Development of a Handbook for Technical Drawing Creation and Management - in an industrial context

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MASTER THESIS

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Abstract

Technical drawings play an important role in many industrial processes, including product development, manufacturing, and lifecycle management, by representing the product definition. The purpose of the study was to investigate which processes influence technical drawing creation and management, what challenges are associated with these processes, and how these challenges can be addressed through the development of a handbook. The thesis was carried out at the company Backer, which develops heating solutions.

The study combined a literature review of relevant standards and engineering practices with an organizational study based on interviews, analysis of existing documentation, and practical observations of workflows and system usages.

The study identified a set of interconnected organizational processes related to technical drawings, including drawing creation, product lifecycle management, review activities, and engineering change management. The identified process structure may support organizations with similar workflows when investigating drawing-related practices.

The organizational study identified several challenges related to the investigated processes, including inconsistent practices, dependency on tacit knowledge, fragmented documentation, and unclear responsibilities. These challenges create risks of inconsistencies in drawings, reduced traceability, and incorrect manufacturing.

The organizational study identified organizational needs which were translated into measurable handbook requirements. Based on these requirements, the handbook was developed through integrating international standards with organizational guidelines. The handbook was verified and validated to see that it would fulfill its intended function and be useful in practical day-to-day work. Although these activities were limited due to the timeframe of the project.

The developed handbook is expected to support more unified drawing practices, improve drawing quality, and facilitate onboarding within the organization.

Keywords: Technical drawings, Drawing management, Drawing standards, Product Lifecycle Management (PLM), Engineering change management, Technical documentation

Sammanfattning

Tekniska ritningar spelar en viktig roll i många industriella processer, inklusive produktutveckling, tillverkning och livscykelhantering, genom att representera produktdefinitionen. Syftet med studien var att undersöka vilka processer som påverkar framtagning och hantering av tekniska ritningar, vilka utmaningar som är kopplade till dessa processer, samt hur dessa utmaningar kan hanteras genom utvecklingen av en handbok. Examensarbetet genomfördes på företaget Backer, som utvecklar värmelösningar.

Studien kombinerade en litteraturstudie av relevanta standarder och ingenjörspraxis med en organisatorisk studie baserad på intervjuer, analys av befintlig dokumentation samt praktiska observationer av arbetsflöden och systemanvändning.

Studien identifierade ett antal sammanhängande organisatoriska processer relaterade till hantering av tekniska ritningar, inklusive framtagning av ritningar, Product Lifecycle Management, granskningsaktiviteter och hantering av tekniska ändringar. Den identifierade processtrukturen kan stödja organisationer med liknande arbetsflöden vid undersökning av ritningsrelaterade arbetssätt.

Den organisatoriska studien identifierade flera utmaningar relaterade till de undersökta processerna, inklusive inkonsekventa arbetssätt, beroende av tyst kunskap, fragmenterad dokumentation och otydliga ansvarsområden. Dessa utmaningar skapar risker för felaktiga ritningar, minskad spårbarhet och tillverkningsfel.

Den organisatoriska studien identifierade organisatoriska behov som översattes till mätbara krav för handboken. Baserat på dessa krav utvecklades handboken genom integration av internationella standarder med organisatoriska riktlinjer. Handboken verifierades och validerades för att utvärdera om den uppfyllde sin avsedda funktion och stödde praktisk användning i det dagliga arbetet, även om dessa aktiviteter var begränsade på grund av projektets tidsram.

Den utvecklade handboken förväntas stödja mer enhetliga arbetssätt för ritningar, förbättra ritningskvaliteten och underlätta introduktionen av nya konstruktörer inom organisationen.

Nyckelord: Tekniska ritningar, Ritningshantering, Ritningsstandarder, Product Lifecycle Management (PLM), Ändringshantering, Teknisk dokumentation

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Lund, May 2026

Klara Samuelsson

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Introduction

1.1 Background

1.1.1 Role of technical drawings

Technical drawings are a fundamental part of engineering work and are used to communicate product information between different functions and stakeholders. By providing a standardized graphical representation of the product, technical drawings support a common understanding of the intended design.

A drawing defines the product geometry, including dimensions, tolerances, and other specifications needed for manufacturing, assembly, and inspection. Technical drawings therefore function as a governing document for the product definition. Drawings are used throughout the product lifecycle, from product development to manufacturing, inspection, and maintenance.

As industrial requirements and product complexity continue to increase, drawings and related product documentation must remain clear and consistent to ensure correct interpretation and efficient collaboration. Incomplete drawings may lead to misinterpretations, manufacturing errors, increased costs and unnecessary rework. Structured drawing practices are therefore essential to maintain product quality.

1.1.2 Standardization and drawing management

The key aspects of technical drawings are defined by international standards, including standards for drawing presentation, dimensioning, and tolerancing. In addition to external standards, organizations often establish internal practices adapted to their own products, workflows and systems. This is important to ensure that drawings are created and managed in a consistent way that is adapted to the operational context. This can include company-specific templates, drawing review and approval routines, revision handling, and change management procedures.

Technical drawings and related product data are commonly managed using Product Lifecycle Management (PLM) systems and Enterprise Resource Planning (ERP) systems. PLM systems support handling of drawings, revisions, and product-related information throughout the product lifecycle, while ERP systems store product information and support activities such as manufacturing, purchasing, and production planning. As drawings are continuously revised during development and use, structured drawing management is necessary to ensure only correct and approved drawings are used within the organization.

1.1.3 Organizational context

This master thesis has been carried out at Backer AB, located in Sösdala in southern Sweden. Founded in 1949, the company mainly focuses on development and manufacturing of heating solutions. Its product portfolio ranges from heating elements, such as tubular heating elements, aluminum elements and flow heaters, to sensors, control equipment and resistors [1]. Tubular heating elements are the company's main specialty and Backer are the largest producer of tubular heating elements in Sweden. Backer AB is part of the publicly listed NIBE Group and serves as the headquarters for the globally operating Backer Group, a leading supplier within the heating element industry [2]. The company's products are used across several industrial sectors, including heating, ventilation and air conditioning (HVAC), household appliances, transportation, industrial applications, commercial equipment, and energy systems.

Onsite in Sösdala the company employs around 350 people, with the majority of employees working in production. The on-site production is focused on manufacturing tubular heating elements and cartridge elements, which is multiple tubular heating elements assembled with a flange. Other components are primarily sourced externally. The engineering department is divided into three different business segments. One segment focuses on large-scale projects within the automotive sector, another on complex one-of-a-kind industrial products, and a third on higher-volume products.

Product development activities at Backer AB involve creation and management of technical drawings and related product documentation using CAD, PLM and ERP systems. In this context, product documentation includes technical drawings, parts lists, specifications, revision history, and manufacturing-related information. With a wide range of products and customers, clear and consistent drawing practices are important to support efficient collaboration and controlled handling of product documentation.

1.2 Purpose

The purpose of this thesis was to investigate what processes influence technical drawing creation and management, what challenges are associated with these processes, and how these challenges can be addressed through development of a handbook for creation, management, and use of technical drawings within the organization.

The handbook was intended to establish a standardized approach to drawing-related activities by combining relevant international standards with company-specific processes and requirements. This included investigating the current organizational drawing-related processes in order to identify inconsistencies and areas for improvement. As well as investigating how international standards, engineering practices, and organizational processes can be integrated into a unified framework adapted to the organizational context.

The handbook was primarily intended for design engineers involved in creation and management of technical drawings, serving as a practical guide in daily work. It was especially intended to support onboarding of new employees and users with limited experience in technical drawings, while also serving as guidance for other organizational functions involved in use and interpretation of technical documentation.

The intended organizational benefits included improving consistency and quality of technical drawings, reducing review and rework time, supporting traceability and handling of revisions and engineering changes, and supporting controlled management and data flow of product information in CAD, PLM, and ERP systems.

In a broader context, the work aimed to investigate which organizational processes are important to consider when

The work aimed to investigate which organizational processes are relevant to consider when mapping drawing-related processes within a technical organization. The approach and findings may support similar organizations seeking to develop drawing guidelines.

1.3 Problem description and research questions

The company maintained internal documentation related to product development, including design guidelines, review checklists, and routines for handling product documentation and engineering changes. including design guidelines, review checklists, and routines for handling product documentation and engineering changes. Relevant information and working methods were distributed across different documents, systems, and individuals, while some practices were insufficiently documented and instead mainly relied on experience and informal ways of working.

As a result, drawing practices varied between designers, and interpretation of drawing requirements and technical information differed between users and departments. This increased the risk of inconsistencies in drawings and related product documentation, misunderstandings between functions, longer review times, and unnecessary rework caused by unclear or incomplete information. The lack of centralized guidance also created challenges related to onboarding, review and approval activities, and handling of revisions and engineering changes.

Similar challenges are not unique to the studied organization and are common in engineering environments where technical documentation must be managed across several functions, systems, and workflows.

The thesis was guided by the following research questions:

- What processes and organizational practices influence creation and management of technical drawings within the organization?
- What organizational challenges are associated with technical drawing creation and management, and how can standardized drawing guidelines address these challenges?
- How can international standards, engineering practices, and organizational processes be integrated into a unified handbook framework for technical drawing management?

1.4 Related work

Technical drawing practices are largely based on international standards published by the International Organization for Standardization (ISO). Relevant standards include ISO GPS [3] for geometrical product specification, ISO 128 [4] for drawing presentation and ISO 129 [5] for tolerancing and dimensioning principles, together with several related standards. Together, these standards form an important basis for technical drawing creation and interpretation.

Previous work specifically related to development of organization-adapted drawing guidelines was found to be relatively limited. However, some related studies provide relevant insights. *Global Mechanical Drawing Instructions* by Markkinen [6] describes development and implementation of structured drawing instructions within an industrial engineering context and represents one of the most closely related works identified during the study. The work has a somewhat different scope from the present study regarding drawing-related processes but provides useful insight into development of standardized drawing guidelines within an engineering organization.

Additional literature provides broader perspectives related to standardization, engineering communication, and documentation practices. Narvydas and Puodziuniene [7] discuss drawing standards in the context of transition between 2D drawings and CAD-model based product definitions, emphasizing the importance of standards for consistent interpretation and presentation of technical drawings.

Sersch, Hamadamin and Gust [8] discuss the importance of communication between departments for creation and interpretation of technical drawings, while also highlighting differences between standardized drawing frameworks and actual industrial practice.

Literature on technical drawings provides fundamental principles for drawing interpretation, dimensioning, tolerancing, and technical communication. Examples include *Ritningsläsningens ABC* by Kai Eriksson [9]. Literature related PLM systems further describe product data management, revision handling, engineering changes, lifecycle management and traceability. Examples include *Product Lifecycle Management* by John Stark [10].

The relatively limited amount of identified work related to organization-adapted drawing guidelines within industrial organizations indicates potential value of the present study.

1.5 Limitations

The thesis was carried out within a timeframe of 20 weeks and under the practical and organizational constraints of the studied company, which limited the scope of the work. The main limitations are discussed below.

The thesis was conducted within a single organization. As a result, the identified challenges and workflows reflect the organizational environment of that company. Perspectives from other organizations were obtained through literature and standards.

Although Model-Based Definition (MBD), where product information is managed directly within 3D CAD models, has been proposed as a possible future direction for engineering documentation, MBD-related implementation aspects were not investigated within the thesis. Such practices are currently not implemented within the organization and would require substantial organizational changes beyond the scope of the project.

Although several potential improvements to systems, templates, and workflows were identified during the project, implementation of such changes was beyond the scope of the thesis.

Due to the limited timeframe the handbook was not validated through complete designs developed according to the proposed practices. In addition, long-term effects and quantitative impacts, such as reduced review time, reduced errors could not be evaluated due to limited availability of relevant organizational data.

1.6 Relevance for sustainable development

Although the thesis does not primarily focus on sustainability-related objectives, the work still includes aspects connected to sustainable development. The thesis relates to Sustainable Development Goal 9: *Industry, Innovation and Infrastructure*, particularly target 9.4 regarding development of more sustainable and resource-efficient industrial processes [11]. By supporting standardized drawing practices, improved lifecycle traceability, and more structured management of technical documentation, the work may support more efficient industrial processes. Established drawing guidelines may also support more consistent working practices and easier onboarding, which may improve the working environment.

The thesis may also relate to Sustainable Development Goal 12: *Responsible Consumption and Production*, particularly target 12.5 regarding reduction of waste through prevention and improved processes [11]. Improved quality of technical drawings may help reduce misunderstandings and design errors that can lead to manufacturing errors and rework, which may contribute to reduced material waste.

1.7 Ethical considerations

The thesis involved collecting information through interviews and discussions with employees within the organization. To ensure anonymization of participants, personal information and detailed descriptions of individuals or organizational roles are not presented in the report. Since the study was conducted within a relatively small organization, consideration was also taken to avoid indirect identification of participants through detailed background or organizational information.

To avoid unnecessary disclosure of company-specific information, details not relevant to the academic purpose of the thesis were excluded from the report. Interview material, notes, and reviewed documents were used only for purposes related to the thesis.

1.7.1.1 Use of Generative AI Tools

This thesis has partly used ChatGPT (OpenAI) to support language refinement, structuring, and formulation of draft material based on content developed by the author. All generated material was critically reviewed and revised by the author, who takes full responsibility for the final thesis content.

1.8 Outline of the thesis

Chapter 1 introduces the thesis by presenting the background, purpose, research questions, and overall limitations of the work.

Chapter 2 describes the methodological approach, project planning, and methods used for information collection, analysis, and verification.

Chapter 3 presents the literature study including technical drawing standards, PLM, and drawing-related practices within engineering organizations.

Chapter 4 presents the organizational study carried out to investigate existing drawing-related processes and identify organizational requirements for the handbook.

Chapter 5 presents the identified organizational and technical requirements for the handbook together with the principles used to structure and formulate the requirements.

Chapter 6 describes the development of the handbook and presents the resulting handbook structure, scope, maintainability considerations, and possible future refinements.

Chapter 7 presents the verification and validation activities together with identified findings and limitations related to the evaluation process.

Chapter 8 discusses the methods and processes used, the overall results of the thesis, and implementation aspects related to the handbook.

Chapter 9 concludes the thesis by summarizing the main findings, contributions, and possible future work.

2 Methodology

2.1 Research approach

The thesis was conducted as a qualitative development project within an industrial organization. According to Creswell [12], qualitative research is suitable for understanding processes and practices within real-world contexts through collection and analysis of information in order to identify patterns and organizational needs. Since the thesis investigated drawing-related processes within an industrial organization, a qualitative approach was considered suitable for the work. A quantitative approach was not considered suitable for the thesis, partly due to limited availability of relevant quantitative data related to drawing errors, review times, and organizational effects within the organization.

The thesis was conducted as an industrial case study. A case study involves in-depth investigation of a specific process or situation through collection of information from multiple sources over a longer period of time [12]. In the thesis, this involved investigation of drawing-related processes and documentation practices through interviews, observations, internal documentation, and continuous interaction with employees throughout the project.

The work also followed an iterative development approach. Although the main information gathering activities were primarily carried out during an initial phase of the project, the handbook was continuously refined throughout the work through feedback, clarification discussions, and findings identified during later project stages.

Additionally, the thesis followed a requirements-driven approach, meaning that development of the handbook was based on identified organizational and technical requirements rather than predefined assumptions about the handbook content. Organizational needs, existing workflows and standards were investigated in order to identify relevant requirements, which then formed the basis for development of the handbook.

2.2 Overall project workflow

At the beginning of the project, a project plan and Gantt chart were developed to structure the work and define the overall project stages and timeline. The Gantt chart is presented in Appendix A.

The project was divided into the following connecting stages:

- **Project initiation and planning -** Definition of project scope, objectives, methodology, timeline, and overall project structure.
- **Literature review -** Investigation of relevant drawing standards, engineering literature and existing research related to technical drawings.
- **Current state analysis –** Investigation of existing organizational processes, documentation, and systems through document analysis and system interaction.
- **Stakeholder interaction and requirement elicitation –** Investigation of organizational processes, needs, and challenges through interviews, discussions and observations.
- **Requirement development –** Formulation and structuring of handbook requirements based on identified organizational needs.
- **Handbook development -** Development of handbook structure and content based on the identified requirements.
- **Verification and validation activities -** Review and feedback activities carried out to assess handbook structure, guideline applicability, consistency with standards, and alignment with organizational requirements.
- **Handbook refinement and implementation preparation –** Final refinement of the handbook based on feedback together with integration into existing documentation systems.

The different stages of the project were closely connected throughout the work, where findings from earlier stages continuously influenced later development activities.

While the overall project structure was generally followed throughout the work, certain activities and timelines were adjusted due to time limitations and because new relevant information and investigation areas emerged during the project. A comparison between the planned and actual project execution is presented in Appendix A. The overall methodological workflow of the project is illustrated in Figure 1.

