of a **digital model**, collaborative work involves pooling the **skills** of stakeholders belonging to different legal and economic entities.

Yesterday, the course of the studies depended on the **challenge** the contractors took up, their **will** to become the authors of the design, or to demonstrate their superiority.

With the proximity possible around a common 3D model, the **joust** moves into the **sphere of the individual.** It is even likely that there is a **dilution of the sense of belonging** to the employer company.

This sharing is **rich** for the project and for the employee. It must also be so for the company. It is therefore necessary to:

- **Check and monitor** the design created by the employees.
- **Adapt** the information circuits and the processes to manage the sharing of skills, in particular from a legal standpoint.

In conclusion

The IM, a real tool for eco-design

Because it promotes:

- the taking into account of **all fields**,
- analysis of the **whole lifecycle**,
- **sustainable development** assessments,
- adaptation of the **solutions** to the **services** expected and even to **needs**,

the IM is a real tool for eco-design.

The IM serving stakeholders, their expertise, and their motivation

In this module on design, it is not superfluous to recall that the design quality of projects follows:

- <u>first of all</u>, from the **quality of the expertises** mobilized by each actor,
- <u>then</u>, from the **determination to optimize the project** shared by all stakeholders.

The **IM** is there only to **help** them.

D4 - Construction

The stakes

Ninety percent of the costs of a project result from its construction. So it is in that activity that the global model must **pay off first**. The site organization must therefore adapt to collaborative work using the IM in order to:

- **optimize** execution from the design phase,
- **prepare** the work well,
- **anticipate** contingencies,
- **control** risks.

The site in different contractual arrangements

Collaborative work with an IM does not always have the same impact on the organization of the site. It depends on the contractual scheme in which the project is steered. Indeed, the principal gain expected by the builders is in **preparing the site**, if possible **from the design phase.**

In this regard, the various contractual schemas for steering the project are not equivalent:

Type of arrangement	Features
Traditional	Design, tendering, work
Collaborative	Group of designers and builder (D&B, private concession, or PPP)

The design schema, then the construction schema

In this schema, the design, even developed using an IM, cannot include the builder's parameters (plant, equipment, distribution of teams, schedules etc.) since the builder is not yet designated.

However, using the IM, he can subsequently verify that his tools and his phasing of the work are consistent with the project already defined. We remain here in a **sequential process that is not collaborative** and so yields small benefits.

The builder may nevertheless use the IM to advantage to:

- **coordinate** the working drawings with his subcontractors (technical disciplines, etc.)
- optimize the **scheduling** of the work,
- simulate **scenarios**,
- optimize his **methods.**

The collaborative design and build schema

In the collaborative schema**,** the builder is included in the design process very early and so participates fully in the "collaborative work". This context is much more conducive to the use of an IM. It is therefore sought as a way to take full advantage of it.

The builder has the same advantages as in the previous case, and can in addition:

- **influence the design** to optimize construction,
- **anticipate** the site organization

Collaborative schemas are to be preferred

To take full advantage of the global model, schemas that involve the builders **as soon as possible** must be favored. This optimizes the project, and in particular its construction.

The value of the IM to the builder

As we have just seen, a **collaborative work** process is more **conducive** to optimizing the project than a sequential process.

Design in volumetric 3D objects

The IM brings together in a single 3D view all of the participants' contributions to the objects and helps understand them.

The builder can verify:

- the **compatibility** of the project with construction sequences (breakdown of concreting into lifts, stop joints, precast parts, etc.).
- the **optimization** of the project for his equipment (shoring, machines, mobile cranes, fixed cranes, etc.).
- certain **quantities,** if the IM has functions:
  - for calculating areas, volumes, etc.,
  - by nature, by region, by structure, by price structure, etc.

The methods engineer has a new visualization tool with which to analyze *clashes* in space and in time.

Time, for a 4D design ...

"Time" can be incorporated in the IM using a series snapshots of the project on different dates corresponding to the phases of the work:

Sequence	Examples
main work sequences	Earthworks, embankments, surfacings, equipment.
detailed sequences	Rotations of shuttering, nesting of precast parts.

... Allowing a film-like visualization of the course of the project

Whence the need for the builder to establish one-to-one links between each object of the IM and a phase of a schedule. This link can be created with schedules of the following types:

- **classical** GANTT bar type (MS Project, PNS, Primavera, etc.)
- a "railway" type **better suited** to linear infrastructure.

Some design software packages provide this function to varying degrees (REVIT Architecture, Digital Project, etc.). Others are dedicated to this type of connection (eg Sync LDT, Navisworks).

The IM can be used to produce a veritable **"film"** of the course the work as a succession of stills or animated sequences. This makes it possible to:

- **View** movements of loads, equipment, cranes, various plant, etc.
- **Settle any *clashes*** in time and space.

A fifth dimension, costs ...

In addition to mastering the project **geometry** (3D) and its **on-time** implementation (4D), the builder must comply with the planned **budget** (5D). But in the current system, these three objectives are managed by separate tools with no "connections" between them:

Tool	Contents
Drawing	Coordinates of geometric information
Schedule	Times, quantities, yields, resources (people, equipment).
Price study	€ (or other currency) obtained by multiplying: • **quantities** (measured on drawings by hand or by queries incorporated in the CAD software) • by **unit prices** from price libraries or tables taking into account yields, the company's resources, etc.

... is easier to steer using the IM

These calculations represent the expertise of the engineer-estimator, who **adjusts** the 3 components **by hand** to make them compatible. This very complex manual task does not allow many iterations and so sometimes falls short of the optimum possible.

The IM, by linking the geometry, the schedule, and part of the cost study, will eventually make it possible to run several scenarios and so choose **the most economical**.

The structure of a cost study for a large project is generally quite complex. At first, we will have to settle for using the IM as a **decision aid** to retrieve bills of quantities and verify in 3D space that the basic tasks, plant, equipment, etc., can coexist.

Even incomplete, such an integrated system in which the 3 components - drawings, schedules, and price studies - are now linked, will make it possible to **compare** several possible scenarios **quickly** and evaluate their **respective costs**.

A simulator to anticipate contingencies and control risks

IM software packages have functions or modules to simulate the functioning of any given technical discipline (electricity, lighting, acoustics, fluids, hydraulics, etc.). They transform the IM into a real **simulator** of the actual project.

This has two major benefits:

- during the execution of the work, the consequences of an incident on the program and completion times are assessed quickly and reliably thanks to the simulator;
- benefits to the project are amplified when the builder brings together his subcontractors and equipment suppliers around the IM from the design phase.

How to steer change

We understand from the prospects described above that the implementation of the IM requires the builder and the associated engineering companies to **change their organizations profoundly.** This change must be steered **methodically** or it risks failure or rejection.

Mobilizing the company's management

Like any major change of organization, the introduction of the IM must be made a general management goal and supported by the project managers concerned.

The merits of the approach are explained to each manager, as quality certification actions and actions related to sustainable development are.