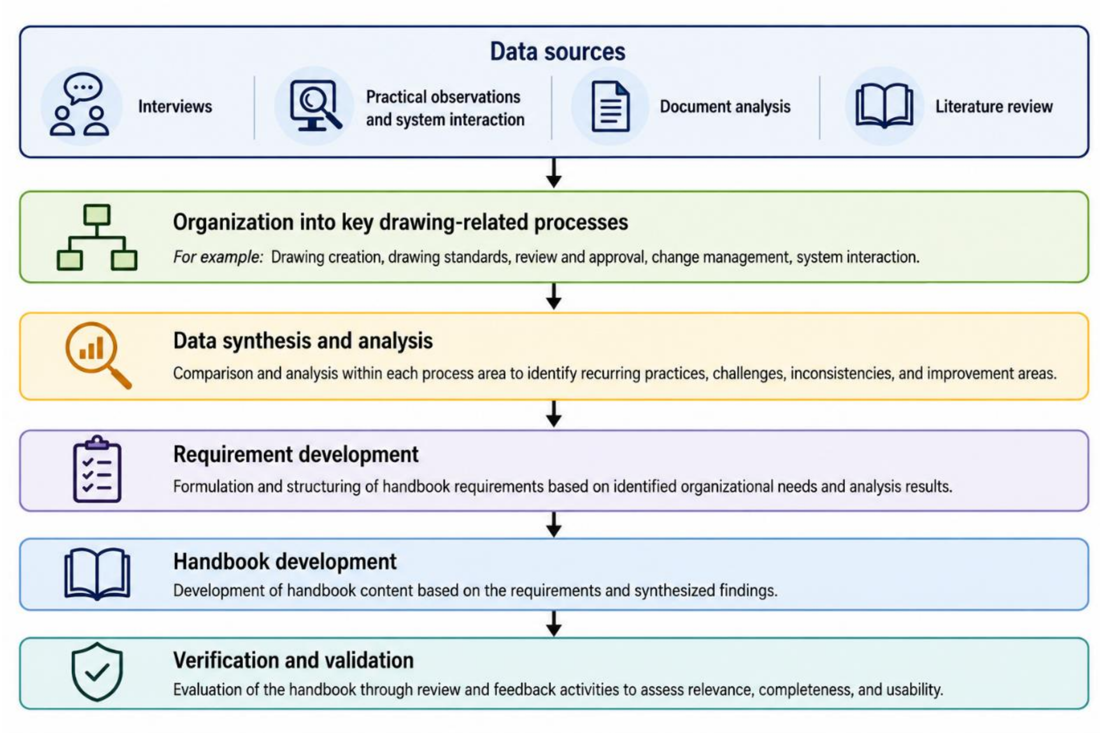


Figure 1: Overall methodological workflow of the project.

2.3 Data sources and empirical foundation

The empirical foundation of the thesis was developed through multiple qualitative data collection activities and continuous interaction with the organizational environment throughout the project. The primary sources of information are described below.

Semi-structured interviews constituted one of the main sources of empirical data and were used to gather perspectives from employees involved in different parts of the drawing lifecycle. The interviews were conducted primarily with design engineers, as well as personnel from production and technical management. The interviews provided insight into the current drawing-related workflows and challenges. The interview process is described further in Section 4.1.2 and Section 4.1.3. In addition to the formal interviews, informal discussions with employees were continuously held throughout the project. These discussions contributed contextual understanding, clarification of technical details, and additional insight into practical challenges.

Document analysis was conducted through reviewing existing internal documentation related to technical drawings, including existing processes, routine and templates, as described further in Section 4.1.4. In addition, the literature review presented in Chapter 3 provided theoretical reference material through relevant ISO standards, engineering literature, and other technical sources.

Practical observations were conducted together with employees involved in drawing creation, review activities, and system usage. These activities supported understanding of practical workflows, review practices, and handling of technical documentation within the CAD and PLM systems.

Independent practical interaction with the CAD and PLM systems was also carried out throughout the project to understand how information was structured and managed within the systems, how different tasks and workflows were performed, and how data was transferred between the systems. Existing drawings were additionally studied to examine current drawing practices and identify both good and problematic examples. Practical observations and system interactions are described further in Section 4.1.5.

2.4 Data synthesis and analysis

To support analysis of the collected material, the empirical findings were organized into a number of key drawing-related process areas based on recurring themes observed throughout the empirical activities. The organizational process descriptions presented in Section 4.2 were developed through grouping, summarizing, and comparing the collected material within these process areas, which supported identification of organizational challenges, inconsistencies, and differences between defined procedures and actual working practices.

The literature review and relevant standards were used as reference material when evaluating the empirical findings and current organizational practices. Based on the identified organizational needs and improvement areas, handbook requirements were formulated and structured into different requirement categories, as described further in Chapter 5. The resulting requirements later formed the basis for development of the handbook structure and content presented in Chapter 6.

2.5 Verification and validation approach

After the handbook had been developed, verification and validation activities were performed to evaluate both the correctness of the handbook content and its suitability for the intended organizational use.

Verification and validation are distinct but related activities. According to ISO 9000 [13] verification refers to confirming that specified requirements have been fulfilled, whereas validation concerns confirming that the product fulfills its intended use. In the context of this thesis, verification addressed whether the handbook was developed in accordance with the defined requirements, while validation concerned whether the handbook was considered useful and suitable for practical organizational use.

Verification activities in the project were grouped into requirement inspection, expert review, and standards analysis, as summarized in Table 1. As the handbook is a document-based deliverable rather than a physical technical system, the applicable verification methods were relatively limited, and most requirements were verified through document inspection. Each verification activity was assigned a one-letter code used later in the requirement specification.

Table 1: Description of the verification methods used.

Code	***Verification method***	***Meaning***
I	Requirement Inspection	Review of the handbook against defined requirements to assess requirement coverage
R	Expert Review	Review of the handbook together with engineering experts to assess correctness of described processes
A	Standards Analysis	Comparison of the handbook with relevant ISO standards to assess compliance

Validation involved expert review intended to assess whether the handbook was considered useful, understandable, and suitable for organizational use. The performed verification and validation activities and their results are described further in Chapter 7.

3 Literature review

3.1 Method

3.1.1 Purpose of review

The purpose of the literature review was to establish the theoretical background relevant to the creation, use, and management of technical drawings within industrial environments, including PLM-related practices, to support development of the handbook.

The review was conducted to identify relevant standards, methods, and established practices related to technical drawings. It also aimed to provide an understanding of how technical drawings and related documentation are managed throughout the product lifecycle, including lifecycle states, revisions, and engineering changes.

A large part of the reviewed material formed the basis for the handbook content, particularly regarding standardized drawing practices such as dimensioning, tolerancing, drawing layout, and drawing content. The literature review also supported identification of relevant organizational processes to investigate further during the organizational study phase of the project.

3.1.2 Scope and focus areas

The scope of the literature review was influenced by the research questions presented in Section 1.3. The review therefore covered not only technical drawing creation and interpretation, but also the broader workflows surrounding technical drawings. In addition, the review included not only technical drawings themselves, but also related engineering documentation throughout the product lifecycle.

A major part of the literature review focused on ISO standards and industrial practices related to technical drawings. Initial focus areas included dimensioning, tolerancing, surface texture, drawing layouts, title blocks, and related drawing principles. ISO standards were the main source for standardized drawing practices, while textbooks and engineering literature were mainly used to provide explanations, industrial context, and practical examples of how the standards are applied.

As the work progressed, the review was expanded to include broader management of engineering documentation throughout the product lifecycle. This included the purpose and functionalities of PLM systems, such as revision management, change management, lifecycle states, access control, and management of technical drawings and related product data such as CAD models and Bill of Materials (BOM).

3.1.3 Literature search strategy and source selection

The literature review was conducted using multiple search services and source types in order to obtain broader coverage of the research area. Literature searches were primarily performed using Scopus, Google Scholar, and the Lund University library search services FINN. ISO standards were accessed through SIS, which provides access to a large number of international and Swedish standards, including standards relevant to technical drawings.

The literature review used multiple types of sources to ensure a comprehensive overview. Peer-reviewed journal articles and conference papers were used to capture broader perspectives and recent developments, although technical drawings are often not a primary focus within research literature. Textbooks and technical literature therefore constituted an important source for explanations of drawing principles, industrial practices, and practical application. A basic engineering drawing textbook was also used early in the review process to identify important areas of drawing creation and relevant standards for further study. Standards documents were reviewed to identify established rules and practices.

The searches were conducted using combinations of keywords related to the focus areas of the study. Examples of search terms included technical drawings, geometrical tolerancing, GD&T, dimensioning, Product Lifecycle Management, PLM, Product Data Management, revision management, and engineering documentation. Different combinations, synonyms, and related concepts were also used to broaden the searches and identify additional relevant literature. References to normative and related standards within ISO documents were additionally used to identify relevant standards connected to the topics studied.

The selected sources were evaluated based on their credibility and relevance for the study. Priority was given to peer-reviewed journal articles, international standards, and academic textbooks.

AI tools were occasionally used to support identification of relevant terminology, related topics, and, in some cases, relevant standards and literature. All referenced sources and standards were independently reviewed and evaluated by the author.

3.2 Result

3.2.1 Technical drawings standards (ISO)

Technical drawing practices are largely based on international standards developed by the International Organization for Standardization (ISO). These standards define key aspects of drawings such as dimensioning, tolerancing, title block fields and drawing sheet formats. The purpose of these standards is to facilitate communication and ensure that technical information is interpreted in a consistent manner across different users and organizations.

One of the central frameworks is the ISO system for Geometrical Product Specifications (GPS) [3], which provides a comprehensive system of standards for the specification and verification of product geometry. The ISO GPS system establishes a common framework for defining product geometry, including dimensional tolerancing, geometrical tolerancing, and surface texture specification. The framework consists of over one hundred interconnected standards covering different aspects of geometrical specification and verification.

In addition to ISO GPS, fundamental standards governing technical drawings include ISO 128 [4] and ISO 129 [5]. The ISO 128 series define the general principles for the presentation of technical drawings, including line types, views, and sectioning, while ISO 129 specifies the rules for dimensioning and presentation of dimensions and tolerances on drawings.

These standards represent part of a broader interconnected system of standards related to technical drawings and engineering documentation. The following sections present selected standards and principles relevant to the development of technical drawings.

3.2.2 Types of technical drawings

Technical drawings are a primary means of communication in manufacturing. Several types of drawings are used in industry, primarily detail drawings, assembly drawings and combined drawings. The following descriptions are based on *Process Planning* by Peter Scallan [14].

3.2.2.1 Detail drawing

Detail drawings provide all the necessary information required to manufacture a part. This includes all dimensions, tolerances, material specifications, special treatments and surface finish requirements. Detail drawings may represent either a single part or groups of similar standardized parts, such as bolts of different sizes.

3.2.2.2 Assembly drawing

Assembly drawings describe how multiple components are assembled to form a product or sub-assembly. In contrast to detail drawings, they typically contain little or no dimensional information and instead focus on relationships between components. Assembly drawings are accompanied by a parts list identifying the components included in the assembly, as described further in 3.2.10.4.

Assembly drawings may represent complete assemblies or sub-assemblies. In some cases, collective assembly drawings are used to represent products that share the same basic structure but differ in configuration. Arrangement drawings may also be used to illustrate the overall product structure and positioning of sub-assemblies relative to each other.

3.2.2.3 Combined drawing

Combined drawings integrate both detail and assembly information within a single document. In this case, the drawing includes both the overall assembly and the necessary information for the individual components. This approach can reduce the need for separate documentation, particularly for simpler products.

3.2.3 Projection methods

Projection methods used in technical drawings are defined in ISO 5456 [15], which provides different methods for representing three-dimensional objects on a two-dimensional media. Terminology and descriptions in this section are based on ISO 5456.

Various projection methods can be used to represent an object. According to ISO 5456-2 [16], orthographic representation is the most commonly used method, and it is regarded as the accepted technical language within technical drawings. Other representation methods defined in ISO 5456 are not described, as they are less relevant in the context of this work.

3.2.3.1 Orthographic representation

Orthographic representation is the standard method used in technical drawings to represent 3D objects using multiple 2D views. It is obtained using parallel orthogonal projections, where the object is represented through systematically arranged views that together describe its geometry. Although six views are theoretically possible (front, above, left, right, below, and rear), in practice only the views necessary to fully describe the object are used. The arrangement of views relative to the principal view depends on the selected projection method, such as first angle or third angle projection. Figure 2 illustrates an orthographic representation where the views are arranged according to the first angle projection method.

Understanding the 3D geometry of the object therefore requires correct interpretation of the views through understanding of the projection method, view arrangement, and drawing conventions such as line types and symbols, described further in Sections 3.2.4 and 3.2.5.

In contrast, pictorial representations such as isometric views provide a three-dimensional visualization of an object on a single projection plane, showing the object as it would appear to an observer. Such representations are generally easier to understand, and they are therefore often used to support orthographic representation but may also be used on their own.

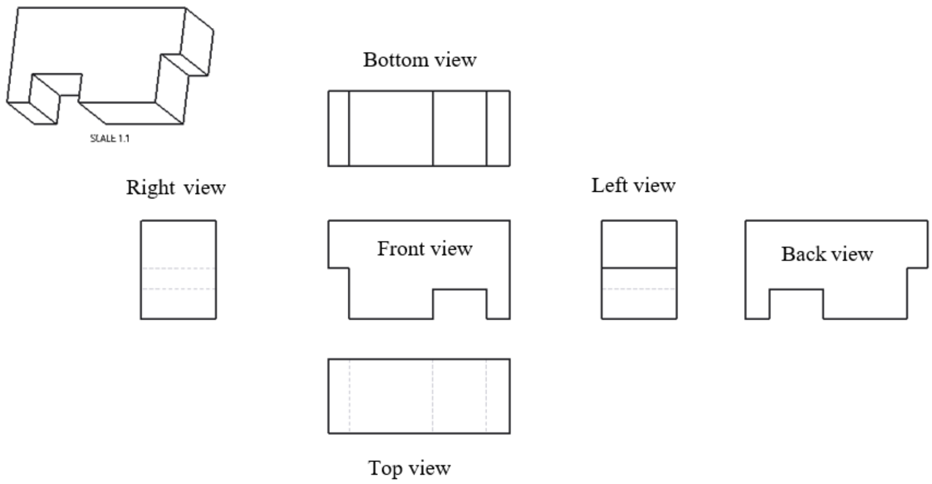


Figure 2: Orthographic representation of an object using first-angle projection, together with an isometric view.

3.2.3.2 First angle projection

The first angle method is an orthographic representation in which the object is positioned between the observer and the projection planes [16]. As a result, the views are projected onto planes behind the object and are therefore arranged on the opposite side relative to the principal view. For example, the top view is placed below the principal view, as illustrated in Figure 2. First angle projection is the standard orthographic projection method used for technical drawings in Europe.

The arrangements of views relative to the principal view can be understood better using the glass box analogy, illustrated in Figure 3 together with the symbol used to indicate first-angle projection. In this analogy, the object is imagined to be placed inside a transparent box and projected onto its surrounding walls. Since the object is positioned between the observer and the walls of the box, the views appear on the opposite side relative to the principal view when the box is unfolded.

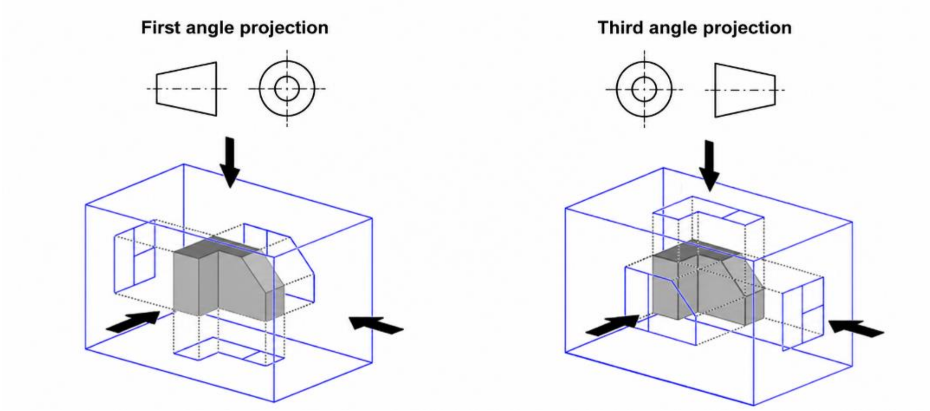


Figure 3: Glass box illustration for first- and third-angle projection, including the corresponding projection symbols. Adapted from [17] and [18], licensed under CC BY-SA 3.0.

3.2.3.3 Third angle projection

The third angle projection method is an orthographic representation in which the projection planes are located between the observer and the object [16]. The views are therefore projected onto planes in front of the object and remain on the same side relative to the principal view. Third angle projection is the standard orthographic projection method used for technical drawings in the United States.

This can also be understood using the glass box analogy shown in Figure 3. In third-angle projection, the walls of the box are positioned between the observer and the object, meaning that the views are projected onto the walls facing the observer. When the box is unfolded, the views therefore remain on the same side relative to the principal view.

3.2.4 Line types

Correct interpretation of technical drawings relies on standardized line types and graphical conventions. Since the representation of a feature may vary depending on the viewing direction, understanding different line types is important when interpreting drawings. ISO 128-2 [19] defines different line types used for graphical representation in technical drawings, summarized in Table 2.

Table 2: Summary of main line types, their appearance, and usage in technical drawings, based on ISO 128 [19].

Line type	*Appearance*	*Use*
Continuous wide line		Visible contours (edges and outlines)
Continuous narrow line		Dimension, extension and auxiliary lines
Dashed narrow line		Hidden contours (not visible in the view)
Dashed wide line		Hidden contours (not visible in the view)
Long-dashed dotted narrow line		Centre lines and lines of symmetry
Long-dashed dotted wide line		Position of cutting planes in sectional view

In addition to line type, line width is an important parameter. ISO 128-2 [19] specifies standardized line widths and distinguishes between narrow, wide, and extra-wide lines related by a ratio of 1:2:4. The selected line widths depend on the type, size, and scale of the drawing. In mechanical engineering drawings, it is most common to use only narrow and wide lines with an approximate ratio of 1:2.

Understanding line types is particularly important when interpreting multiple views, where the same feature may be represented differently depending on the viewing direction. For example, a visible contour in one view may appear as a hidden line in another. In modern CAD systems, these conventions are typically applied automatically through predefined styles. However, understanding of the underlying principles remains important for correct interpretation and validation of technical drawings.

3.2.5 Views

3.2.5.1 Selection of views

The selection of views in technical drawings should be made to convey the maximum amount of information about the object in a clear and efficient manner. According to ISO 128-3 [20], the principal view, usually the front view, should present the object in its most informative orientation, such as its functional, manufacturing or mounting position.

Additional views, cuts, and sections should be selected so that the number of views is kept to a minimum while still providing a complete and unambiguous representation of the object, without unnecessary repetition of details. Views should preferably be selected to minimize the need for hidden edges and outlines, which can alternatively be addressed using sectional views described further in the next section.