Two implementation scenarios

Two scenarios can be considered for implementation on a real project:

Scenario	Benefits	Drawbacks
Large project	Capital expenditures (hardware and software) are small compared to the value of the project. The time available for preparation is longer. The gains from using the IM are significant.	If the IM tool is not mastered, the impact on completion times and costs can be large.
Small project	The number of people to be trained and equipped is smaller. A small project can be as effective as a large one for revising the current processes of the disciplines and to highlighting improvements in the design stages.	The IM is perceived as a 3D representation tool rather than as a platform for collaborative work. The gains may be considered too small compared to the effort in equipment and training. The cost of the studies may be considered unusually high compared with the usual ratios.

Important note

Whatever the size of the project, the adoption of IM increases the **cost of the studies**. This additional cost is **offset** by an **overall gain** from better design and integration of the project. We therefore strongly advise adjusting the studies budget accordingly and clearly stating that this has been done.

The subcontractor builder

Inherently, the collaborative work done around the IM presupposes that the stakeholders are identified and mobilized as early as possible.

Indirect stakeholders come on board gradually ...

It also presupposes that the indirect stakeholders (subcontractors and suppliers) know how to communicate and "feed" the IM with their technical data.

But they are going to **equip themselves and train themselves gradually** as the projects they deal with and their investment capacities allow. And some of their studies are carried out and represented using software packages other than the ones that are the first to be made interoperable with the IM.

... with the builder, a direct stakeholder as an intermediary for the transition

To solve this problem, we can adapt the solutions used in shipbuilding, for example, where the principal contractor - the builder **- transcribes** its subcontractors' data to **make them compatible** with the standards of the IM.

This task is performed by an "**integration tool**" capable of analyzing *clashes* and passing the information on to the subcontractors concerned.

The IM and working drawings

Some stakeholders worry that IM eliminates the 2D drawings that are used on site.

The working documents remain, produced using the IM...

The following working documents **continue to be produced** in their usual form for a substantial period

- working drawings, eg for earthworks, formwork;
- sequence drawings;
- detailed methods drawings;
- drawings per technical discipline;
- technical notes.

Working conditions (outdoors, in bad weather, shocks, etc.) and work habits make this necessary. However, the IM makes it easier to produce them.

Current modelling software can produce cross-sections of the structure studied in any plane. The cross-sections are then completed with dimensions, comments, details, references, etc. to constitute the working drawings.

... and are completed by look-up on modern devices ...

Modern devices (smart phones, tablets, iPAD, e-books, etc.) will inevitably play an increasing role in looking up documents when in the field. It will be possible to consult the IM from the site using suitable laptops. "Zero drawings" is probably **possible**.

... and tools for the automatic positioning of equipment on site

In addition, the development of GPS and radars makes **automatic positioning** in the field possible. And automatic guidance systems for construction equipment are already in use on sites.

These **guidance systems** will be **connected to the IM,** and many tasks will be performed without drawings. An operator will simply check on his laptop that the reality shaped by the machine matches the virtual object in the IM.

D5 - Operation

As we have seen for the design and construction parts, the IM is not a container for static information. This continues to apply during the **operation** of the structure, up to its possible **dismantling**.

Simplifying the IM for operation

The information generated by a design and construction project is rich.

Information that is too rich for operation, but must be archived by law

It is even **too rich to be usable** as is over the duration of operation of a structure: project quality management involves preserving information useful for the project and for knowledge management. But it is useful only for the **archiving required by law,** not for the operation of the structure.

For example, project information management involves **preserving** successive versions and alternatives for the whole project, along with the letters exchanged, arbitrations, approvals, etc. The **life of the project,** including both design and construction, in short!

However, this information is useful only for **recourse** or **other query** requiring access to information specific to design management or to the life of the project.

Culling the IM ...

It is therefore necessary to cull the IM. This means turning over to the operator an IM from which at least the following have been removed:

- Information concerning the management of ***workflows*** (versions, alternatives, approvals), keeping only the built and accepted version of the structure.
- **Temporary objects** (construction equipment used to model production methods, for example, or the transitional phases of earth-moving).
- Information concerning the **initial specifications** of the order.

... to leave only the reality handed over

In short, keep only the objects, properties, and documents relating to the work as built in order to start off with an **IM that reproduces virtually what was actually delivered.**

The IM, a structure management tool

Thus, it is possible to use the IM as an **interface** to:

- **access** the actual information measured *in situ*,
- dynamically **monitor** the behavior of the structure.

The IM as source and custodian of information

More specifically, this means that the IM becomes:

- the **source** of all information about the project;
- the **custodian of the actual information** measured in the field by various pressure, temperature, and wind sensors.

This makes it possible to:

- **check** whether the structure actually behaves as expected**;**
- **simulate** its subsequent behavior in cases of non-compliance with its normal conditions of use.

Example: a truck crashes into a bridge pier and burns. The instrumentation of the pier reports the information. It can subsequently be used to **simulate** the accident conditions virtually, using a computing engine kept in the IM, and so **estimate** whether the bridge structure remains viable.

The IM to store and manage changes to the structure

The information hosted by the IM is a **virtual transcript** of reality. The designers / builders provide an up-to-date version (as-built) when the structure is handed over.

It is the **operator** who must **keep** this information **up-to-date**. This means that all **reports** of incidents**,** repairs**,** and other work must be **attached to the virtual objects** concerned in the real world. Objects that are repaired or replaced must be **modified** accordingly in the IM.

This means using the IM as **custodian** for all the information reported by maintenance (CMMS)[11].

Guarding against computational obsolescence of the IM

An infrastructure project is not a consumable or a standard commodity. It reshapes the landscape **in a lasting manner**. And, even when small, it is large enough to constitute, by nature, a structure that will not be dismantled before a **at least 30 to 100 years,** depending on the contract.

Maintaining the management system and the data

The operator must maintain the **virtual data** of the IM reproducing the reality on the ground (construction and operation). To attain this objective, it must maintain both the computer system that serves as support and the computer formalization of the IM.

This involves the following essential linked components:

- **the** information **management system** (software and hardware), by investing regularly in a more powerful and more innovative system;
- **the data** in a computer formalization (file format) that is up to date, efficient, and compatible with the existing or planned information system;
- **regular renewal of the media** to avoid loss of data.

Example of obsolescence

We illustrate this with the example of someone who wrote a professional thesis in the 1980s, and cannot today use the computerized version from back then, if there was one, for the following reasons:

- **Drives** for the physical medium on which the document is stored **no longer exist**. Assuming that such a drive can be found, the medium on which the information was stored has a good chance of no longer being readable.[12]
- The **format** in which the document is stored is **incompatible** with current operating systems.
- The format of the document is **incompatible with modern word processing software**.

Finally, to amplify, we can say that, to keep this professional thesis fully up to date, the author would have to **revise it regularly** to keep it current.

[11] Computerized Maintenance Management System
[12] Contrary to commonly held ideas, the life of modern data media is limited, for example 2 to 5 years for a CD / DVD once burned (the dispersion on these times is very high).

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E - Redistribution of responsibilities

Introduction

Responsibilities

We have so far described:

- the creation of value by the IM (section B)
- the structuring and circulation of information (section C) that can achieve them,
- the necessary organizational adjustments (section D).

Here we say more about **developments and changes** in the assignment of responsibilities. They are entailed or made desirable by the development of collaborative work and the use of the IM.

Five topics analyzed

This chapter is in 5 parts:

- the evolution of contractual arrangements,
- the sharing of responsibilities,
- approval methods in concurrent engineering,
- changes in responsibilities for each actor,
- intellectual property and know-how.

E1 – The evolution of contractual arrangements

Contractual arrangements

There are currently many possible contractual arrangements. We need not identify them here to analyze the impacts of collaborative work and the IM.

Three contractual arrangements taken as examples ...

We consider only the following three contractual arrangements:

- **"Classical",** in which the client is bound by contracts with a principal contractor, construction companies, and other service providers.
- **Design and Build** (D&B), represented by a single contract between a client and a designer-builder consortium.
- **Concession** (PPP), in which the concessionary authority has a global contract with a group of designers, builders, operators, and financiers.

... to highlight their differences

Here we show the differences in their suitability for:

- the development of **collaborative work**,
- the establishment of a **shared IM**.

We do not attempt a detailed analysis. It should nevertheless be emphasized that a seemingly minor **transfer of responsibility** may greatly modify the workings of the arrangements, in particular with respect to collaborative work.

Five kinds of contractual arrangements

Five kinds of contractual arrangements between the stakeholders can be distinguished. They are represented in the diagrams below by signs differentiated by the following key:

Figure E1-1: Key to contractual arrangements

Classical contract schema

The contractual framework currently most widely used is one based on a client that combines the functions of **owner** of the structure and **operator**. This applies for example to infrastructure projects for the state or for local governments. These organizations have their own technical staffs in charge of projects and their own infrastructure operating departments.

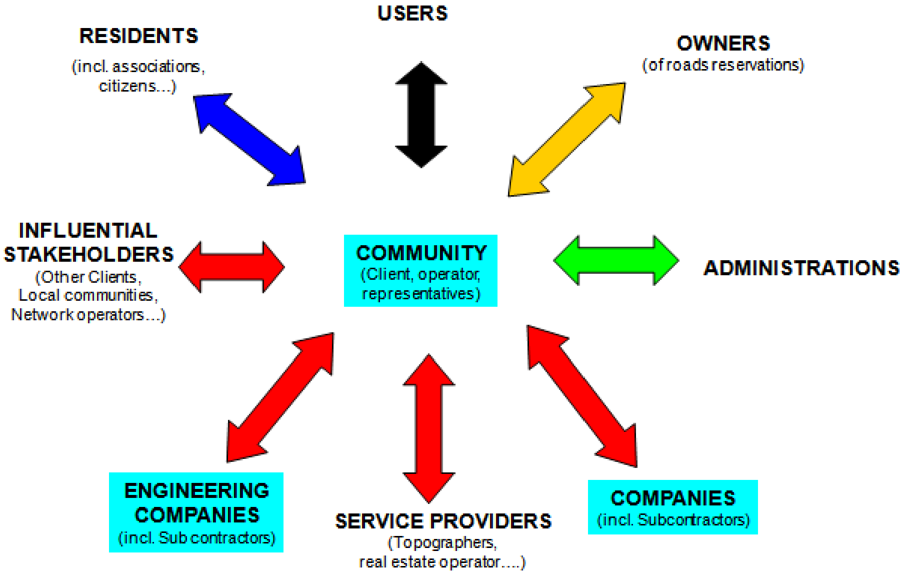

Figure E1-2: Classical contract schema

The client awards contracts

The client enters into contracts with each of the direct stakeholders, in particular with the principal contractor and the construction companies. It may also, in some cases, enter into a contract with an outside operator for the operation of its structure.

The principal contractor manages the client's contracts

The principal contractor is responsible for the **design** and for **managing** the execution of the works contracts. It also manages **service contracts** (client assistance, land, etc.) the client enters into with other service providers in connection with the project.

Builders without contractual ties to the principal contractor

The builders thus have contractual ties **only with the** client, even if the construction contracts signed by the client are managed by the principal contractor.

There is no contractual tie between the designer and the builder.

Collaborative work and the use of the IM specified in each contract

For collaborative work to develop between the stakeholders:

- this must be specified in **contracts**,
- the objectives of the stakeholders must be **convergent** in this respect,
- an **entity** must be put in charge of harmonizing and leading the collaborative arrangements.

Design and build (D&B) contractual schema

The D&B schema, prevalent in recent years, is defined by the constitution of a consortium of designers and builders. A **single contract** binds this group to the client.

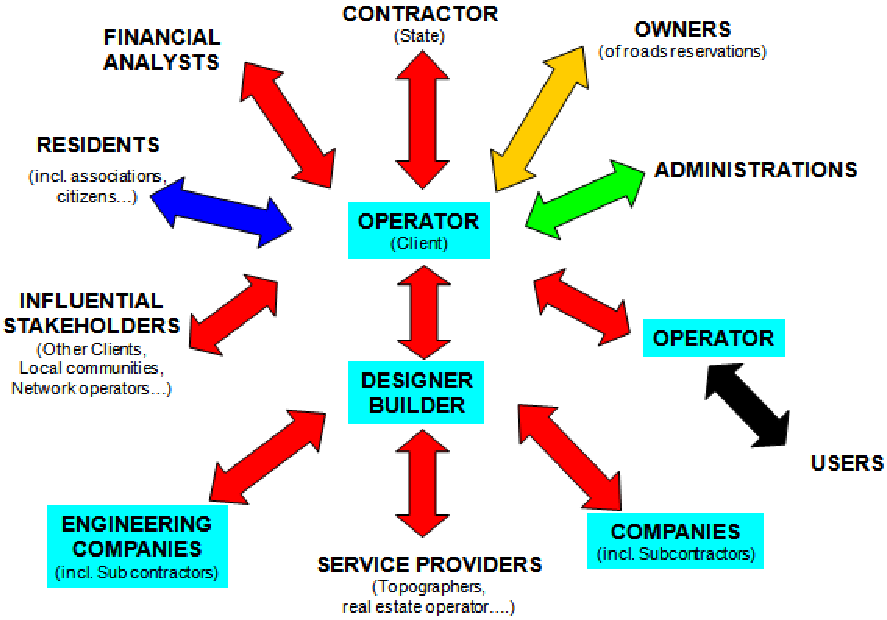

Figure E1-3: Design and build (D&B) contractual schema with concession

The client can be a statutory undertaker or a community

In the diagram upper, we have selected as client a **statutory undertaker**.

The schema can also be an adaptation of the classical schema with the state or a local government, with the engineering firms, contractors, and builders grouped in a single contract.

This does not eliminate the need for a contract between the client and the principal contractor to manage the execution of all contracts signed by the client.

There is a transfer of the client's responsibility

The major change with respect to the classical schema is a transfer of responsibility for the design from the principal contractor to the **design & build group**.

Concurrent engineering is encouraged

This transfer is a first step towards concurrent engineering, because it makes it possible to identify a **community of objectives** shared by design and construction.

Collaboration between the designer and the builder is encouraged, even if it remains to arrange collaborative work within the design & build group by contract.

The **common objective of optimization** of the project is better reflected in the contractual incentives. There is only one contract containing these clauses, entered into between the client and the group.