Different types of simplified representations may also be used to improve clarity and reduce unnecessary detail. Features that require additional illustration but do not justify a complete view may be shown using partial views limited to the relevant area of interest. Symmetrical objects may be represented using half or quarter views since the remaining geometry can be understood by symmetry. [9]

3.2.5.2 Arrow method

The identification of views in technical drawings is standardized to ensure clarity and avoid ambiguity. According to ISO 128-3 [20], views not placed according to the standard projection arrangement, such as section views or auxiliary views, shall be identified using reference arrows and corresponding capital letters. In this approach, commonly referred to as the arrow method, the arrow and letter are placed in the principal view to indicate the viewing direction, while the same letter is used to identify the corresponding view [9]. An example of the application of the arrow method for a sectional view is shown in Section 3.2.5.3.

The arrow method allows views to be positioned independently of the standard projection arrangement since the viewing direction is explicitly indicated by arrows and labels. However, using the arrow method for all views is generally avoided, since unrestricted placement may reduce drawing clarity and result in a disorganized layout. In practice, the method is mainly applied to individual views such as section views or auxiliary views, while the principal views remain arranged according to standard projection conventions. This supports a clear drawing layout while still allowing flexibility where needed. [9]

3.2.5.3 Cuts and sections

To improve clarity and avoid excessive hidden lines, sectional views are used. A section represents the object as if it were cut along a defined plane, revealing internal features. Sectional view conventions are defined in ISO 128-3 [20]. Cut surfaces are indicated using thin continuous hatching lines, typically drawn at a 45° angle. Different areas of the same component shall be hatched in the same way, while neighboring components shall be hatched using different directions or spacing.

The position of the cut is indicated using a long-dashed dotted wide cutting plane line with arrows showing the viewing direction of the sectioned surface. The cutting plane and corresponding section are identified using matching capital letters following the arrow method, for example A–A. An example of a sectional view and cutting plane designation is shown in Figure 4.

The position of the cut is defined by a cutting plane line indicating where the object is imagined to be divided. It is drawn as a long-dashed dotted wide line, with thickened ends and arrows indicating the viewing direction of the sectioned surface. The cutting plane is identified using the same capital letter at each end, placed together with the section arrows, e.g. A, as seen in Figure 4. The corresponding section shall be identified by the same capital letter, repeated to form a designation such as A–A, following the arrow method. Figure 4 illustrates an example of a sectional view.

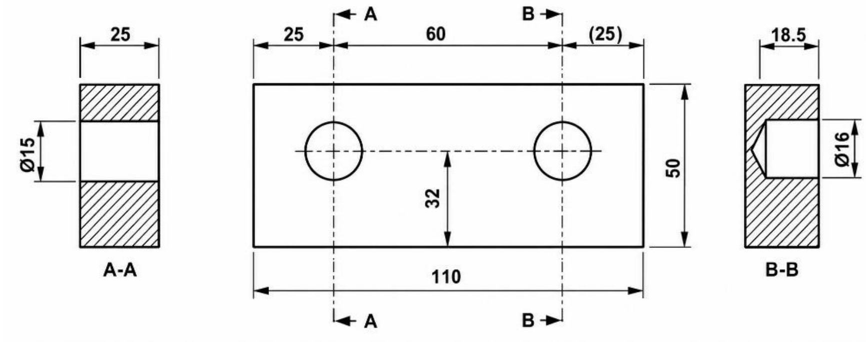


Figure 4: Example of sectional views illustrating a through hole and a countersunk hole

Sectional views are particularly useful for illustrating internal features such as holes, countersinks and counterbores, which may otherwise be difficult to interpret. As a general principle, dimensioning of hidden contours should be avoided. Sectional views are therefore often preferred to convert hidden features into visible ones. Hidden contours are consequently seldom drawn in sectional views.

Different types of sectional representations may be used [9]:

- **Full section** – The object is completely cut along a plane.
- **Offset section -** The cutting plane is bent to pass through multiple features, such as several holes, allowing them to be shown in a single section.
- **Half section –** Used for symmetrical objects, where one half of the view is shown in section and the other as an external view.
- **Local section** – Only a limited portion of the object within the same view is shown in section to reveal specific internal features.

Half and local sections are integrated within the same view rather than presented as separate views and are therefore efficient methods for improving clarity without increasing the number of views, which saves space on the drawing.

3.2.6 Dimensioning

Dimensioning is a fundamental aspect of technical drawings, defining the size, geometry, and spatial relationships of a component. General principles for dimensioning are established in ISO 129-1 [5], which defines rules for both the presentation and application of dimensions. Descriptions in this section are based on this standard. These principles ensure that drawings are clear, unambiguous, and suitable for manufacturing, assembly, and inspection.

3.2.6.1 General rules

According to ISO 129-1 [5], only the dimensions necessary to unambiguously define the nominal geometry shall be shown. Each dimension should only be indicated once using a dimension line and a dimension value.

Dimensions alone are not sufficient to fully define the requirements of a product. They must be used together with other specification methods, such as dimensional tolerances, geometrical tolerances, or surface texture requirements. The indicated dimensions on a drawing shall be authoritative and used as the basis for manufacturing, meaning that geometry shall be defined by the specified dimensions rather than by direct measurement of the drawing.

Dimensions that can be derived from other dimensions should not be indicated as primary dimensions but may instead be included as auxiliary dimensions. Auxiliary dimensions are shown in parentheses and are used for information only, not for manufacturing or inspection purposes. They may be used to simplify interpretation of the drawing by avoiding the need to calculate derived dimensions. Auxiliary dimensions shall not be toleranced. Theoretically exact dimensions are shown enclosed in a square box and define exact values not subject to dimensional tolerances. Any permissible variation is instead controlled using geometrical tolerancing.

3.2.6.2 Dimensioning principles

Dimensions should be applied in a way that supports manufacturing, assembly, and inspection. Several important dimensioning principles are summarized in [21]:

- **Avoidance of redundancy:** Dimensions shall not be duplicated, unless clearly identified as auxiliary dimensions.
- **Functional dimensioning:** Dimensions should reflect the functional and mating relationships of the part.
- **Clarity and grouping:** Dimensions should be arranged logically and grouped to improve readability.
- **Completeness:** All dimensions necessary to completely define the geometry shall be provided, ensuring that the component can be defined without ambiguity.

These principles guide the selection and arrangement of dimensions, as described in the following sections.

3.2.6.3 Arrangement of dimensions

According to ISO 129-1 [5], the arrangement of dimensions on a drawing shall clearly reflect the design intent. The standard describes different methods for arranging dimensions, including chain, parallel, and running dimensioning, as well as combinations of these methods. Figure 5 shows a comparison of the different dimensioning methods.

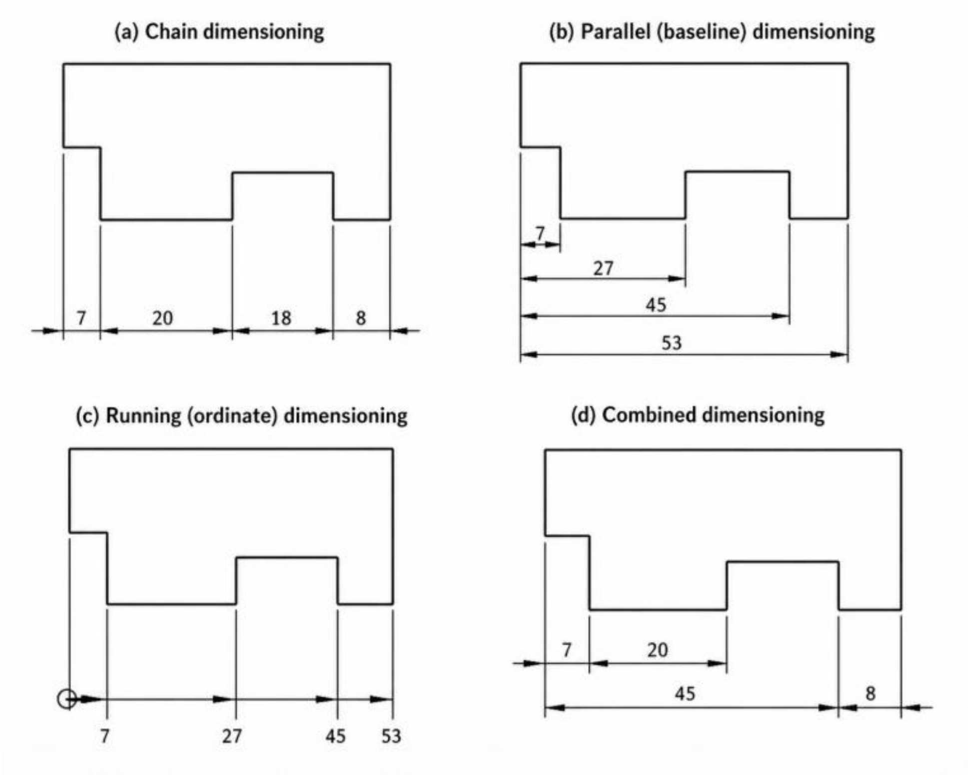


Figure 5: Comparison of dimensioning methods: (a) chain, (b) parallel (baseline), (c) running (ordinate), and (d) combined dimensioning.

3.2.6.3.1 Chain dimensioning

In chain dimensioning, individual dimensions are placed sequentially in a series, where each dimension starts from the end of the previous one. This creates a continuous "chain" of dimensions along a feature, as seen in Figure 5. Since each dimension depends on the previous one, tolerances may accumulate along the chain, which can affect the overall size or position of features.

3.2.6.3.2 Parallel dimensioning

In parallel dimensioning, sometimes referred to as baseline dimensioning, all dimensions are measured from a common reference, and the dimension lines are arranged parallel to each other, see Figure 5. This method provides clear and independent dimensions and avoids tolerance accumulation between features but may require significant drawing space due to the number of parallel dimension lines.

3.2.6.3.3 Running dimensioning

Running dimensioning is a simplified form of parallel dimensioning, where all dimensions originate from a common starting point. Instead of using separate parallel dimension lines for each feature, the dimensions are given along a single line, reducing the required drawing space, as seen in Figure 5. The dimension values represent the distance from the origin to each feature rather than distances between neighboring features.

3.2.6.3.4 Combined dimensioning

In practice, different dimensioning methods are often used together within the same drawing. Several dimensioning approaches may be considered correct, provided that the resulting dimensioning is clear and unambiguous. An example of combined dimensioning is found in Figure 5. The choice of dimensioning method depends on which dimensions are most important.

3.2.6.4 Placement and readability

According to ISO 129-1 [5] dimensions shall be placed in the view or section where the feature is shown most clearly. Dimensions should preferably be placed outside the contour of the object, and dimensioning of hidden features should be avoided unless absolutely necessary.

Dimension values shall be positioned above the dimension line and arranged so that they are not crossed or obscured by other lines. For linear dimensions, units may be omitted if specified elsewhere on the drawing or in an associated document. However, angular dimensions shall always include their unit.

3.2.6.5 Graphical representation of dimensions

The graphical representation of dimensions follows standardized conventions defined in ISO 129-1 [5] and supported by the line conventions in ISO 128 [19]. Key graphical elements include dimension lines indicating the extent of a dimension, extension lines defining where the dimension applies, and terminators marking the limits of the dimension. Terminators are typically represented by using arrowheads. Property indicator symbols such as Ø (diameter) and R (radius) are placed before the dimension value to describe the shape of the feature. Repeated features may be dimensioned using simplified notation, for example 2× ⌀18.

3.2.7 Dimensional tolerancing

Dimensional and geometrical deviations must be controlled to ensure that a component fulfils its intended function. If deviations in size, shape, orientation, or position exceed acceptable limits, the functionality of the component may be affected. Tolerancing should therefore define the allowable variation of features clearly and unambiguously.

Tolerances are essential not only to ensure proper function of a component, but also to enable economical manufacturing. Overly tight tolerances increase production cost and complexity, while unnecessarily loose tolerances may compromise functionality. Appropriate tolerancing therefore represents a balance between functional requirements and manufacturing efficiency.

There are three main ways to specify tolerances on a technical drawing. Tolerances may be specified directly using numerical tolerances or standardized ISO tolerance classes, while dimensions without individual tolerances are controlled by general tolerances. These methods are often used together within the same drawing. The following sections describe these approaches based on engineering drawing literature and relevant ISO standards.

3.2.7.1 Numerical tolerances

Numerical tolerances represent the most direct way of specifying allowable deviations from a nominal dimension. A numerical tolerance is typically expressed as a numerical value with an associated tolerance value, for example 54 ± 0.4. In this case, 54 mm is the nominal size, while ± 0.4 mm defines the allowable variation. The maximum permissible size, referred to as the upper limit of size, is therefore 54.4 mm, while the minimum permissible size, referred to as the lower limit of size, is 53.6 mm. The difference between these limits is called the tolerance width, which in this case is 0.8 mm. All dimensions within this range are considered acceptable. The definition and interpretation of linear size tolerances are given in ISO 14405 [22].

3.2.7.2 ISO tolerance classes

Standardized ISO tolerance classes represent an alternative way of specifying tolerances compared to numerical tolerances and general tolerances. Instead of defining the allowable deviation directly, the tolerance is indicated by a nominal size followed by a tolerance class designation in accordance with ISO 286 [23]. This section is based on engineering drawing literature [9] and corresponds to the system defined in ISO 286.

ISO tolerance classes are primarily used to define fits between mating components such as holes and shafts. The standardized system controls how components fit together, supporting interchangeability of components produced in different manufacturing environments.

Tolerance classes are designated by a letter and a number, for example H7 or h7. The letter defines the position of the tolerance interval relative to the nominal size, as illustrated in Figure 6. The number represents the tolerance grade, defining the tolerance width. The permissible deviations for different tolerance classes and nominal size ranges are specified in standardized tolerance tables in ISO 286 [23]. Tolerances for holes and other internal dimensions are indicated by uppercase letters, while tolerances for shafts and other external dimensions are indicated by lowercase letters.

By combining a tolerance for a hole and a shaft, different types of fits can be obtained. In a clearance fit, the hole is always larger than the shaft, allowing free assembly. In an interference fit, the shaft is larger than the hole, requiring force or special tools during assembly. A transition fit represents an intermediate case where either clearance or interference may occur depending on the actual dimensions. The selection of appropriate tolerance combinations is therefore directly linked to the functional requirements of the assembly.

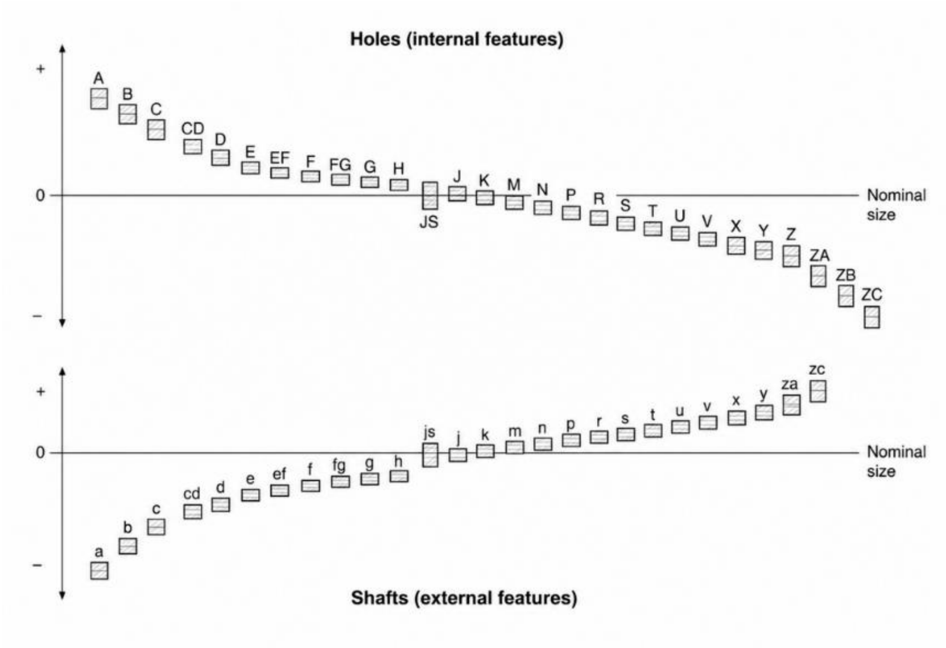


Figure 6: Simplified illustration of ISO tolerance interval positions for holes and shafts relative to the nominal size. Adapted from the tolerance position system defined in ISO 286 [24].

3.2.7.3 General tolerances

General tolerances are tolerances that apply to dimensions without individually specified tolerances. They are commonly used in to simply drawings while maintaining controlled part accuracy. ISO 2768 [24] provides general tolerances for linear and angular dimensions using four tolerance classes: fine, medium, coarse, and very coarse.

ISO 2768-1 applies to linear dimensions such as lengths, diameters, radii, and chamfer heights, as well as angular dimensions, including angles not directly indicated on the drawing, such as right angles or angles of regular polygons. For angular dimensions, the permissible deviation depends on the length of the shorter side forming the angle, where larger dimensions allow greater angular deviation. Angular tolerances control the general orientation of features, but do not govern their form deviations. General tolerances do not apply to auxiliary dimensions or theoretically exact dimensions. General tolerances for linear dimensions are given in Table 3. [24]

Table 3: General tolerances for linear dimensions, adapted from [24].

Tolerance class	***Permissible deviations for basic size ranges***								
Designation	Description	0.5 up to 3	over 3 up to 6	over 6 up to 30	over 30 up to 120	over 120 up to 400	over 400 up to 1000	over 1000 up to 2000	over 2000 up to 4000
f	fine	±0,05	± 0,05	± 0,1	± 0,15	± 0,2	± 0,3	± 0,5	-
m	medium	± 0,1	± 0,1	± 0,2	± 0,3	± 0,5	± 0,8	± 1,2	± 2
c	coarse	± 0,2	± 0,3	± 0,5	± 0,8	± 1,2	± 2	± 3	± 4
v	very coarse	-	± 0,5	± 1	± 1,5	± 2,5	± 4	± 6	± 8

When selecting a tolerance class, the customary workshop accuracy must be considered, representing the tolerances that can be reliably achieved in practice within a specific workshop under normal production conditions. If general tolerances according to ISO 2768 are applied, this should be indicated in or near the title block, for example ISO 2768-m. Features requiring tighter tolerances than the general tolerances must be toleranced individually. Since the general tolerances in ISO 2768 are based on typical workshop capabilities, specifying larger tolerances does not normally provide economic benefit. If larger tolerances are nevertheless required, these should be specified individually on the drawing.

The use of general tolerances offers several advantages as described in ISO 2768 [24]. Drawings become easier to read, improving communication between the designer and the user. Designers also save time by avoiding unnecessary tolerance calculations, as it is sufficient to verify that the general tolerances are acceptable for the function of the part. General tolerances also indicate which features can be manufactured using normal workshop capability. Features with individually specified tolerances are typically critical for function and may require additional manufacturing effort. This distinction supports production planning and improves quality control.

3.2.8 Geometrical tolerancing

Geometrical tolerances are governed by ISO 1101 [25]. The standard establishes a unified system of symbols and rules used to define and interpret geometrical requirements in technical drawings. These tolerances are applied to ensure that a component fulfils its intended function while remaining manufacturable and verifiable.

While dimensional tolerances define allowable variation in size, geometrical tolerances define allowable variation in form, orientation, and location of features. Geometrical tolerances are primarily applied to features that are critical for the function or assembly of a component. Compared to dimensional tolerances, geometrical tolerances are more complex to interpret and verify and are therefore mainly used where geometric control is functionally important.

A key concept in geometrical tolerancing is the tolerance zone, defined as the region within which a feature is permitted to vary. The zone is bounded by ideal geometric elements such as lines, planes, or surfaces, and its size is determined by the specified tolerance value. The shape of the tolerance zone depends on the type of geometrical tolerance being applied. For example, for circularity, the tolerance zone is defined by the space between two concentric circles.

3.2.8.1 Types of geometrical specifications

Different categories of geometrical tolerances control different aspects of the deviation of a feature. ISO 1101 [25] defines 14 different geometrical tolerances, divided into the following four categories:

- **Form tolerances:** Define the allowable deviation of a feature from its ideal shape. They apply to individual features and do not require datums, since the feature is evaluated against its own ideal geometry.
- **Orientation tolerances:** Define the allowable deviation in the angular relationship of a feature relative to a reference datum.
- **Location tolerances:** Define the allowable deviation of a feature’s location, i.e. its true position, relative to one or more reference datums.
- **Runout tolerances:** Define allowable variation during rotation about a datum axis, describing how much the feature deviates or “wobbles” during rotation and reflecting combined effects of form, orientation, and location.

Orientation, location, and run-out tolerances require datums since the deviation must be evaluated relative to another feature. A datum is a theoretically exact reference defined by a plane, axis, point, or a combination of these elements. Datums and datum systems are defined in ISO 5459 [26]. An overview of the geometrical tolerances, their classification, and datum requirements is presented in Table 4.

Table 4: Overview of geometrical tolerances and classification, adapted from ISO 1101[25].

Tolerance	Characteristics	Symbol	Datum needed
Form	Straightness	—	no
	Flatness	⏥	no
	Circularity	○	no
	Cylindricity	⌭	no

	Line profile	⌒	no
	Surface profile	⌓	no
Orientation	Parallelism	//	yes
	Perpendicularity	⊥	yes
	Angularity	∠	yes
Location	Position	⌖	yes
	Concentricity	◎	yes
	Symmetry	⌯	yes
Runout	Circular runout	↗	yes
	Total runout	⌰	yes

3.2.8.2 Representation in technical drawings

Geometrical tolerances are specified using a tolerance indicator, which is a rectangular box divided into sections arranged from left to right. The first section contains the tolerance symbol representing the type of geometrical requirement. The second section defines the tolerance value itself, including its magnitude and any additional modifiers, e.g. Ø7. The third section, which is optional, includes datum references that define how the feature is oriented or positioned relative to other elements. This section may contain one or more datums, indicated in sequence (e.g. A, B, or B–C).

An example of a tolerance indicator is shown in Figure 7. The example prescribes that the axis of the specified feature shall lie within a cylindrical tolerance zone of diameter 0.04 located at its theoretically exact position. The position of the feature is evaluated relative to a datum reference system defined by datums A, B, and C.

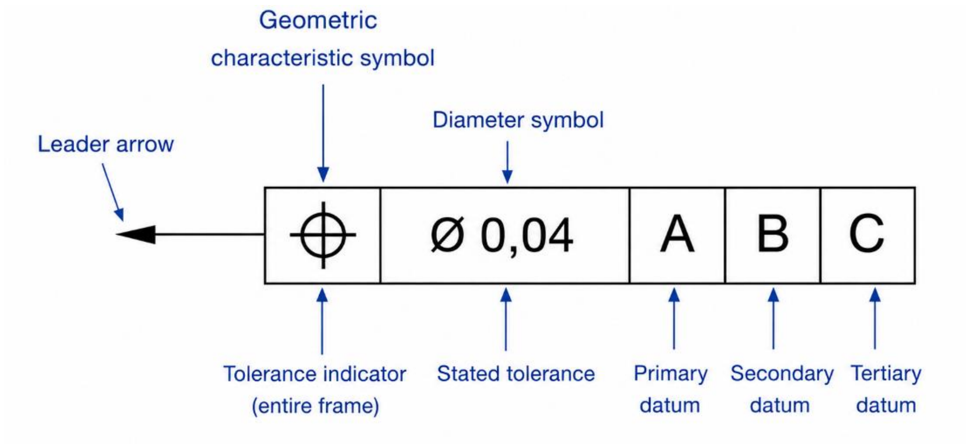


Figure 7: Example of a tolerance indicator showing a position tolerance, adapted from [27], licensed under CC BY-SA 3.0.

The following sections describe the main types of geometrical tolerances in further detail. The descriptions are based on ISO 1101 and supported by additional explanatory material [28].

3.2.8.3 Straightness

Defines the allowable deviation of a line element from a perfectly straight line. The tolerance zone consists of two parallel lines within which the feature must lie. Straightness is commonly used for guiding or sealing surfaces. [28]

3.2.8.4 Flatness

Defines the allowable deviation of a surface from a perfectly flat plane. The tolerance zone consists of two parallel planes within which the entire surface must lie. Flatness is commonly applied to mating surfaces where unevenness may affect contact or sealing. [28]

3.2.8.5 Circularity (Roundness)

Defines the allowable deviation of a circular feature from a perfect circle. The tolerance zone consists of two concentric circles within which all points of the circular surface must lie, as seen in Figure 8. It is a two-dimensional tolerance that controls the shape of a circular cross-section. Circularity is widely used since many components must be sufficiently round to function properly. For instance, when a shaft rotates within a hole, both parts must be sufficiently circular to maintain consistent clearance and prevent vibration or uneven wear. [28]

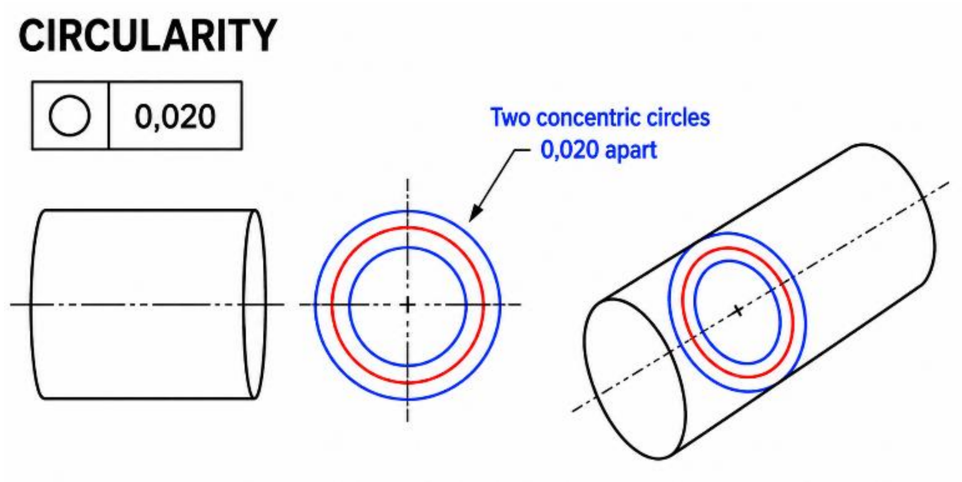


Figure 8: Illustration of circularity.

3.2.8.6 Cylindricity

Defines the allowable deviation of a cylindrical surface from an ideal cylinder. The tolerance zone consists of two coaxial cylinders within which the entire surface must lie. Cylindricity controls the complete cylindrical surface and combines the effects of circularity and straightness. Cylindricity is commonly used for shafts, pins, and other cylindrical features requiring uniform contact in sliding or rotating applications. [28]

3.2.8.7 Parallelism

Defines the allowable deviation in the parallel orientation of a feature relative to a reference datum. The tolerance zone consists of two parallel planes or lines parallel to the datum, as seen in Figure 9. It is used to ensure that a surface or line remains at a constant distance from the datum, maintaining a 0° orientation. Parallelism does not directly control the angle, but instead defines a tolerance zone within which the feature must lie. When applied to surfaces, parallelism also limits variation in surface form and is therefore closely related to flatness. It is commonly used to ensure consistent alignment and spacing between features. [28]

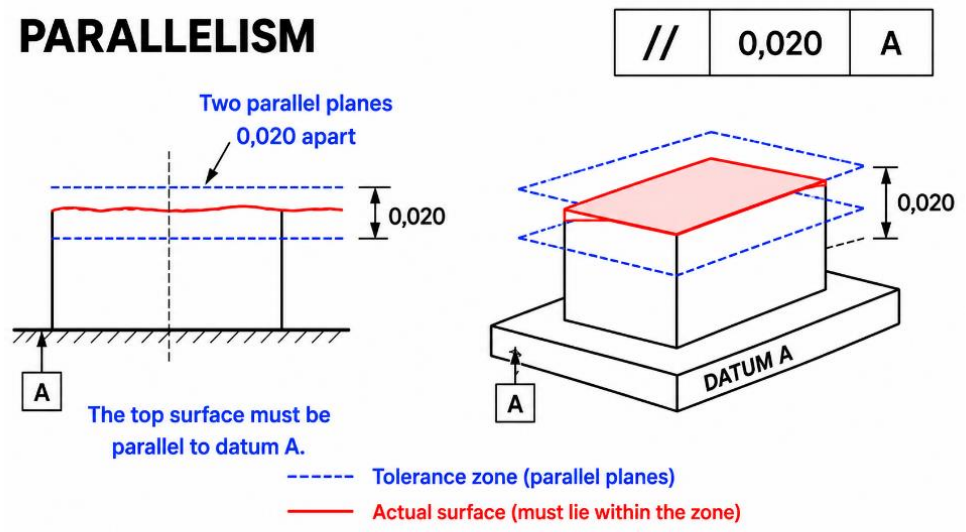


Figure 9: Illustration of parallelism.

3.2.8.8 Perpendicularity

Defines the allowable deviation of a feature from a 90° orientation relative to a reference datum. The tolerance zone consists of two parallel planes or lines oriented perpendicular to the datum. When applied to an axis, the tolerance zone becomes cylindrical, within which the axis of the feature must lie. This is commonly used for holes, where the center axis must remain perpendicular to the reference surface to ensure proper alignment during assembly. [28]

3.2.8.9 Angularity

Defines the allowable deviation of a feature from a specified angle relative to a reference datum. Parallelism and perpendicularity are special cases of angularity. The tolerance zone consists of two parallel planes or two parallel lines oriented at the specified angle relative to the datum. Angularity does not directly control the angle using a ± value, instead it defines a tolerance zone at the specified orientation, thereby indirectly controlling the angular deviation. Angularity is commonly used when features must function together at a defined angle. [28]

3.2.8.10 Position

Defines the allowable deviation of a feature from its theoretically exact location, known as the true position. Position is typically applied to features of size, such as holes, slots or pins, and controls the location of their central elements (e.g. axis or center point). The tolerance zone is three-dimensional and may, for example, be cylindrical when applied to the axis of a feature, as illustrated in Figure 10.

When specifying a position tolerance, datum references are included to establish a coordinate system. This allows the exact location of the feature to be defined relative to other features. In Figure 10, the axis of the hole is required to lie within a cylindrical tolerance zone located at the theoretically exact position relative to datum surfaces A and B. [28]

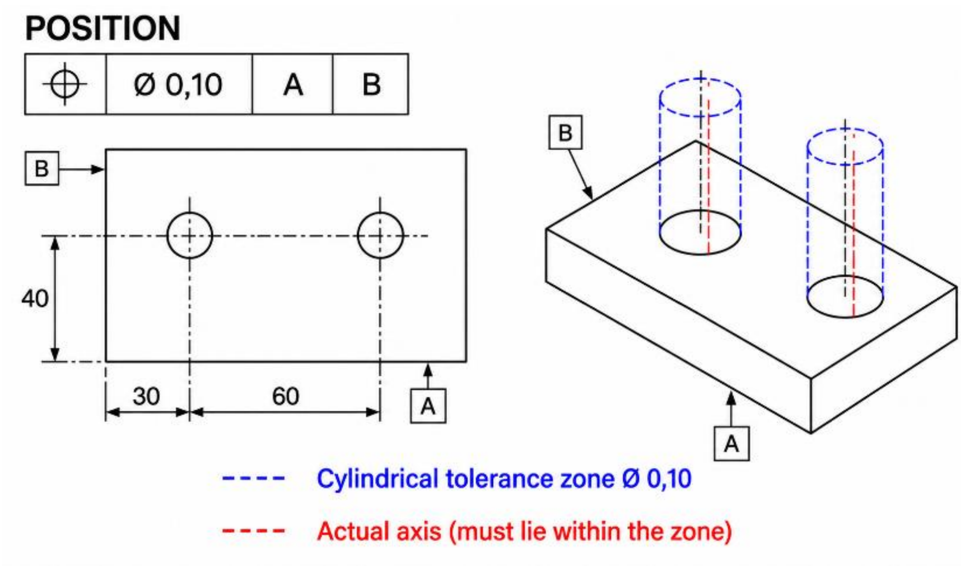


Figure 10: Illustration of the position tolerance.

3.2.8.11 Circular runout

Defines the allowable variation of a surface when a part is rotated 360° about a reference datum axis. It is primarily used to control circular features, describing how much variation they have relative to the axis of rotation. This variation is often referred to as "wobble".

The tolerance is evaluated at individual cross-sections, making it a two-dimensional control, as shown in Figure 11. It is commonly used for rotating components such as shafts, drills, axles, and gears, where excessive variation can lead to vibration, noise, or uneven wear. [28]

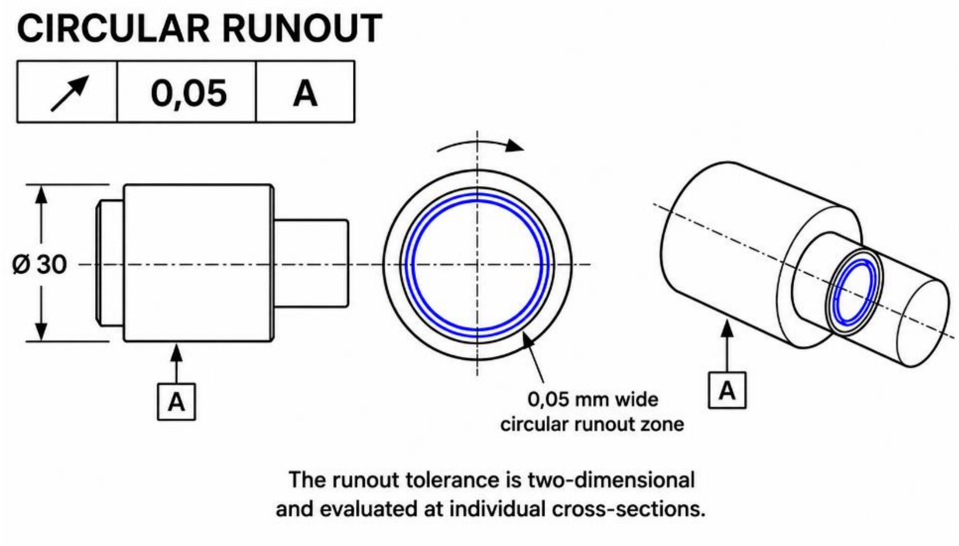


Figure 11: Illustration of circular runout.

3.2.8.12 Total runout

Defines the allowable variation of one entire feature or surface when a part is rotated 360° about a reference datum axis. Unlike circular runout, which is evaluated at individual cross-sections, total runout evaluates the complete surface simultaneously, making it a three-dimensional tolerance. It is typically applied to rotating components where the entire surface is functionally important and is used to prevent vibration and uneven wear in high-precision rotating components. [28]

3.2.9 Surface roughness

Surface roughness is a commonly used concept in technical drawings used to describe the texture of a surface. It refers to microscopic irregularities of a surface, consisting of tiny peaks and valleys, which influence properties such as friction, lubrication, wear and cleanability. Greater variation in these surface features corresponds to a rougher surface. Surface roughness can therefore be regarded as a measure of how much a real surface deviates from its ideal geometry. [29]

3.2.9.1 Functional importance and influencing factors

Surface roughness plays an important functional role. A certain level of roughness can improve friction and help retain lubrication between contacting surfaces, while excessive roughness can increase wear. On the other hand, excessively smooth surfaces may reduce lubrication retention and grip, potentially leading to increased temperatures and slippage during operation. Achieving lower roughness values requires more time-consuming and expensive manufacturing. By specifying appropriate roughness limits, functional performance can be balanced with manufacturing cost. [29]

The framework for defining, measuring, and specifying surface roughness is provided by ISO 21920 [30], which establishes terminology, parameters, and evaluation methods for profile-based surface texture. However, it does not prescribe specific roughness values, which must instead be selected based on functional requirements. Surface roughness is influenced by several manufacturing-related factors, including machining parameters, tool condition, and material properties [31].