Contractual schema of the concession (or PPP)

The schema of the concession or public-private partnership (PPP) is particularly representative in relation to collaborative work and to the IM when it binds the four major stakeholders in the project together by contract as a "statutory undertaker-designer -builder-operator" group.

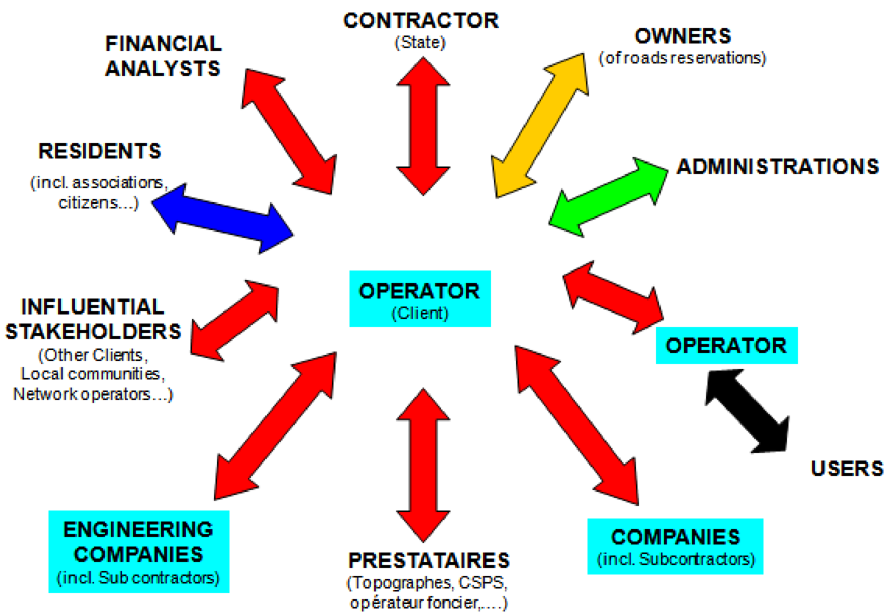

Figure E1-4: Diagram of the concession contract (or PPP) without D&B

A contract by objectives

The concessionary authority then enters into, with this group, a **global contract by objectives.** This grouping allows a global optimization of the project even greater than in the case of D&B.

A single player other than builder-designer-operator is a degraded form

In current practice, a concession or PPP often has more limited ambitions. It covers a mere transfer of some responsibilities (and risks) from the client to a single actor.

This configuration reduces to the classical schema plus one additional player: the **holder** of the concession or PPP contract. This can simplify the awarding of certain contracts, but without instituting collaborative work. It is less effective than the global consortium contracting with the concessionary authority.

Collaborative work and the use of the IM are instituted by contract within the group

Collaborative work always requires a **contractual translation**. In the case of the concession or PPP, this can take place earlier in the course of the project and with greater regulatory flexibility.

Various legal structures are possible to give stakeholders an interest in the overall optimization of the project: a financial interest in a concessionary company, a joint venture, protocols based on performance targets, etc. These **formalize a real partnership**.

This is the arrangement most conducive to collaborative work

Of the three schemas presented, this is the one that seems to us most favorable to the development of collaborative work, if the contract holder in fact includes the direct stakeholders the project.

The establishment of genuine **concurrent engineering** is made possible by the participation, with common objectives, of the various major stakeholders (design, construction, operation) in all phases of the project.

This schema is currently being **used more and more** in large projects. It can be expected to spread in coming years, including to smaller projects.

Contracts and incentives for collaborative work

The incentive clauses now found in most contracts are based on **bonuses** and **penalties** that are tied to the goal of overall optimization of the project.

They are **far from sufficient** to drive the development of collaborative work. It is therefore necessary to develop, with lawyers, **clauses that encourage** all stakeholders to **mobilize** to optimize the project.

The contractual arrangements proposed above offer various opportunities in this respect, summed up below.

Schema	Opportunities	Constraints
"Classical"	The responsibilities of and risks incurred by each actor are defined in **separate contracts** with the client. The **client** is also the **operator**. **Collaborative work** can avoid divergences resulting from poor coordination of the contracts. The **bilateral contracts** facilitate control of the confidentiality of innovations.	All contracts are with the client. There is therefore a risk of a **bottleneck and loss of responsiveness** in coordination with each player in the project. The collaborative work must be defined in a **coherent and complementary** manner in each contract.
Design and Build (D&B)	There are additional facilities to include **incentive and participative clauses** for the designer and builder to optimize the project. This type of contract allows a **partnership** as defined above (i.e. with sharing of gains). The **IM** (imposed or shared) is a medium for this partnership.	The clauses must be in the group's **internal contract**. This type of contract leads the group to **take more risks**. This fact must be reflected in the contract **price** agreed to by the group and the client.
Concession (PPP)	This type of contract allows a **partnership** as defined above. The designer-builder-operator group makes possible **maximum optimization** of the project by establishing comprehensive concurrent engineering (including the operator).	The clauses must be in the group's **internal contract**.
	Note: We must take into account the **time scale**, which is much **longer** since it covers operation.	

The IM and / or collaborative work

The use of an IM **imposes** a number of clauses in contracts: ownership, management, approval, etc. However, it **does not** necessarily **determine** the nature of the contractual relations.

The IM can be used without collaborative work

It is possible to use and impose an IM **without** there being real **partnerships** with and between the users. This is possible in all contractual schemas.

Collaborative work without the IM

Conversely, collaboration and partnerships do not require the use of an IM. Concessions and PPPs are currently steered without an IM. It is just these experiences that have led the COMMUNIC partners to engage in **joint reflection** on **improvement** through the use of an IM.

The optimum is collaborative work with the IM

However, the contractual arrangements that encourage collaboration among all stakeholders are those in which an IM is easiest to implement and creates the most added values.

E2 – The sharing of responsibilities

Opportunities and risks in collaborative work

The goal: optimization and innovation

The establishment of collaborative work has as overall objective ensuring the optimization and success of the project by involving all stakeholders very early. In this way:

- the technological capability of simulating and evaluating the overall project from the start opens up possibilities of **optimization** or even opportunities for **contractual incentives**.
- pooling the resources and approaches of the designers, builders, and operators is likely to encourage **innovations**, both **technical** and **organizational**.

The **common goals** that must be shared must be declared.

The distribution of partnership gains must be clear

The purpose of the "partnership" contracts is the distribution of a potential gain.

The partnership requires a common contractual relation among the stakeholders in the building process, since otherwise it may not be possible to decide how the gains are shared among the "partners". It must therefore be specified from the outset how any profits or losses that result from the collaborative work will be shared. **It is these clauses that create motivation.**

Know the responsibilities of each actor

Collaborative work requires that all participants know their contractual relations with the principal stakeholder, or at least the roles and responsibilities of each.

This transparency allows a better functioning and helps build trust.

Obstacles identified: growth of legal considerations and regulations

What emerges, in spite of all, from our thinking is that encouraging the use of the IM will involve **changing** the current **legal framework** to make it more **transparent**.

For example, the sequential steps of the project study cycle (MOP law in particular) must be adjusted to be **more in line with** the realities of this new way of working.