3.2.9.2 Surface roughness parameters

Surface roughness is commonly characterized using profile parameters obtained from two-dimensional measurements along a line. The most commonly used are the arithmetical mean roughness, Ra, and the mean roughness depth, Rz.

Ra represents the average deviation of the surface profile from the mean line over a specified sampling length, providing a general indication of surface texture suitable for many engineering applications. Rz, on the other hand, is based on the average difference between the highest peaks and lowest valleys within defined sections of the profile. It is more sensitive to extreme surface features and therefore better represents isolated irregularities that may affect functional performance. [31]

Lower values of Ra and Rz indicate smoother surfaces. Ra offers a simpler and more consistent overall measure of surface texture and is therefore the most commonly used parameter in engineering practice.

3.2.9.3 Representation in technical drawings

Surface roughness requirements are specified in technical drawings using standardized symbols defined in ISO 21920 [30]. The basic symbol may be modified to indicate whether material removal is required or prohibited, as seen in Figure 12. The specified roughness value is placed adjacent to the symbol to define the allowable surface texture.

The application and structure of surface roughness symbols are standardized in ISO 21920 [30]. General surface roughness requirements that apply to all surfaces may be stated in the title block, while specific requirements for individual surfaces are indicated directly on the drawing. In addition, the symbol can include further information such as machining method, surface lay, or other parameters when required.

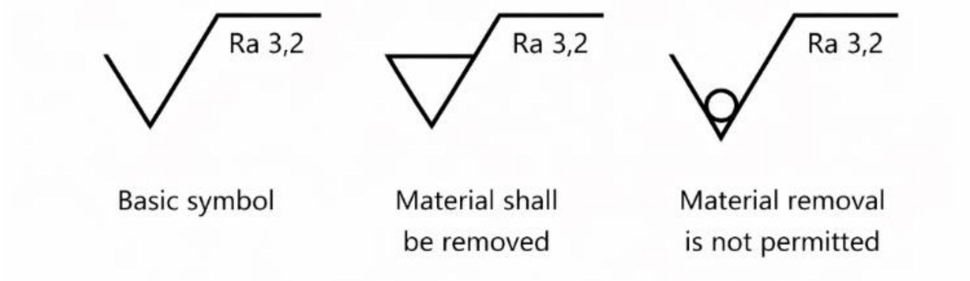


Figure 12: Standardized surface texture symbols used in technical drawings to indicate surface roughness requirements and material removal conditions.

3.2.9.4 Selecting Ra

Engineering drawings must include information about the required surface quality of components. It is typically specified using the parameter Ra, where commonly used values are 25, 12.5, 6.3, 3.2, 1.6, 0.8, 0.4, and 0.2 µm [9]. The selection of Ra is primarily based in the functional requirements of the surface. Surfaces involved in contact, sealing or precise fits generally require lower roughness values, while non-critical surfaces can tolerate higher values.

Surface roughness should only be specified where necessary. Overspecification should be avoided, as lower Ra values increase manufacturing cost and machining time. In many cases, normal manufacturing processes already provide an acceptable surface finish. [32]

The selected roughness may also be related to the specified tolerances. In general, tighter tolerances require smoother surfaces. One way to relate surface roughness to tolerances is through the use of ISO tolerance grades, as done in [9]. For example, mating surfaces with ISO tolerance grades 5–7 typically require Ra values in the range 0.2–1.6 µm, while surface with lower precision requirements may use higher roughness values. These relationships are not used to directly determine Ra but rather serve as practical guidelines to verify that the chosen value is consistent with the required level of precision.

The selected Ra value must be compatible with the manufacturing process. The achievable roughness is strongly dependent on the manufacturing process. Typical ranges for Ra for different manufacturing methods are shown in Table 5.

Table 5: Surface roughness values for typical manufacturing processes, adapted from [33].

Surface description	*Typical manufacturing processes*	*Typical Ra (µm)*
Very rough	Saw cutting, rough forging	25
Roug	Rouch machining, drilling	12.5
Clearly visible tool marks	Standard milling, turning	6.3
Visible tool marks	General machining	3.2
Smooth, slight marks	Precisions, reaming	1.6
Very smooth, no visible marks	Grinding, honing	0.8
Near-mirror finish	Precision grinding, lapping	0.4
Mirror-like finish	Polishing, superfinishing	0.2

Table 5 is not used to directly select Ra values, but rather to verify that a chosen roughness is achievable with a given manufacturing process.

3.2.10 Drawing sheet layout

A drawing sheet is the standardized format used to present technical drawings, including graphical representations and associated information. Common areas found on technical drawings include the drawing field, title block, parts list, and revision field. Figure 13 illustrates the general placement of these areas within a drawing sheet. The descriptions of the drawing sheet structure and its common areas presented in this section are based on standard engineering drawing practice as described in [9]. The overall size, borders, and basic layout of technical drawing sheets are specified in ISO 5457 [34]. The exact arrangement and the content of their fields are defined by company-specific standards and may vary between organizations.

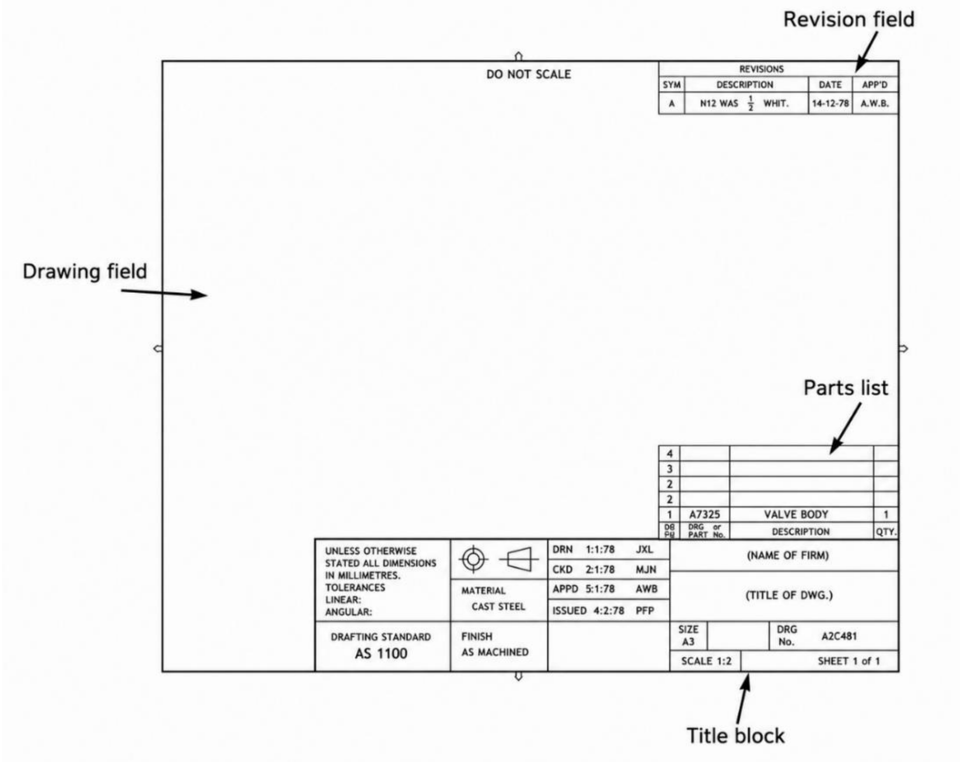


Figure 13: Example of drawing sheet layout, adapted from [35], reused in accordance with the website's terms of use.

3.2.10.1 Drawing field

The drawing field constitutes the main area of the sheet, where the geometry of the component or assembly is represented. In detail drawings, it contains the views, dimensions, and annotations necessary to define the component. Additional instructions may also be included in this field, for example to specify requirements for manufacturing, ensuring that the finished component conforms to the intended design.

3.2.10.2 Revision field

Located at the top of the drawing sheet, the revision field is used to document changes made to the drawing. When a modification is introduced, as for example updating a dimension, the previous value or information is recorded in the revision field together with an identifying number. This number is placed in the drawing field, within a small triangular marker located adjacent to the updated information. This creates a clear link between the change indicated in the drawing and its corresponding description in the revision field, ensuring traceability of design modifications.

3.2.10.3 Title block

The title block is located at the bottom of the drawing sheet and contains essential administrative and identification information, such as drawing number, title, author, and date. The content and structure of the title block are further described in Section 3.2.12.

3.2.10.4 Parts list

The parts list is typically positioned above the title block and provides structured information about the components included in an assembly. Each item is assigned a position number that links the list to its graphical representation in the drawing. A detailed description of the parts list is provided in 3.2.11.

3.2.11 Bill of Materials and Parts list

A Bill of Materials (BOM) is a structured representation of all components required for a product or assembly. In the context of technical drawings, this is commonly referred to as a *parts list*, as defined in ISO 7573 [36]. While the terms are sometimes used interchangeably, a BOM generally refers to a broader hierarchical product structure used in digital systems and lifecycle management, whereas a parts list refers to the drawing-based representation of items included in a specific assembly [37]. A parts list can therefore be regarded as a single-level BOM describing the components of one assembly without representing hierarchical relationships between subassemblies.

The purpose of a parts list is to provide the necessary information to support activities such as manufacturing, procurement, and maintenance by clearly identifying all constituent items of an assembly and linking them to their graphical representation. The basic content and requirements for parts lists are defined in ISO 7573 [36].

According to the standard, a part list shall include a set of structured data fields that enable identification and specification of all items in an assembly. Fields for general use include:

- **Part reference:** Numerical identifier assigned to each item in the assembly, used to link entries in the parts list to their corresponding graphical representation in the drawing. The references are typically shown in the drawing using numbered balloons placed adjacent to the components. Identical items within the same assembly shall have the same part reference.
- **Quantity:** Specifies the total number of each part or material required for a specific assembly.
- **Unit:** Defines the unit of measurement associated with the quantity. May be omitted if the unit is “pieces”.

- **Reference designation:** Unique identifier assigned to each individual occurrence of an item. Different occurrences of identical parts therefore receive different reference designations.
- **Part number:** Unique article number used to identify a part or material within the organization. Depending on the application, an item may be defined by the article number alone or together with additional technical designation data.
- **Part name:** The textual description of a part or material.
- **Technical data, designation:** Additional information used to define the item, such as dimensions, material, standard designation, or manufacturer information.
- **Remarks:** An optional field for supplementary information.

The data fields presented in ISO 7573 [36] define the fundamental content and purpose of the parts list. Additional company-specific fields may be added or used to replace existing columns according to organizational needs. The parts list may be included directly on the drawing or provided as a separate document. When placed on the drawing, it is typically located adjacent to the title block.

3.2.12 Title block

The structure and the content of the title block in technical product documentation is defined in ISO 7200[38]. The standard specifies standardized data fields intended to support identification, traceability, and document management throughout the product lifecycle. The title block therefore serves as an important link between the graphical representation of the drawing and the associated metadata used for document control and lifecycle management. Since ISO 7200 applies to technical documents in general, it primarily defines document-management-related fields rather than technology- or application-specific requirements.

ISO 7200 [38] defines eight mandatory standardized data fields intended to support identification, traceability, and document management throughout the product lifecycle. These mandatory fields are described below.

1. **Legal owner** – Organization responsible for the document, typically stated as a company name or logotype.
2. **Identification number** – Unique reference number used to identify the document.
3. **Date of issue** – Date of release or revision of the document, used for traceability.
4. **Sheet number** – Identifies the individual sheet within the document.
5. **Title** – Describes the content of the document.
6. **Creator** – Person responsible for preparing or revising the document.
7. **Approval person** – Person who has formally approved the document. The name of other reviewers may also be included.

8. **Document type** – Defines the role of the document, e.g. drawing or specification, to support document retrieval

defines several optional data fields grouped into identifying, descriptive, and administrative categories. Optional identifying data fields include revision index for document revision status, the total number of sheets, and language code indicating the language used for language-dependent content. The only optional descriptive data field is the supplementary title, which provides additional information not included in the main title, such as adaptation to specific markets, standards, or environmental conditions.

Optional administrative fields may include responsible department, identifying the organizational unit responsible for the document, technical reference specifying a contact person with technical knowledge of the content, document status indicating the stage of the document in its lifecycle, and classification data or keywords supporting document retrieval and management. Paper size may also be included to specify the intended document format. These fields support document management, retrieval, and lifecycle control.

The fields defined in ISO 7200 represent general document-management information. Technical drawings therefore commonly also include additional drawing-related and company-specific fields not specifically defined in the standard, such as scale, projection method, general tolerances, surface roughness requirements, material specifications, lifecycle status, or PLM-related metadata. The position of the title block on technical drawings is specified in ISO 5457 [34]. For A0 to A3 the title block is placed in the bottom right-hand corner of the drawing space, while for A4 it is located in the lower part of the drawing space.

3.2.13 Drawing sheet size and format

The format and layout of technical drawing sheets are defined in ISO 5457[34]. The standard specifies the size and layout of drawing sheets for technical documentation in all fields of engineering, including those produced using computer-aided design.

Standard sheet sizes are defined for formats A0 to A4. The standard states that the original drawing shall be created on the smallest sheet size that permits sufficient clarity and resolution. The designation of the sheet size shall be placed at the bottom right-hand corner of the drawing sheet. ISO 5457 also defines layout elements such as borders, frames, centering marks, and reference systems supporting positioning and interpretation of the drawing. Formats A0 to A3 are used in horizontal orientation, while A4 is used in vertical orientation.

3.2.14 Lettering in Technical Drawings

Lettering refers to the use of graphical characters to convey non-graphical information, such as text, dimensions, and instructions, in technical drawings. Lettering principles, including font size, proportions, and character design, are defined by ISO 3098 [39]. The standard applies to technical product documentation in general, including CAD-generated drawings, and aims to ensure that information is clear, consistent, and legible.

The nominal size of lettering is defined by the height of the uppercase letters. ISO 3098 [39] defines eight nominal lettering heights: 1.8 mm, 2.5 mm, 3.5 mm, 5 mm, 7 mm, 10 mm, 14 mm, and 20 mm. The standard does not assign specific applications to individual text sizes. In practice, text heights are selected to ensure readability across different drawing scales and formats, including when drawings are printed. As a general recommendation, a text height of approximately 2.5 mm is used for descriptive text, general notes, and dimensions [40]. Larger sizes are used for more prominent information, where 3.5 mm is typically used for labels and structure names, 5.0 mm for main titles, and 7.0 mm for headings or emphasized information.

ISO 3098 [39] also defines requirements for character proportions, spacing, and line thickness. Line widths shall be in accordance with ISO 128-2 [19], and lettering shall be consistent in style, size, proportions, and spacing to ensure legibility.

3.2.15 Scales

3.2.15.1 Use of scale in technical drawings

The use of scales in technical drawings is defined in ISO 5455 [41], which specifies recommended scales and their designations. A scale defines the ratio between a dimension shown on the drawing and the corresponding real dimension of the object.

A scale of 1:1 indicates a full-size representation. Scales larger than 1:1 are enlargement scales and are expressed as X:1, while smaller scales are reduction scales and are written as 1:X. The scale used on a drawing is designated in the form SCALE X:X, although the word SCALE may be omitted if the meaning is clear. As specified in ISO 5455 [41], the designation of the scale applied to a drawing shall be indicated in the title block. If more than one scale is used, the main scale shall be given in the title block, while additional scales are stated adjacent to the relevant view, detail, or section.

Recommended scales are given in ISO 5455 [41] to ensure consistency. The recommended enlargement scales are 2:1, 5:1, 10:1, 20:1 and 100:1, while the recommended reduction scales are 1:2, 1:5, 1:10, 1:20 and 1:100. When a larger or smaller scale is necessary, the scales may be extended by factors of 10. In exceptional cases, intermediate scales may be applied if required for functional reasons.

The choice of scale depends on the size and the complexity of the object to be represented, as well as the purpose of the representation. The selected scale shall be large enough to present the information clearly and allow the drawing to be interpreted easily. Together with the size of the object, the scale determines the overall size of the drawing. When features are too small to be clearly shown or dimensioned in the main view, they shall be represented in separate detail views or sections using a larger scale, as seen in Figure 14. For small objects shown at a large scale, an additional simplified full-size view may be included to provide an overall reference of the object's form.

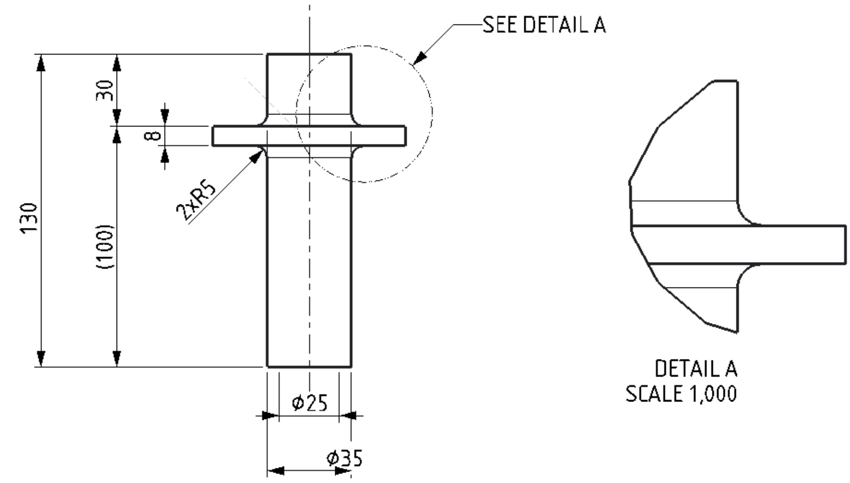


Figure 14: Example of a detail view.

3.2.15.2 Role of scale in practice

The use of scale in technical drawings presents an inherent contradiction in engineering practice. On one hand, drawings are created at a defined scale to represent the size, shape, and proportions of an object. This allows the drawing to convey a clear overall impression of the object and, in principle, makes it possible to measure directly from it. On the other hand, one fundamental rule in engineering drawing is that one should not derive any dimensions by measuring from the drawing itself, often expressed through the note "Do not scale drawing".

As noted in ISO 5455 [41], the scale of a printed drawing may differ from the scale stated on the drawing. In practice, drawings are frequently printed, copied, or exported using settings such as "fit to page", which can alter their physical size. As a result, measurements taken directly from a drawing may be inaccurate, and dimensions must therefore be considered the authoritative source of information. If drawings are printed using controlled settings, e.g. at 100% scale on the intended paper size, the stated scale may be approximately preserved, although measurements should still not be taken directly from the drawing. Some engineering drawing literature therefore argues that including a stated scale on drawings may even be unnecessary and misleading in practice [9].

In modern engineering practice, the role of scale has further changed with the use of CAD. Drawings are often viewed digitally, where zooming in is unrestricted and the displayed scale is not fixed. At the same time, the geometry is defined precisely in the digital model, allowing accurate measurement directly from the source rather than the drawing.

Despite this, scale can still serve a purpose in technical drawings. The selected scale influences both the layout and readability of the drawing. It determines how much information can be included within the available drawing space while ensuring that views, dimensions, and text remain clear and legible. In addition, scale provides contextual understanding of the object's relative size and proportions, even though reproduced drawings may not preserve the exact scale relationship.

3.2.16 Summary of technical drawing principles

Together, these standards and principles provide the foundation for creating clear, consistent, and unambiguous technical drawings. They support communication between design, manufacturing, inspection, purchasing, and other functions involved throughout the product lifecycle, while also enabling traceability, quality assurance, and efficient management of product information. In modern engineering practice, technical documentation is closely integrated with Product Lifecycle Management (PLM) systems, which will be described in the following sections.

3.2.17 Product Lifecycle Management systems

3.2.17.1 Purpose of PLM systems

Product Lifecycle Management can be described as the systematic management of a company's products and related information throughout the entire lifecycle, from initial concept to retirement, aiming to increase product value while reducing cost and development time [10].

The importance of PLM has increased as products and product systems have become more complex, particularly within manufacturing and high-technology industries. Collaboration between cross-functional teams and suppliers, often operating in global networks, requires structured methods for managing and sharing product information. At the same time, increasing global competition and customer demands require companies to develop more advanced, customized and higher-quality products. This pressure is further reinforced by shortening product and component life cycles, which demand faster development processes and reduced time-to-market.

Together, these developments create significant challenges for organizations. To remain competitive and financially sustainable, companies must be able to manage product information efficiently, coordinate activities across the supply network, and make informed decisions throughout each product's lifecycle. PLM therefore serves as a strategic framework for supporting collaboration, controlling product data, and managing product creation and lifecycle processes in complex development environments.

3.2.17.2 Product data management (PDM)

Certain fields of PLM are particularly relevant for the creation, storage, modification and review of technical drawings. These include Product Data Management (PDM), change management, workflow and review processes, and collaboration and access control.

PDM is closely related to PLM but represents a narrower focus. While PLM provides a broader framework for managing all aspects of the product lifecycle, PDM primarily consists of tools and methods for efficiently managing product data [10]. PDM can thus be viewed as a subset of PLM focused on the organization, storage, and control of product data, making it a central element of PLM. Product data can be defined as the information determining the physical and functional properties of a product, i.e. its form, fit, and function, together with lifecycle information and metadata [42]. This includes CAD models, technical drawings, BOMs, specifications and documents related to manufacturing, testing, inspection and assembly.

In practice, the terms PLM and PDM are often closely connected and may be used interchangeably depending on context. In this report, the term PLM will generally be used when referring to the systems and processes managing product-related information.

PDM emerged in the late 1980s as a response to the growing volumes of CAD-generated design files, supporting activities such as item standardization, BOM management, revision control, and structured documentation throughout the design process [42].

3.2.17.3 Lifecycle states and revision management

During product development, effective management of document flow is essential. A central part of document management is the handling of document status. In the PLM system documents and component items move through a defined lifecycle in which their status changes as the workflow progresses. Examples of lifecycle states can be seen in Figure 15. A document is typically created and prepared, reviewed, formally approved, and then released for use. The transition between each phase is often confirmed through the use of electronic signatures [43]. The system also maintains information about the document version, including what changes have been made, when they were made, and by whom. This structured progression ensures control and traceability throughout the lifecycle.

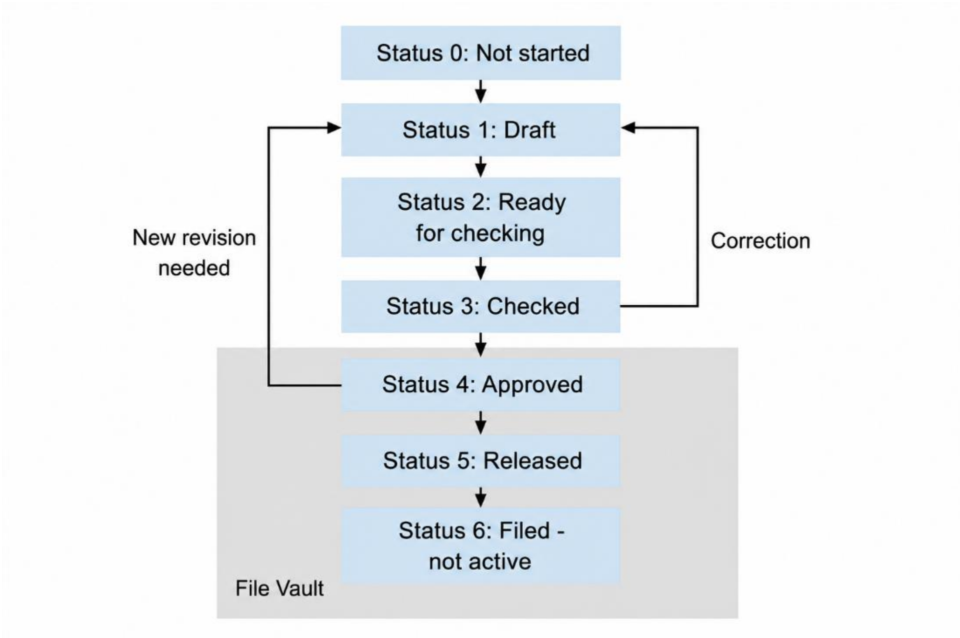


Figure 15: Example of the statuses of a document in a PLM system, adapted from [10].

The PLM system can automatically manage these status transitions when new files are created, or existing ones are updated within the system [42]. For example, files are *checked out* during editing, creating a temporary lock that prevents simultaneous modifications by other users. Once modifications, such as drawing updates, have been completed, the file is checked back into the system.

Another important feature is user privilege management [42]. The PLM system manages information access and maintenance rights based on the user and the current lifecycle status. It defines user roles and permissions, determining who is authorized to create new information, implement, review, and approve changes, and who is limited to view-only access within the system.

Access rights may change throughout the product lifecycle. During the creation phase, a document owner typically has broad modification rights, whereas in later stages, such as review, release, or archive, changes are restricted and may only be performed through formal change procedures. User permissions can include general rights such as read, write, modify, and delete access, as well as PLM-specific functions such as lifecycle status management, metadata modification, file locking, document check-in/check-out, and creation of new parts or documents [43].

In PLM systems, deletion rights are typically restricted to specific roles, such as administrators. In many organizations, PLM systems are configured so that product data, particularly released data, cannot be permanently deleted. Instead of deletion, objects are commonly moved to controlled lifecycle states, such as obsolete or non-active. This approach supports traceability and prevents uncontrolled loss of product information.

3.3 Literature review discussion

3.3.1 Contribution of the literature review

The literature review provided a comprehensive foundation in technical drawing practices and PLM-related data management. The reviewed standards and literature supported understanding of technical drawing creation, interpretation, and management, while also highlighting how drawing activities are closely connected to broader lifecycle and product data management processes within PLM systems. This proved valuable for both the development of the handbook and the preparation of the empirical investigation by helping identify organizational processes that should be examined more closely, such as drawing creation, review practices and use of technical documentation across different organizational functions.

However, while standards provide essential guidance, they have limitations. ISO standards do not cover every aspect of drawing creation or management. Few scientific articles specifically address detailed technical drawing practices in industrial settings, and standards alone cannot fully capture practical application, variations across industries, or company-specific requirements. This highlights the need for adaptation. Internal procedures must be developed to complement the standards, ensuring that drawing management aligns with the specific context, product complexity, field, and size of the organization.

3.3.2 Scope limitations

Model-Based Definition, which represents an emerging approach to technical documentation with potential to partially replace traditional 2D drawings, was not included in the literature review. MBD is currently not implemented within the organization, which still relies partly on printed drawings. Implementation of MBD was considered beyond the scope of this project due to the significant organizational and technical changes required. MBD would therefore not be included in the handbook and was consequently not considered relevant within the scope of the project.

In addition, the literature review did not focus extensively on how modern CAD systems automate parts of the drawing creation process. Although many drawing functions are partly automated within CAD systems, understanding the underlying drawing principles and standards was still considered important to support correct interpretation, verification, and consistent creation of technical drawings within the handbook

The literature review could also have included more detailed investigation of additional PLM-related topics, such as engineering change management, revision management, integration between CAD and PLM systems, and what types of drawing-related data are managed in PLM systems. However, while technical drawing principles are largely standardized and well suited for literature-based study, understanding these PLM-related processes was considered more valuable through investigation of how they were implemented within the organization's existing PLM system.

Overall, the literature study effectively supported the handbook development by providing both theoretical and practical guidance. Despite these potential extensions, the selected literature provided a solid understanding of the subject and sufficient context to support both the handbook content and the analysis of the company's processes.

4 Organizational study

4.1 Method

Section 4.1 describes and motivates the methods used to study the current organizational practices. Through interviews, analysis of internal documentation, practical observations and interaction with company systems, existing workflows and challenges were identified.

4.1.1 Requirement elicitation process

As described in [44], requirement elicitation is a process that involves identifying stakeholder needs, expectations, and constraints through interactions with stakeholders and analysis of the problem domain. The collected information is then analyzed and refined into clear and actionable requirements.

4.1.1.1 Requirement elicitation techniques

Several techniques can be used for requirement elicitation. According to [45] these can be divided into the four categories: conversational, observational, analytic, and synthetic methods. Conversational methods gather information through verbal interaction with stakeholders, for example through interviews or workshops, and are useful for understanding stakeholder needs and expectations. Observational methods focus on understanding the current organizational environment by observing how tasks are performed in practice, which can reveal implicit knowledge or requirements that stakeholders may not articulate. Analytic methods derive requirements through analysis of existing documentation, systems, standards, and processes. Synthetic methods combine multiple approaches, often through collaborative activities such as prototyping or scenarios, to develop a shared understanding of problems and solutions.

4.1.1.2 Selection of elicitation techniques

According to Anwar and Razali [46] the selection of requirements elicitation techniques depends on several factors, including stakeholder characteristics, the stage of the project and the analyst’s familiarity with the techniques. The authors describe conversational techniques as particularly suitable when stakeholders possess strong domain knowledge and experience, since they support detailed explanations and reasoning. In addition, the stage of the project may influence technique selection, where analytic methods such as document analysis are useful during early stages develop of an initial understanding of the problem domain. The authors also emphasize that requirements are typically gathered from multiple sources, including stakeholders, documents, and existing systems, and therefore different elicitation techniques are often combined.

The literature provided support for the selection of elicitation techniques used in this project. Multiple elicitation techniques were combined in order to gather information from different sources and obtain a broader understanding of existing processes. Existing documentation was reviewed early in the project to develop an initial understanding of current practices. Interviews were selected as the primary elicitation approach since the stakeholders, primarily design engineers, were considered to possess strong knowledge of the drawing process and would therefore be able to provide detailed explanations of workflows and challenges. Informal discussions were also used to gather additional information and clarify specific topics throughout the project. Throughout the project, continuous discussions were also held with a representative from technical management to clarify organizational processes and establish intended working practices in areas where formal procedures were limited.

Observational elements were included primarily through observation of drawing reviews, where the reviewer demonstrated how drawings are reviewed in practice. System interaction was carried out later in the project as understanding of the processes increased, supporting interpretation of workflows and data handling within the CAD and PLM system. The following sections describe in more detail how each of these methods was applied.

4.1.2 First round of interviews

The interviews were divided into two rounds with different purposes. This section describes the first round of interviews.

4.1.2.1 Purpose of the interviews

During the early stages of the organizational study knowledge about the company's drawing process and working practices was still limited. The first round of interviews therefore aimed to develop an overall understanding of current practices, terminology, responsibilities, and experienced challenges, providing a contextual basis for the second interview round.

4.1.2.2 Participant and interview procedure

Participants were three design engineers from different business areas, with varying levels of tenure within the organization, providing both established organizational knowledge and perspectives from more recently employed engineers. All participants possessed significant professional experience in product development and drawing creation. Interviews were conducted individually to allow each participant to provide their own perspective without being influenced by other participants. Interviews in both rounds were conducted at the Backer office and lasted approximately one hour each.

The interviews were conducted as semi-structured interviews, guided by an interview guide containing a set of topics and questions. The guide ensured that important aspects of the drawing process were covered, while allowing flexibility to adapt questions based on participants' roles and responses. As a result, the exact set of questions varied slightly between interviews. Follow-up questions were asked as needed, enabling participants to elaborate on their experiences and introduce additional relevant aspects.

Semi-structured interviews were selected to balance coverage of key topics with flexibility to explore participants' experiences. Structured interviews are highly standardized and ask all participants the same questions in the same order, which ensures comparability but limits exploration of new topics [47]. Unstructured interviews focus on broad topics without predefined questions, providing rich insights but risking that some areas are left unaddressed.

4.1.2.3 Interview topics and structure

The interviews covered the complete drawing lifecycle, from creation in CAD to use in production and later change management activities, including supporting systems such as PLM and review processes. The interview guide was organized into the following thematic areas: creation and use of drawings, engineering change management, drawing content and standards, PLM usage, model-based definition, review processes, and cross-departmental collaboration. The main themes and examples of covered topics are summarized below. The full interview guide is provided in Appendix B.

Creation of drawings: Respondent were asked to describe the workflow from 3D modeling to finalized drawings in CAD. Questions addressed errors that can occur when drawings are created inconsistently, such as unclear notes, dimensioning or tolerancing mistakes, and ambiguities in manufacturing requirements. They also explored variation between designers and the potential impact on clarity. Participants were also asked to reflect on their balance between adherence to company standards and use of individual working methods, and to identify aspects of the current approach to preserve in future guidelines.

Drawing lifecycle and PLM system: Questions examined how drawings are distributed, stored, and managed after release, including access rights and traceability. The approval process and lifecycle stages were explored to understand how responsibilities are defined and how revisions are controlled within the PLM system. The integration between CAD and PLM was explored.

Engineering change management: Questions addressed how modifications to released drawings are managed and what steps and systems are involved.

Drawing content and standards: Questions focused on the technical content of drawings, including dimensioning, tolerances and selection of views. Interviews also explored the content of the title block, including mandatory fields and language usage.

Organizational context and collaboration: Questions examined how drawings are used across the organization. Additionally, communication challenges between the departments and responsibilities related to drawing use were explored

Future development: Questions explored the organization's readiness for advanced digital practices, including model-based definition.

Notes from each interview were transcribed, summarized, and grouped according to the thematic areas in the interview guide. This categorization helped identify recurring issues, differences in practices, and potential requirements for the handbook, and supported the development of questions for the second round of interviews.

4.1.3 Second round of interviews

4.1.3.1 Purpose of the interviews

The first round of interviews provided a broad understanding of current drawing practices and organizational context. Based on the insights from this initial round, the second round of interviews was conducted to support identification of requirements for the handbook. Compared to the first round, the questions were focused more specifically on identifying needs, potential risks, and areas where clearer guidance or standardization would be beneficial.

Many of the themes explored in the first round were revisited. However, by this stage a significantly better understanding of the processes had been established, allowing the questions to be formulated more precisely and focused on specific aspects of the drawing process that required further clarification. A structured interview guide was therefore developed to systematically cover key aspects of drawing creation, including standardization, review processes, change management, and system interactions.

4.1.3.2 Participant and interview procedure

The participants in the second round were two design engineers who did not participate in the first interview round, allowing additional perspectives on existing drawing practices and internal processes to be captured. Both participants had relatively long tenure within the organization and extensive professional experience, although their levels of experience differed. The number of participants in the second interview round was limited by participant availability, the size of the organization, and project time constraints.

The interviews were conducted individually using a semi-structured approach, although the second round followed a more structured format than the first. The interview guide, containing questions covering all relevant topics, was generally followed in the same order for each participant to ensure that nearly the same set of questions was asked in each interview. Follow-up questions were asked when participants elaborated on relevant aspects, allowing additional insights to be explored while maintaining coverage of the main topics.

4.1.3.3 Development of the interview guide

The effectiveness of interviews depends greatly on the formulation of questions and the order in which these questions are asked, in order to ensure the information gathered reflects the requirements accurately [48]. The questions were formulated to support understanding of what must be defined, standardized, or clarified so that drawings become consistent and correct.

The WH6 framework [48] was used to formulate questions for effective requirement elicitation. The framework recommends asking questions using the seven interrogatives, *who, what, where, when, why, how, and which*, to capture multiple perspectives including responsibilities, processes, motivations, and timing. It also emphasizes the logical ordering of questions based on dependencies between the interrogatives. For example, avoiding asking "how" before "what," to reduce the risk of missing key information. Not all interrogatives were applied to every topic, but the framework helped systematically guide the interviews.