And the detailed preliminary design (PRO) and detailed working design (EXE) phases become **increasingly intertwined**. They are no longer as distinct as in a classical engineering schema, which requires finalization of the PRO phase before calls for tender are issued. This makes it possible to award construction contracts before moving on to the production of working drawings and the working methodology in the working (EXE) phase.

Two contextual factors can be an obstacle to the collaborative spirit and the creativity associated with it:

- The **growth of legal considerations** in relations between stakeholders, who are encouraged to optimize their contracts rather than the project. The sum of the optimizations of the contracts is less than the potential global optimization of the project.
- **Excessively confining legislation** and **regulations.** The Procurement Code, general specifications, the MOP law, etc.

Clauses in the contracts could anticipate ways of **eliminating these obstacles** in the context of each project.

Anticipate handling changes of content, missions, or resources

The very early intervention of the builder and operator is likely to cause **many revisions of studies** in the overall economic and technical interest of the project. These revisions have an **impact on the budget** allocated to the designer.

Conversely, the designer can ask the builder to build **test structures** in advance (prototypes, pre-loads, test embankments, test segments, etc.).

Again, collaborative work should allow some flexibility in the **provision of resources** by stakeholders. So arrangements should be made in the contract to favor adjustment of the resources if that optimizes the project. For example, studies might have to be strengthened to achieve a more economical project, or conversely an early check of the constructability of an alternative may be needed.

Study contracts where risk sharing is assumed between builders and designers can be considered as a **package** and completed by a **schedule** to deal with contingencies, risks, and changes. These clauses provide **flexibility** and guarantee the **responsiveness** of the stakeholders.

Intellectual property and non-poaching clauses

The contracts must also:

- Deal with **intellectual property** and the sharing of **innovations** between partners.
- Include strong **non-poaching** clauses to create the trust needed for collaborative work.

These clauses are a prerequisite for the establishment of **trust** between stakeholders.

Risks and opportunities associated with the IM

The establishment of a shared IM is accompanied by opportunities and risks that must be **dealt with contractually**.

The rights and duties of each actor must be established by contract

The database must be common and shared by all partners. This makes it possible to use (without re-entry) the information generated by other disciplines to **add value and expertise** to them.

Traditionally, the sending of a 2D drawing on paper or in non-editable electronic form (PDF) requires re-keying of the data by the other partners who want to:

- **use** it in their own design and simulation tool,
- **appropriate** it and **check** its quality (consistency and compliance).

Retrieving data from a shared database requires **confidence in the quality** of the information, since they are used as is, without questioning and without challenge.

The data remain the **property** and therefore the **responsibility** of the party that created or enhanced them. And what is designed with these data also remains the property of its author, without the responsibility for the basic data being changed.

The IM is therefore a great opportunity to **develop partnership** between stakeholders in the building process. In addition, it requires clarification in terms of **responsibilities**. The contract must in particular specify for each actor:

- access rights to the IM,
- content of the IM,
- the functions provided,
- access to or retrieval of the IM upon project completion,

and especially:

- the duty of **sharing** information,
- **responsibility for the information.**

All of this is an opportunity for each actor to **optimize its service** while reducing the associated production costs.

Diluted, but traceable, roles

The origin of the **optimizations** is sometimes diffuse since they are often the result of collaborative work.

The **contractual incentives** may be more difficult to implement, but the IM records the ownership and history of information.

The **roles**, **contributions,** and **responsibilities** of each are traceable.

The ability to identify relevant information

If the IM can be used to better express interfaces, it also gives access to **more global information** than that strictly necessary for each actor.

While it normally facilitates understanding the subject, this openness may be accompanied by misunderstandings about the nature of the information, which may be **contractual or not**. The contracts (and the parameters of the IM) will have to identify contractual information in the IM, with an order of **precedence**. Note that we do this today by listing the contract documents in order of use in the contract.

Management of vagueness to avoid misunderstandings in external communication

There is a risk, especially in the case of residents and third parties, of failing to distinguish between:

- what is **defined** and therefore proposed, in their opinion,
- and what is **uncertain** and may still change.

Indeed, the IM manages the concept of vagueness, and the users (direct stakeholders) know how to take it into account. However, third parties (eg residents) may see all of the objects with the same realism. A **charter** on the use of the IM for **external communications** must be developed and referenced in contracts.

Watch out for the size of the IM

We must avoid drift in the use of the IM by uncontrolled size. The IM would then host a "monster", of which we could no longer reasonably ensure the consistency.

Rules must therefore be defined for the deposit of information: deposit only **relevant information useful** to the other stakeholders. A structure of **nested models** (like Russian dolls) may be a solution. Contracts must specify the choice.

Guarantee the perenniality of the IM

Rapidly changing **computer technology** is a threat to the perenniality of the IM (this point was discussed at the end of D5).

Responsibility for maintaining the information it contains must be assigned to an **actor**. We obviously think of the client. But he may delegate, for example, to the operator, or outsource this maintenance.

The contracts include the **commitment** to maintenance and accessibility.

A new approval process

The IM leads to **changes in method** for validations and approvals. The changes of status of the information may result in transfers of responsibility. These processes must be contractually defined.

For	See Module
Approvals internal to the project	E3
External authorizations	D2

The standards imposed must be defined

A prerequisite to the overall model is interoperability of the software used by the stakeholders with the IM. This interoperability is based on an exchange standard using a **neutral format** and on a **common data model**. This constraint must be made contractual.

Tools do not replace expertise

While the IM is an **exchange gateway** between architects, city planners, landscape designers, and the engineer, it does not replace the constructive logic.

There is a **risk of deviance** from its use: the 3D IM requires **more** learning and mastery of computing than traditional tools. This training does not eliminate the need for the technical training needed to think about the design.

The IM is therefore **not an end in itself, nor does it guarantee** control of the design.

Impacts on the sharing of responsibilities

Collaborative work and the IM are essential givens for the project organization. Both in fact have an impact on the breakdown of responsibilities between stakeholders.

Responsibility for design is more widely shared

In a D&B or PPP project, the involvement of the builder (or even the operator) in the preliminary phases of design **affects the engineering tasks**.

Even if the responsibility of the builder and of the operator is low in the early stages of study, their needs and constraints are taken into account. This eliminates some decision steps in order to:

- optimize costs,
- reduce project completion times,
- identify risks and contingencies.

The IM creates technological opportunities to modify the roles and responsibilities of the stakeholders.

For example, the downstream stakeholders (builders, operators) are involved much earlier in the project approval process. The traditional **gap** between **design** and **construction narrows**.

For example, it is **easier to transfer** responsibility:

- for the **working drawings** from the builders to the **designers**.
- for the general operation **schedule** to the **builder**.

The responsibilities of each actor with respect to the IM are specified

In general, collaborative work **dilutes responsibilities** between stakeholders. Since this phenomenon may be accentuated by the use of the IM, it is essential to define:

- **the use** of the IM, its **scope** and its **ownership**;
- the **contractual value** of the IM and the information and tools it contains;
- contractual management of the **confidentiality** and **intellectual property** of the information contained in the IM (See Section E5: intellectual property).

The responsibility of the owner (creator) of information is strengthened

The IM creates responsibilities and duties.

For each item of information, an **owner is registered**. The owner is responsible for it upon its **creation** and for all **subsequent modifications**. This responsibility was not as clearly and precisely defined without the IM**.**

However, the transition to the use of a shared collaborative IM cannot be imposed immediately on all project stakeholders. **Some sub-contractors** have less added value and cannot be involved in the collaborative process. Their responsibility within the IM (eg entry of the value of some attributes) is therefore transferred to the stakeholders who employ them and who must often re-capture their data.

A **precise contractual definition** of the responsibilities of each must be formalized.

A specific new responsibility is vested in the manager of IM

However, responsibility for the **consistency, availability,** and **dissemination** of the information contained in the IM is assigned to a player with specific skills. This management of the IM, an interdisciplinary task, must be pooled and become a new role: **IM** m**anager** (See Module D1).

The role of IM manager can either be entrusted to one of the **direct stakeholders** in the project (eg the principal contractor) or be the object of a contract between the principal and an outside actor (eg a collaborative services platform).

The project's quality system will reflect this distribution of responsibilities

The roles and responsibilities are reflected in the contracts and in the project's quality system, which must state, in particular:

- by whom and how the **input data** are received,
- how the as-built **documents** are received,
- the **process** of **approval** of the elements of the IM.

The IM, an aid in drafting and executing the contract

IM can advantageously be used make contractual relations reliable when awarding contracts.

Help in execution ...

The IM allows **simulations**, **explanations,** and a **representation** of the project that facilitate its adoption by the various stakeholders. The schedule and the implementation phases are much easier to explain with simulations. The IM can:

- **Simulate before** contracts are signed (risk analysis and search for alternatives, in particular).
- **Obviate misunderstandings** between the contracting parties through a clearer understanding of the context.
- **Archive** the **reference state** before the optimizations (traceability, history of the project).
- **Detect anomalies** to be included by contract in the quality systems.

Define more explicitly the **interfaces** between stakeholders (scope of intervention of each).

... And help in the management of the contracts

Similarly, the IM aids the management of contracts. It is a tool for:

- **traceability** of changes of program and modifications;
- **evaluation** of changes in simulated scenarios;
- **simulation** of costs and completion times when preparing amendments;

Precautions for an IM becoming contractual

We must take into account possible misunderstandings in the understanding of what the IM represents. It is necessary to be **vigilant** when the IM is a part of a contract.

The IM is a pictorial representation (icon) of the project as it stands **at a given date,** but its features are not all equally binding. Some representations are largely conventional and approximate (trees, decorative items, etc.). In this regard, legal precautions must be taken by stating, for example: "**representations not binding"**.

It is also useful to provide different representations of a project, more or less schematic, according to the maturity of the project.

Prospect: the IM as tool for virtual tests of certain functions

In industry, the IM can replace physical tests on full-scale mock-ups by **numerical simulations** (eg *crash test* in the automotive industry).

For this use to be officially recognized, the IM must be **certified**, meaning "*compliant with requirements specified in a baseline"* (AFNOR).

Many tests of infrastructure can be performed on the IM

In the field of interest to us, linear infrastructure, it is conceivable that a **certified IM** should allow "acceptance" of the characteristics of the structure prior to its physical construction.

Several areas might be concerned, among them:

- **Road Safety -** visibility, compliance of the geometrical characteristics of the alignment, of the positioning of equipment, signage, etc.
- **Rail Safety –** block system, signage, etc.
- **Fire Safety** in underground structures **-** simulation of smoke, the evacuation of people, etc.
- **Performance** in operation and maintenance.

The digital tools guaranteeing this performance must **be approved**.

E3 - Approval procedures in concurrent engineering

Approval process in industry

Before analyzing the impacts of the IM on approval procedures in the construction industry, we consider what is done in other industries (in particular the automotive and aerospace industries).

Approval concerns components, assemblies, and finally the product

In the design phase of an industrial project, only **components** (or units) and **assemblies** are validated.

The product is broken down into elementary components optimized for mass production. Each component is then validated. The components are then assembled and fastened together, usually in an assembly plant.

The product, as an assembly of components, must also be validated.

The "V-shaped " approval cycle

The lifecycle of an industrial project for mass-produced items is "V-shaped."

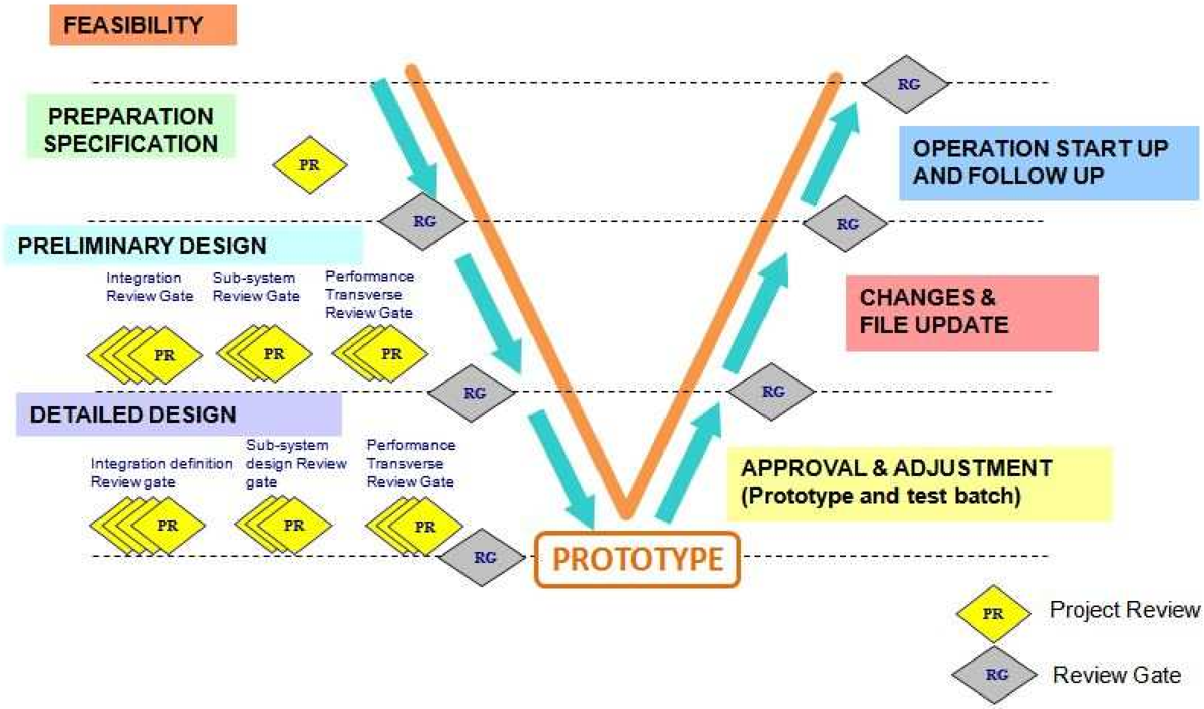

Figure E3-1: Example of V-shaped cycle used in manufacturing

The entire descending first branch of the V is the **definition and design phase.** The base of the V is reached when the first prototype is **built.**

The ascending second branch is the **phase leading up to mass production** of the item and its maintenance.