Additionally, questions were formulated according to established best practices for requirement elicitation [49]. Accordingly, the questions were designed to be open, non-leading, and phrased using neutral language to encourage participants to describe experiences, needs, and challenges in their own words without implying right or wrong answers. The interviewer remained as neutral as possible throughout the interviews and avoided introducing personal opinions that could influence participants' responses. Each question focused on a single topic to reduce ambiguity, while binary yes/no questions and predefined answer options were avoided to encourage more detailed responses and a broader range of perspectives. The interviews focused primarily on current practices and experiences rather than hypothetical future scenarios, since the literature suggests that present behavior generally provides more reliable insights than predictions about future behavior.[49]

4.1.3.4 Interview topics and structure

The interview guide was divided into several thematic areas. The main themes and examples of covered topics are summarized below. The full interview guide is presented in Appendix C.

Structure and scope of the handbook*:* Questions addressed which aspects of drawing creation should be standardized, where current practices depend on individual interpretation, and what knowledge is important for newly hired engineers. They also explored how the handbook should relate to existing documentation and organizational practices.

Drawing creation standards: Questions focused on current practices related to dimensioning, tolerancing, views, scales, and projections, as well as the use of ISO standards and product-specific exceptions. The interviews also explored areas where inconsistencies, misunderstandings, or variation between engineers commonly occur.

Templates and layouts: Questions examined the structure and use of drawing template, particularly the title block, discussing which fields of the title block should be mandatory, optional and which could potentially be removed. The interviews also explored the occurrence of recurring textual information in drawings.

Language policy: Questions explored what languages are used in drawings. Focusing on existing language rules, potential risks related to language ambiguity, and situations where English or mixed-language documentation may be appropriate, as well as the most useful language for the handbook itself.

Review and approval process: Questions addressed responsibilities during review and approval, criteria for determining when drawings are ready for release, and common errors identified during reviews.

Engineering change management: Questions addressed revision management, including when new revisions should be created, how changes should be documented, and how minor adjustments are handled.

Interaction with PLM & ERP: The questions focused on data flows between CAD, PLM, and ERP systems, which manual processes may introduce risks, and which system-related procedures should be described in the handbook to help prevent mistakes.

Collaboration and responsibilities: Questions focused on collaboration between departments, responsibilities related to technical drawings, misunderstandings between engineering and production, and what knowledge different departments can reasonably be expected to possess.

Future considerations: Questions explored whether the handbook should prepare for future use of model-based definition, as well as how responsibility for maintaining and updating the handbook should be managed over time.

Together, the interviews contributed to a deeper understanding of current drawing practices, organizational needs, and areas requiring clearer guidelines, which supported the identification of requirements for the handbook.

4.1.4 Document analysis

Document analysis was conducted to support understanding of existing organizational processes. The analysis was also used to determine which documents should be referenced in the handbook and which topics did not require further description in order to avoid overlapping with established documentation. The material included internal procedures for engineering change management, describing how changes should be initiated, evaluated, approved and implemented. In addition, the company's product development process documentation was reviewed to place drawing creation within a broader context.

The existing design handbook was also reviewed since it defines general practices related to design. The developed drawing handbook is intended to complement the existing design handbook while replacing sections containing limited guidance related to drawing practices with more detailed instructions. In addition, an existing internal checklist used to support design reviews was reviewed, as it includes verification points related to drawings. Furthermore, internal technical information documentation containing product and production-related data was reviewed to support understanding of product-specific requirements relevant to the handbook.

4.1.5 Practical observations and system interaction

Practical observations and system interaction activities were conducted to support understanding of how drawings were managed in practice. Observations were carried out through participating in three drawing review sessions together with the person responsible for reviewing drawings for on-site production. This was done to understand how reviews were performed, which aspects of drawings were evaluated, common mistakes identified, and what different systems were used during the process. The observations also provided a production perspective on drawings, complementing the engineering perspectives gathered through the interviews.

In addition, design engineers demonstrated selected activities in the CAD and PLM systems, such as check-in and release. Independent interaction with the systems was also performed to understand system functionalities, how information is transferred between systems, and which activities require manual handling.

4.2 Result

The results presented in this chapter are based on information gathered through interviews, document analysis, practical observations, and system interactions. Since the different activities largely revealed consistent findings, the results are presented according to key processes related to drawing creation and management rather than by method. This structure allows the results to be presented coherently by summarizing current practices and highlighting identified gaps, inconsistencies, and risks relevant to the development of the handbook.

4.2.1 Key processes for drawing creation and management

The elicitation activities identified several interconnected processes considered important for technical drawing creation and management within an organization. The findings showed that drawing-related activities extend beyond drawing creation itself to include processes related to product development, product data management, review and approval, production and purchasing activities, change management, and organizational knowledge transfer.

Figure 16 presents an overview of the key processes identified and the relationships between them. The figure illustrates the overall workflow and associated data transfer between the identified processes, while also highlighting supporting and influencing factors affecting these drawing-related activities.

The following sections present the organizational findings related to each of the identified processes in detail.

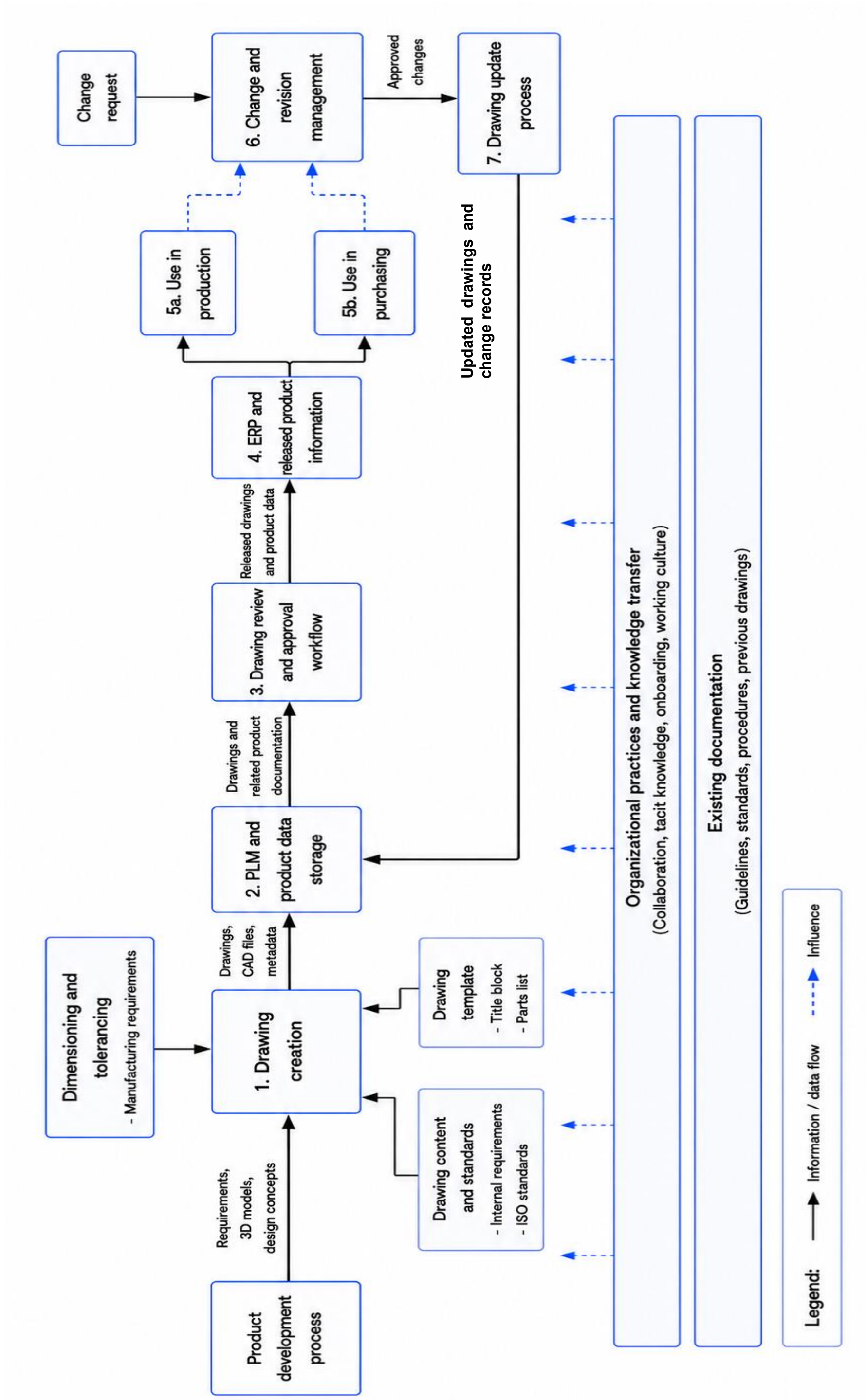


Figure 16: Overview of workflow with key processes for drawing creation and management.

4.2.2 Product development process and role of drawings

4.2.2.1 Product development workflow

Understanding the overall product development workflow helped clarify the role of technical drawings within the organization.

The company uses different product development workflows depending on project complexity, categorized as fast flow, advanced flow, and project flow. The advanced flow represents the intermediate level of the company's product development workflows and was used as the primary reference workflow in this study, as it was considered representative of a typical product development process within the organization.

Figure 17 presents a simplified version of the workflow based on the company's internal product development routine. Product development begins with activities such as requirement specification, analysis of previous designs, and risk assessment. These activities form the basis for the subsequent design work and influence the requirements that must be reflected in the technical documentation.

Based on the agreed specification and the outcomes of the preceding development activities, a 3D model is created, often using existing designs or components as a starting point. Based on the 3D model, the drawing and related documentation, such as the BOM, are created. The workflow then continues with activities such as design review, prototype validation, and approval of the technical documentation. These activities may result in updates to drawings and related product documentation, to ensure that requirements and identified design changes are properly reflected in the product definition.

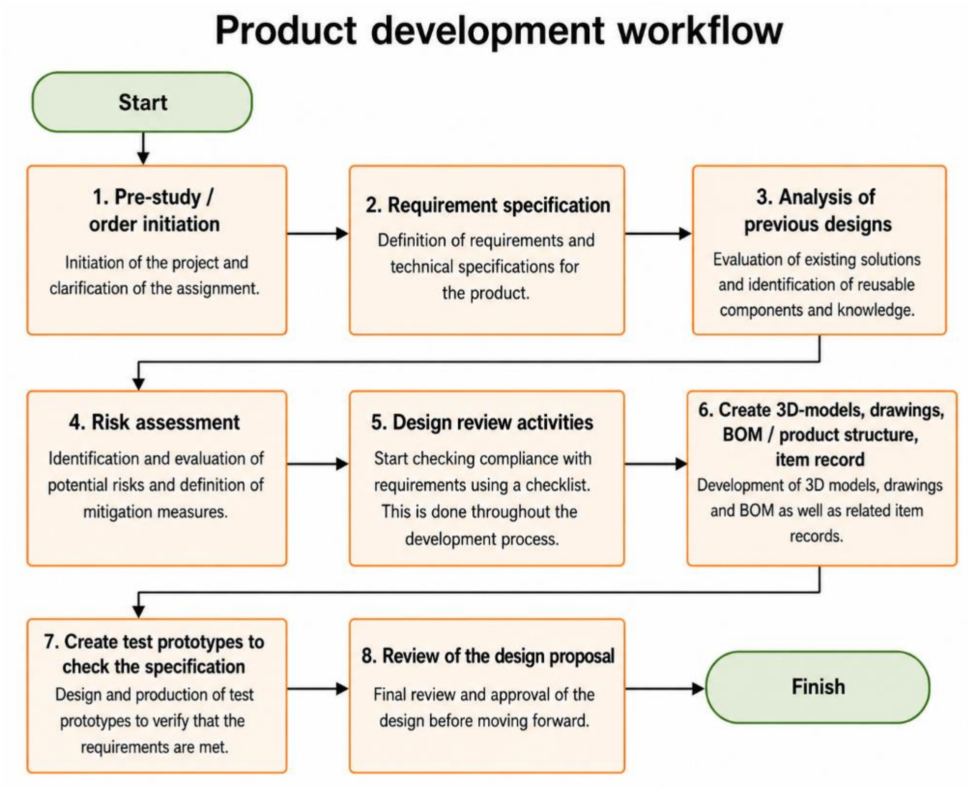


Figure 17: Simplified overview of the product development workflow, based on the company's internal product development routine.

4.2.2.2 Role of the drawing

The drawing defines geometry, dimensions, tolerances, and other technical requirements related to the physical product. Within the organization, it functions as the governing technical definition of the product geometry throughout the product lifecycle and represents the agreed definition of the physical product between the company and the customer. As a controlled document, only approved revisions are considered valid, and modifications are managed through defined revision and change management processes.

The findings showed that drawings are used across multiple organizational functions, including production, purchasing and quality assurance. According to the interviews, production and purchasing were considered the primary users of drawings within the organization.

4.2.3 Use of drawings in production

Drawings are a central part of the production process, as they define product geometry and technical requirements. They form the basis for manufacturing and inspection activities and serve as the authoritative source for dimensions, tolerances, and other product requirements.

4.2.3.1 Workflow and supporting documentation

In on-site production, drawings are used in printed form. It accompanies the product together with the operation list, which specifies the sequence of manufacturing steps required to produce the component, and the data card, which contains calculated technical data related to the heating element being manufactured. All documents follow the product throughout the manufacturing process, and operators sign the operation list after completing each step.

The drawing, the data card, and the operation list were described as complementary sources of information. However, the drawing is the governing document, meaning that the drawing takes precedence in cases where information differs between the documents. The operation list is created based on the drawing before production can begin. While the list of operations describes the manufacturing steps to be performed, the drawing specifies the geometry, dimensions, and other technical details required to carry out these operations. For example, the drawing may indicate where stamping should be performed, how components should be assembled, or where brazing material should be placed. It may also provide a bend table necessary for performing a bending operation. The data card contains additional calculated manufacturing and verification data that is not fully represented in the drawing, which is useful in certain manufacturing steps.

4.2.3.2 Manufacturing and verification

After manufacturing, a final inspection may be performed to verify that the product meets the specified requirements. During this inspection, the produced component is measured, and its dimensions are compared directly to those defined in the drawing. To facilitate this inspection and the overall manufacturing process, inclusion of auxiliary and functional dimensions was described as helpful to reduce the need for operators to perform calculations. Examples of dimensions described as important included overall dimensions, hole positions, bend positions and angles, interface dimensions, alignment information, and locations for welding or brazing operations.

4.2.3.3 Identified challenges

Because drawings are used in printed form during manufacturing, readability is important. Dimensions, notes, and views must remain clear when printed, which requires appropriate use of scale, as described further in Section 4.2.7.2. In addition, the drawing needs to include a sufficient number of views and technical information to allow production personnel to interpret the product without prior knowledge of the design.

Since drawings are used in printed 2D form, complex 3D geometries were described as difficult to interpret and visualize in some situations. Some participants therefore suggested introducing screens in production to allow personnel to view CAD models directly, which was considered a possible way to improve product understanding and reduce reliance on printed drawings.

The study further identified challenges related to interpretation of drawings in production. Unclear or incomplete drawings were described as a recurring source of questions from production personnel. These questions were typically directed to the drawing reviewer and, in some cases, also to the design engineers when additional clarification is needed. This was described as time-consuming and as causing delays in manufacturing, highlighting the importance of clear and complete drawings in order to avoid ambiguity.

4.2.4 Use of drawings in purchasing

Drawings are used by the purchasing department to communicate product requirements to external suppliers. In supplier communication, CAD models are often used to communicate the overall geometry and design intent, while drawings are primarily used to define tolerances and additional technical requirements. Purchasing activities also involve handling drawings received from customers, including reviewing the specified customer requirements against internal manufacturing capabilities. This is described further in section 4.2.9.1.

The drawing is intended to function as the authoritative technical product definition in supplier communication and therefore needs to contain all information necessary for manufacturing. However, the interviews identified differences between the intended use of purchasing drawings and how they are used in practice. Purchasing drawings were described as often being developed together with suppliers, where certain manufacturing details are communicated separately through emails or other external communication instead of being included in the drawing itself.

While this approach was described as making communication with suppliers easier and reducing the amount of information included in the drawing, it was also identified as creating challenges related to traceability and reuse. If a component later needs to be sourced from another supplier, some manufacturing information may only exist in earlier supplier communication rather than in the drawing itself.

4.2.5 Types of drawing based on intended use

Although only one drawing template is currently used within the company, a distinction was described by the technical management between production drawings and purchasing drawings, where the intended use of the drawing influences what information is considered necessary. This distinction was not described as a formally implemented classification system, but rather as a conceptual way of adapting drawing content to its intended purpose.

Production drawings are used internally in manufacturing and are intended to support operators in performing the required operations. These drawings should be simple and include only information necessary for production. What information is required depends on the specific product and is largely defined by the production technique department. Information that is not directly relevant for manufacturing, such as the overall application of the product, is therefore typically not required.

Purchasing drawings were described in two main contexts. One involves drawings received from customers, which are reviewed against the company's manufacturing capabilities, after which revised drawings may be created and returned for customer approval. The other involves drawings created to communicate with external suppliers. Although the direction of communication differs, both were described as requiring complete technical information, including dimensions, tolerances, and other requirements necessary for manufacturing and external communication.

Despite the differences in purpose, the same drawing template is currently used across all contexts, and the distinction between production and purchasing drawings is not well known. This may result in drawings containing more information than necessary, particularly in production drawings. Making the distinction more explicit was described as a possible way to improve clarity and better adapt drawings to their intended use.

4.2.6 Drawing creation process

4.2.6.1 Workflow for drawing creation

Drawings are created in the CAD software PTC Creo based on 3D models. The simplified drawing process identified during the study consisted of the following main activities:

Model completion → Drawing creation → View creation → Dimensioning → Addition of tolerances and notes → Review → Approval

The drawings maintain associativity with their 3D models, meaning that changes to the models propagate automatically to the drawings. After creation, the drawings are checked into the PLM system Windchill, where they follow a workflow for review and approval. Once approved, the drawings are exported as PDF files and uploaded to the ERP system Epicor for further organizational use. This workflow reflects creation of new drawings, while modification of existing and legacy drawings is discussed further in Section 4.2.13.4.