The V-shaped representation of this cycle places checks on the same level of detail on the same horizontal line:

Check	Level of detail
Development	Detailed Design
Update of files	Preliminary design (main phases)
Tracking in operation	Preparations specific to the program defined at the beginning of the project.

Tacit approval of the design without drawings

For much of the design phase, there are **no approvals of drawings** as such.

Approval, as the design process proceeds, is **tacit**: attention is paid to *clashes* between data, to interference. As long as no clashes are identified, the data are regarded as valid, even if there is no specific approval status.

Drawings are used only for the phase of production of the prototype, then for the **mass production** phase.

There is an approval of the industrial product at the **end of manufacturing**, by a certified outside organization (eg motor vehicle department), which **approves the product for use**.

Approval of infrastructure projects with the IM

This **process** based on the tacit approval of components can be **transposed** to the information carried by the IM for infrastructure projects. However, some adjustments are necessary.

Work on objects and not on drawings

Compared to our traditional way of working, based on drawings, the IM contributes an **overview** based on objects. While the drawing favors a local vision (discipline-specific approach), the IM facilitates **coordination**, the **assembly** of objects or components.

Steps towards an increasingly detailed design

As in the case of an industrial project, the lifecycle of a construction project is made up of **several phases** punctuated by "progress reviews"(*Quality Gates*).

Each **progress review** serves to decide **on what basis the project will continue** in order to maintain compliance with customer specifications. The approach is risk management in terms of cost, completion times, and feasibility.

As the project is refined and gains detail:

1. We fix the envelope of the alignment (the corridor) during the first stage.
2. We specify the type of work by area (bridge, tunnel, excavation, and embankment).
3. We specify the major parts of a structure (length of bridge spans, single- or multi-tube tunnels).

In fact, we keep breaking down into increasingly detailed components.

Building prototypes

Construction projects are **more flexible** than projects in other industrial sectors because there is no mass production: it's all **prototypes.**

The components are mostly produced in situ

The bulk of the project is built in place, ***in situ***. Some items may be prefabricated in a factory and assembled on site, but only a very small fraction, especially for an infrastructure project.

Unlike manufacturing, construction does not manage the assembly of components "directly". The component can be seen as part of the **end product** provided by a discipline for a particular structure.

The components are **assembled** to constitute built objects, but all this is done on site by the various disciplines.

The phasing of fabrication is essential

The **coordination** discipline is charged with **seeing to the compliance** of the assembly. Moreover, the phasing of **construction** is **essential**.

Responsibilities in the approval process

Clashes and claims arise primarily at the boundaries between discipline-specific components. The definition, specification, and acceptance of interfaces are critical and require strong structuring. This is a point where the IM can contribute a lot, provided that needs are clearly expressed.

The design department, responsible for the design review

The design review **checks compliance with a stated need**. It is a review internal to a design department, which decides on the conformity of the element designed to the need.

The component obtains an internal checking status that allows it to be shared in a common trunk with the other project stakeholders. It is an approval of the discipline-specific information.

Project management, responsible for the project review

The project review **checks the consistency of the objects** with the constraints of other the disciplines. It is:

- a **review** that brings together all disciplines of the project and rules on the consistency of information with all of the data in the model.
- an **approval** the consistency of the various discipline-specific items of information.

The principal, responsible for the statement of needs

In both types of review, the client is rarely present, and indeed may not be in a position to judge the relevance or coherence of complex technical data. He then delegates one or more experts to make sure that regulations are correctly applied, the expected quality is achieved, and the design meets the stated needs.

Note that it is essential to formalize the client's requirements, to express them clearly and in a quantifiable manner. A need for "good quality" is subjective and is not comparable to a measurable value.

This clarification of the client's requirements can be achieved progressively in the early stages of design, when the sketches and preliminary proposals have been drafted and presented to decision-making stakeholders.

The client, responsible for the progress review

In addition to the design review and project review, we now introduce the new notion of "progress review", which:

- makes it possible to continue designing or constructing objects or parts of the project.
- freezes the assumptions to be taken into account by all stakeholders in the next phase.
- records the **design satisfying the client's needs**, which are often poorly expressed early in the project but become increasingly accurate with each new design proposal.

An infrastructure project is complex and very long to complete. It is therefore necessary to obtain interim "approvals" in order to be able to change levels of detail or to start work.

The design cannot generally be fully completed, because, unlike manufacturing, it is impossible to wait for final approval of all components and assemblies before starting to make the product. The final acceptance of the structure is one of these steps.

Level of detail, precision and uncertainties

We saw in the previous chapter that the envelopes are refined from stage to stage of the project lifecycle:

- Each discipline commits to a volume or outline dimensions that change slightly with each new design phase.
- Each envelope is tightly constrained by the surrounding envelopes: interfaces with adjacent or clashing disciplines must be checked and possibly adapted or modified to suit the new constraints imposed.

Precision appropriate to the phase of the lifecycle

At each phase of the project lifecycle, the level of detail to be reached is clearly defined.

This level of detail **must** be reached, but must not be exceeded. It's all a matter of "**just what's needed";** the design must above all not be "over-complicated", made too detailed. Work must be limited to the development requirements imposed by the current phase of study.

Precision in the absence of an identified value leads, especially in a very early preliminary stage, to a **level of detail incompatible** with the **simulation tools** used. In addition, excessively large **volumes of data** can degrade exchange and transfer performance.

Taking the risk of working with shared data that is not frozen

At each phase, and for each task at hand, it must be checked that the inputs are validated, or at least that their status is "shareable" (there are no clashes with other data).

If an input is not validated, but does not conflict with another value, it is often best to accept it in order to progress, despite the risk of its being changed later. This is the **very principle of concurrent engineering**: if everyone waits until the surrounding data are validated and frozen, nobody can move.

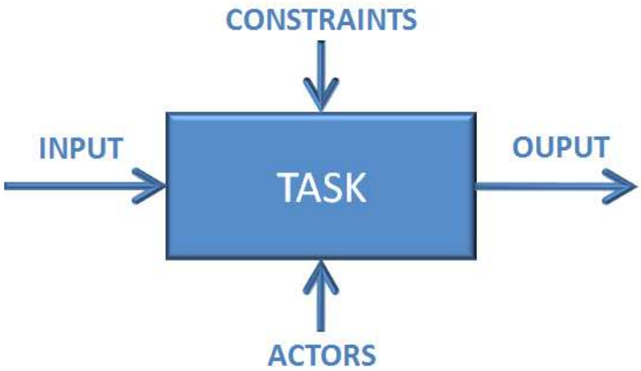

Figure E3-2: Diagram of an elementary task

Save the design assumptions of each task

For each completed task, you must also specify and store the versions of inputs that are taken into account. These are the specific assumptions used to perform the task (see the concepts of baseline and effectivity date described in Section C4 of deliverable L1).

This systematic approach makes it possible to design without being paralyzed by the developments simultaneously in progress on the assumptions used.

At the end of each task, the internal design review verifies compliance of the work done with the stated need. This compliance makes it possible to "publish" the output so as to share it with the other disciplines.

The owner of each item of information must provide information about the associated uncertainty

It must also be recalled that each item of information has a single owner. The breakdown into objects must therefore take the disciplines into account. Each attribute that specifies the properties of an object and each link must belong to the expert in charge of defining and evaluating it.

On one level, the uncertainty is also reflected by the scale: the smaller the scale, the larger the uncertainty. **This no longer applies to the model**. The "zoom" function masks everything. We must find another graphic display rule to represent "fuzzy" areas.

In short, there is a risk of giving the impression that we know something because the IM gives us a "pretty picture". We must therefore be careful not to conceal our ignorance behind a pretty picture; form must not prevail over substance.

Model checkers

The risk introduced by the possibilities of computing

The IM and the exchange of data directly usable by a machine (without analysis by a human) highlight a **significant risk concerning the quality of the model.**

Traditionally, the architect drew the organization of a building and the structural engineer took the drawing and prepared the structural drawing, which the quantity surveyor used to prepare the bill of quantities for concrete. Does the use of a collaborative IM make it possible to produce the bill of quantities directly from the architect's mock-up? Computationally, yes. But isn't there a risk?

Model checkers to help people decide, not replace them

To address these risks, there are tools to check the model, called ***model checkers***. A *model checker* is used to automatically detect inconsistencies and to help people make decisions. There is no question of making decisions automatically without acceptance by a human being.

M*odel checkers* are **tools serving people**, especially those who create the data, those who place them in an environment, and most important those who check them.

Checking the semantics of the objects

This means checking compliance with:

- the modeling protocol
- the list of fields that characterize the objects.

Identifying clashes

This means automatically detecting:

- *clashes* between physical objects (duplications, objects overlapping each other's spaces),
- non-physical *clashes* between objects (minimum distance between two objects)
- *clashes* between an object and a volume to be left vacant to be able to work there,
- *clashes* between an object and regulations (*Smart Code*)
- *clashes* between an object and a specific feature of the project.

Checking exchange standards

This means automatically verifying compliance with formats for exchanges with the IM by discipline-specific software that puts information into or takes information out of it.

E4 - Intellectual property and know-how

Introduction

Collaborative work and the IM as vectors of innovation

Collaborative work encourages innovative thinking by all stakeholders through the sharing of varied expertise. Similarly, the IM is a tool that, by providing an overall vision of the other disciplines, encourages individual contributors to adapt their own designs to fit better into the project. It is thereby stimulates questioning and ultimately innovations.

The innovations may be specific to one actor or result from the work of two or more stakeholders.

Stakeholders must be reassured to innovate

We have seen in previous chapters that the introduction of an IM tool changes the roles of all, and so leads to contractualizing them in a new form. This contractualization must reassure the stakeholders concerning their intellectual property rights in their contributions to the project.

Contractualizing the protection of intellectual property

To enhance and protect these contributions, there must be contractual responses to the following questions:

- How can we identify the authors (individuals, corporations, organizations) of innovative solutions?
- How can we encourage corporate partners in the innovation process?
- How can we distribute the gains among the "inventors"?

The initial contributions of the stakeholders and incentives for innovation must be considered separately. That is the purpose of this chapter.

Initial contributions and prior knowledge

This means clarifying under what conditions a partner's prior knowledge will be made available to the project and to the other stakeholders.

In the agreements among the various stakeholders in the project, it may be advisable to incorporate something like this:

"*Insofar as the project requires the use of prior knowledge that is owned by a partner, the others agree to use it only to perform their tasks under the project.*

"This right is non-exclusive, free of charge, and non-transferable, and may not be sub-licensed.

"The communication and / or provision by a partner of its prior knowledge can in no way be construed as conferring any rights on the other parties, other than as stated above."

We can also add:

"*Patents, software and other specific developments protected by tangible or intangible property law, and know-how (methods, technologies, information kept confidential) in the same field as the project or in a related field, owned or controlled by one of the partners and obtained at the time of the present protocol or before its effective date, shall remain the sole property of their respective holders*".

Protect pre-existing private data

Here the difficulty comes from the more subtle border between unshareable private data and private data made available to one or more stakeholders in the project.

This problem has already been clearly identified in the shared use of drawing cabinets and, more generally, of the servers used for the electronic management of project documents.

The solution with the IM is to make the private directories of a particular actor **inaccessible** (and even totally invisible on screen if necessary) through a hierarchy of access rights (see Section C for details). It should nevertheless be noted that the use of an IM, where millions of items of information are shared, makes the protection of private data much more complex than in traditional situations.

Promoting and sharing innovation

The classical sequential schema is simpler, but provides no leverage

In the sequential mode, each player benefits directly from a good idea or a good practice, but there is no "multiplier" effect.

For example, if the contractor discovers a new and more economical way of doing something during construction, it will have an incentive to apply it. If, on the other hand, the innovation yields savings only by reducing the quantities of something paid for on the basis of a price schedule, the contractor's motivation will be limited because the bulk of the saving will accrue to the client.

This difficulty can be overcome by the use of incentive packages apportioning the gain among the project participants.

Finally, the sequential mode reveals more clearly the contributions of each, in terms of innovation, because there are few exchanges and they are marked by the issuing of documents.

The collaborative scheme has a multiplier effect

In the collaborative mode with the use of an IM, innovation is sometimes created in a diffused manner by the working group. On the other hand, the savings to the project (which are perceived earlier) will benefit several stakeholders through a "multiplier" effect.

In this case it is customary to agree to apportion potential gains in accordance with a principle agreed to in advance. This principle will consider assignment to a partner whose contribution is decisive and can be clearly identified.

The filing of a patent can be remunerated according to the same distribution principle

This means making the principle clear from the outset and adapting it to each patentable innovation by stipulating:

- the inventors,
- the companies to which they belong,
- the procedures for filing patent applications, both in France and abroad
- their terms of maintenance,
- the apportionment of the remuneration of the patent,
- the customary apportionment of revenues.

Poaching of skills

Collaborative work allows the discovery of talents

Collaborative work develops exchanges between individuals. Each actor **discovers the real skills** of the collaborators in the project.

Use of the IM may **reduce physical contact** because information is exchanged remotely. But this does not prevent discovering the talents of partners. And there will be phases of work at the physical platform.

Finally, work in project mode develops in employees a sense of **dual membership,** between the company that employs them and the project on which they work, sometimes for several years. There is therefore a **risk of poaching** during the project or upon its completion.

Provide non-poaching clauses

Non-poaching clauses in contracts are often hard to apply. Nevertheless, the fact of putting them in writing acts as a brake. So they should be included **systematically**.

The development of collaborative work is **based to a large extent on trust** between partners. Compliance with a written clause is part of that trust, especially for future projects for which a new partnership will have to be created.

Results from the execution of the project

Each stakeholder continues to own the execution of its share of the project

The following clause may usefully be included in contracts:

"*Each party owns the results of carrying out its part of the project, whether patentable or not.*
"In this connection, the party will decide on the advisability and nature of the protective measures to be taken and initiate the necessary procedures in its own name and at its own expense. "

Results produced jointly are jointly owned

The following clause may usefully be included in contracts:

"*Unpatentable results, obtained jointly by the parties during the execution of project work, will be owned jointly by the parties who have contributed to the production of the joint results.*"

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