4.2.6.2 CAD system challenges

Currently, no internal guidelines exist for performing different tasks in Creo, and that engineers are instead referred to external resources such as the PTC online documentation. Some interviewees described Creo as relatively complex compared to other CAD systems they were familiar with. The system was described as requiring multiple steps for certain operations, and participants sometimes felt uncertain whether actions had been performed correctly. This indicated a need for clearer internal guidance regarding the use of Creo.

4.2.6.3 Variation in drawing practices

A recurring theme in the interviews was the significant variation in how different design engineers create drawings. The participants described that engineers often rely on personal working methods based on prior experience, background, and interpretation of standards. As a result, drawings produced by different engineers may differ considerably in content, dimensioning and tolerancing approaches, and presentation of technical information.

The results indicate that this variation is largely related to the absence of shared internal guidelines describing how drawings should be created. Participants stated that this variation in drawing practices frequently leads to misunderstandings and sometimes even errors, as drawings may be interpreted differently by colleagues or production personnel. Participants therefore emphasized that clearer and shared guidelines could help reduce these issues and improve consistency in drawing creation.

At the same time, participants highlighted the importance of following both company requirements and applicable ISO standards during drawing creation. However, the interviews indicated that the awareness and interpretation of existing standards and guidelines differed between engineers.

4.2.6.4 Differences between business segments

The organization consists of three business segments working with different types of products. In particular, the automotive segment was described as having stricter requirements for documentation and drawing quality. Participants noted that adopting guidelines aligned with automotive standards could potentially increase the time required to create drawings for other segments. At the same time, the participants acknowledged that such guidelines could improve the overall quality of drawings across the organization.

4.2.7 Drawing content and standards

4.2.7.1 General principles for drawing content

The content, structure, and presentation of information are important aspects of drawing creation. Clear and complete drawings were described as important for ensuring that production personnel and other stakeholders can correctly interpret the product definition and manufacturing requirements.

Although a large amount of drawing information can be generated automatically by the CAD system, the creation of complete drawings depends a lot on the judgment of the design engineer when determining what information is necessary and how it should be presented.

4.2.7.2 Layouts, views and scales

Consistent drawing layouts were described as important for improving readability and interpretation. The use of standard scales such as 1:1,1:2, 1:5 and 1:10 was recommended by participants. However, the importance of strictly following standard scales has decreased somewhat as drawings are increasingly viewed digitally, where zooming functionality reduces dependence on physical scale.

However, screens are not available in production, where printed paper drawings are generally used in A3 format. Appropriate scaling therefore remains important to ensure that drawing information is readable in printed form. It was also noted that automatically generated text sizes in the CAD system sometimes become too small when drawings are scaled to fit the drawing sheet, making appropriate scale and text size selection important.

The placement and selection of views were also discussed. Views should be placed logically and consistently so that the reader can easily understand the drawing. The European projection method is the intended standard. However, participants described cases where the American projection method had been used by individual designers, creating confusion during interpretation. Further standardization of view placement was suggested as a potential improvement. Inclusion of at least three views was also considered beneficial for improving understanding of the product geometry.

Elements such as bend tables and descriptive notes may also benefit from more standardized placement on the drawing. Currently, these elements are positioned differently depending on the designer and available space on the drawing sheet, reducing consistency between drawings. If all required information does not fit on a single sheet, participants suggested using additional pages rather than overcrowding the drawing.

4.2.7.3 Duplication of information across systems

An identified challenge related to drawing content was the large amount of textual information included in drawings and the duplication of information across different systems and documents. Information related to manufacturing operations and treatments may appear both on the drawing and in supporting documentation such as operation lists and data cards. This creates additional effort when updates are made and increases the risk that information is not updated consistently across all related documentation.

The interviews indicated differing opinions regarding how much information should remain directly in the drawing. Several design engineers expressed a preference toward minimizing textual information, in order to reduce maintenance effort and the risk of inconsistencies during revisions. In contrast, production emphasized the importance of keeping more information directly in the drawings, since production personnel are accustomed to having manufacturing information readily available in a single document, even when the same information exists in supporting documentation. Some duplicated information was also considered useful for designers when searching for or reusing previous designs, illustrating a balance between minimizing duplication and maintaining accessibility of important information.

4.2.8 Drawing templates

The organization uses standardized drawing templates in Creo to support consistent drawing presentation. The templates define predefined drawing elements such as sheet format, title block layout, projection method and revision fields. The overall structure follows the general layout seen in Figure 13.

Different templates are used depending on the drawing type and required sheet size. Separate templates exist for detail drawings and assembly drawings. Where the only difference is that assembly drawing templates include a parts list, while detail drawing templates do not. Additional templates are used for subsequent sheets in multi-sheet drawings, where the part list is not included regardless of drawing type.

4.2.8.1 Revision field

The revision field records modifications made to the drawing and supports traceability between drawing revisions and the change management process. When updates are made, the revision field is updated with a description of the modification together with a reference number linked to the corresponding change request in the change management system. See Section 4.2.13 for more information about the change management system.

Changes related to specific geometry, dimensions, or parts list items are marked directly in the drawing using revision symbols, linking the modified information to the corresponding entry in the revision field. The revision field and an associated revision marking from an existing drawing are shown in Figure 18 and Figure 19.

No.	△	CHANGE DESCRIPTION	DATE
1953	B	Changed from press to solder nipple	2024-03-05

Figure 18: Revision field showing change reference number, description, and date.

	No.	QTY.	DESCRIPTION	PART NO.	MATERIAL	MFG. NOTE
B	4	2	*Nipple*	*40544903*	*AISI 303*	
	3	2	*Gasket*	*51326903*	*Micalit_F*	*27x18,8x1,5*
	2	1	*EL 1.4404 1500/230 140 L591*	*5052159001*	*EN_1.4404*	*591±10*
	1	2	*Collar washer*	*60070201*	*Brass_Ni_pl*	*NV 10*

Figure 19: Parts list with revision symbol (triangle) indicating the modified item, corresponding to the entry in the revision field shown in Figure 18.

4.2.8.2 Parts list

For assembly drawings, a parts list is automatically generated from the assembly structure and model metadata in the CAD system. The parts list contains the part refence, quantity, description, part number, material, and manufacturing notes for the included components. Components in the drawing are linked to the parts list through numbered balloons placed adjacent to the corresponding geometry. Missing or incorrectly placed balloons were described as a common issue identified during reviews, making it more difficult for production personnel to link components in the drawing to the corresponding entries in the parts list. An example of a parts list from an existing company drawing is shown in Figure 19, and some corresponding item balloons are shown in Figure 20.

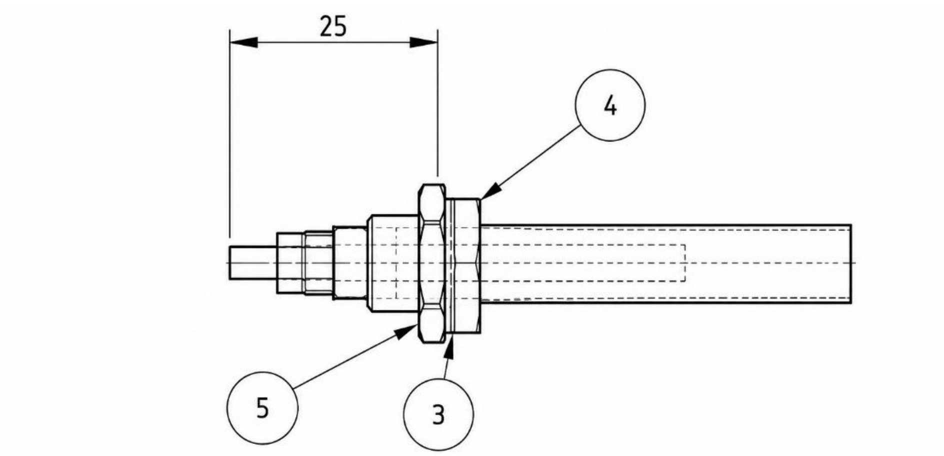


Figure 20: Examples of item balloons corresponding to entries in the parts list in Figure 19.

4.2.8.3 Title block structure and metadata

The title block, located in the lower right corner of the drawing, contains predefined fields used to store key metadata related to the drawing, including lifecycle information, revision data, tolerancing information, and approval status. The title block supports identification, traceability, and lifecycle management of the drawing throughout its lifecycle. The current drawing template was introduced around two years ago and provides a standardized structure used for all drawings within the organization. Figure 21 shows an example of a populated title block from an existing company drawing.

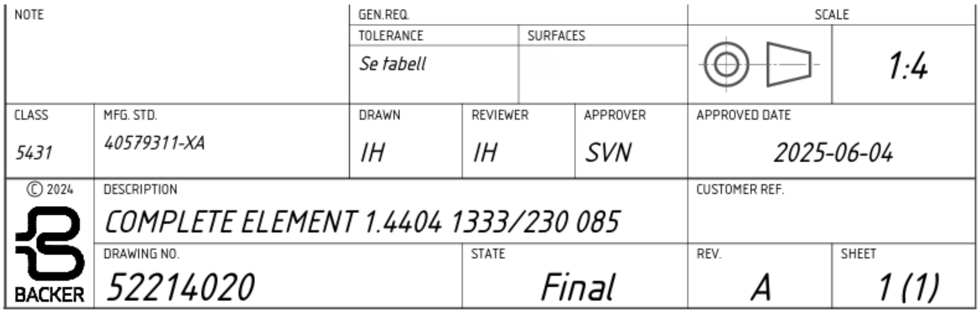


Figure 21: Populated title block from an existing company drawing.

Information regarding how the title block functions was identified through practical interaction with the CAD and PLM systems. Information in the title block may either be populated automatically through the integration between Creo and Windchill, included in the drawing template, or entered manually by the user as model parameters in Creo. Information controlled through Windchill, such as revision, lifecycle state, reviewer, approver, and approval date, is automatically managed by the PLM system. Certain elements included through the drawing template, such as general tolerances and surface roughness, may require manual modification depending on the drawing requirements.

Table 6 presents the identified title block fields, their purpose, and how they are managed within the system environment. The fields were compared to the recommendations in ISO 7200 [38], which describes title block fields for all types of technical documentation, as described in Section 3.2.12. M denotes mandatory fields according to the standard, O optional fields, and X fields not mentioned in the standard.

Table 6: Fields of the title block and their purpose and source, and their status according to ISO 7200.

Field name	***Description***	***Required***	***Source/entry method***	***ISO 7200***
Drawing number	Identifier assigned when creating the drawing and model file. See Section 4.2.11.6 for naming conventions.	Yes	File creation	M
State	Current lifecycle state of the drawing.	Yes	Windchill	O
Revision (rev.)	Current revision level of the drawing	Yes	Windchill	O
Sheet	Current sheet number and total number of sheets	Yes	Template	M
Description	Descriptive name of the part or assembly, according to established naming rules.	Yes	Manual input in Creo	M
Class	Product classification according to internal classification rules.	Yes	Manual input in Creo	O
Manufacturing standard	Applicable manufacturing standard and associated test codes, according to internal standards	Production drawings only	Manual input in Creo	X
Customer reference	Customer's own reference number	No	Manual input in Creo	X
Drawn	Initials of drawing creator	Yes	Windchill	M
Reviewer	Initials of drawing reviewer	Yes	Windchill	X
Approver	Initials of drawing approver	Yes	Windchill	M
Approved date	Date of approval	Yes	Windchill	X
Scale	Scale used for drawing views	Yes	Template	X
Projection method	First-angle projection symbol	Yes	Template	X
Tolerance	Information about if general tolerances are applied, ex. ISO 2786-m	Yes	Manual input in drawing	X
Surfaces	Surface roughness indication.	No	Manual input in drawing	X
Note	Additional drawing-related information	No	Manual input in Creo	O
Company logo	Company identification	Yes	Template	M

4.2.8.4 Identified issues and perspectives regarding title block fields

The interviews indicated differing opinions regarding which title block fields are necessary and how they should be used. Several fields were described as inconsistently used, highlighting a need for clearer internal guidance on how the fields should be completed.

One example discussed was the *class* field, containing a four-digit product classification code. Some participants regarded the field as unnecessary, while others considered it useful when searching for similar products in the ERP system. Similar opinions were expressed regarding the *reviewer* field, which some considered redundant since creator and approver information is already included. Since formal approval inherently involves review of the drawing, the approver, or sometimes the creator, is often also entered as reviewer. Drawings may however also be reviewed for feedback without formal approval, and the field then provides the possibility to record this activity in the drawing even though this is not a required activity.

The *customer reference* and *note* fields were also described as inconsistently used. The customer reference field may support customer communication and reordering, but it was noted that the field is often left empty in practice. Concerns were also raised regarding inclusion of customer-specific information in the drawing, since the same product may later be supplied to another customer, creating additional administrative work when the information needs to be changed. The notes field was similarly frequently left empty, while comparable information was instead written elsewhere on the drawing, indicating uncertainty regarding the intended use of the field.

The *manufacturing standard* field was described as important for internal production drawings, since it specifies manufacturing and testing requirements used in production. The field is intended to contain both an 8-digit manufacturing standard code and a two-letter test code. However, the title of the field only refers to the manufacturing standard, making it unclear that multiple entries are intended. Missing test codes were described as a recurring mistake identified during reviews and may result in required tests not being performed in production.

4.2.9 Tolerancing practices

4.2.9.1 Backer standard tolerance table

The company uses a company-specific tolerance table referred to as the *Backer standard,* for drawing for on-site production. The table defines general tolerances based on nominal dimension intervals, where each size range is assigned a corresponding permissible deviation. The table reflects tolerances considered feasible within the company's manufacturing processes and is based on internal production experience rather than on international ISO standards. It therefore represents a company-specific application of general tolerancing principles for tubular heating elements and cartridges.

The tolerance table is placed in the lower left corner outside the drawing frame on drawings intended for internal production. When tighter tolerances than those defined in the table are required, individual tolerances are assigned directly to the relevant dimensions. Such tolerances may require special manufacturing processes and therefore generally need to be confirmed with production.

Drawings received from customers for production are recreated internally and assigned internal drawing numbers. The drawings are evaluated against the Backer standard and internal manufacturing capabilities to determine whether the specified tolerances are achievable in production. Where required, tolerances are adjusted to align with internal production capabilities before the resulting drawing is submitted to the customer for review and approval.

Separate drawings are intended to be maintained for customer communication and internal production. Internal production drawings reference the Backer standard, while customer drawings instead specify tolerances individually or through general tolerancing practices, typically according to ISO 2768. The internal tolerance table is not intended for customer drawings, since external stakeholders are generally unfamiliar with the Backer standard.

4.2.9.2 Identified implications and challenges

The findings showed that the Backer standard plays an important role in supporting internal production, as operators are familiar with the table and rely on it during manufacturing and inspection activities. Previous attempts to remove the table from drawing sheet were described as creating uncertainty in production regarding which tolerances should be applied. The interviews indicated divided opinions among design engineers regarding the use of the Backer standard. Some viewed it as practical because it reflects internal production capabilities, while others preferred ISO standards due to their wider recognition in external communication.

At the same time, the use of a company-specific tolerance standard created challenges in external communication. Maintaining separate drawings for internal production and customer communication was described as increasing administrative work. As a result, separate customer drawings without references to the Backer standard were not always created in practice, despite the intended separation between internal and external documentation.

The results also highlighted differences between customer requirements and internal manufacturing capabilities. In some situations, customers request tolerances that are difficult to achieve reliably in production. This emphasized the importance of verifying that requested tolerances are feasible before confirming them to customers. The tolerances defined in the Backer standard were generally described as coarser than those in ISO 2768. The interviews also indicated a risk that customer drawings could be approved with tighter tolerances than those referenced in internal production drawings based on the Backer standard, creating inconsistencies between customer and internal production tolerances

Additionally, the interviews also described that the use and application of the Backer standard was one of the aspects that new engineers often find most difficult to understand, particularly in relation to when internal tolerancing practices should be used instead of ISO-based tolerancing approaches.

4.2.10 Drawing review and approval

The review and approval of drawings was identified as a central process related to drawing management, as it is important that only controlled and correct drawings are released for use in production and purchasing.

4.2.10.1 Review and approval in PLM

All drawings follow a formal approval workflow in the PLM system Windchill before they are released. The workflow controls drawing lifecycle states and ensures that drawings are reviewed, approved, and released in a traceable and controlled manner before use. The lifecycle states are described in Table 7. Lifecycle state transitions are managed automatically by Windchill based on user actions within the workflow and confirmed through electronic signatures to maintain traceability regarding who performed each action and when.

Table 7: Description of lifecycle states used within the PLM system.

Lifecycle state	Description
Draft	Drawing under development.
Under review	Drawing submitted for review and approval.
Published	Drawing approved for limited use, for example prototype manufacturing, testing, or samples.
Approved	Drawing approved within the workflow.
Final	Drawing formally released for purchasing and production.
Canceled	Drawing or revision withdrawn before release or completion.
Obsolete	Drawing previously released but no longer valid for use.

Figure 22 illustrates the identified review and approval workflow in Windchill. The workflow begins when a drawing is created and checked into the PLM system in the state *Draft*. Once completed, the drawing is submitted for review and approval and enters the state *Under Review*. During submission, the designer selects a designated reviewer responsible for reviewing the design documentation, and includes associated drawings, CAD models and assemblies.

Following the review activity, the drawing is either approved or returned with comments to designer for correction and resubmission. Approved drawings proceed toward release as either *Published* or *Final*, depending on their intended use. *Published* drawings follow the same workflow as drawings for release, however for these drawings the creator may approve their own drawing. Only drawings in state *Final* shall be used for production or purchasing.

If modifications are required to an already released drawing, a new revision is created and processed through the workflow again. Drawings that are no longer valid transition to *Obsolete*, while withdrawn drawings are marked as *Canceled*.

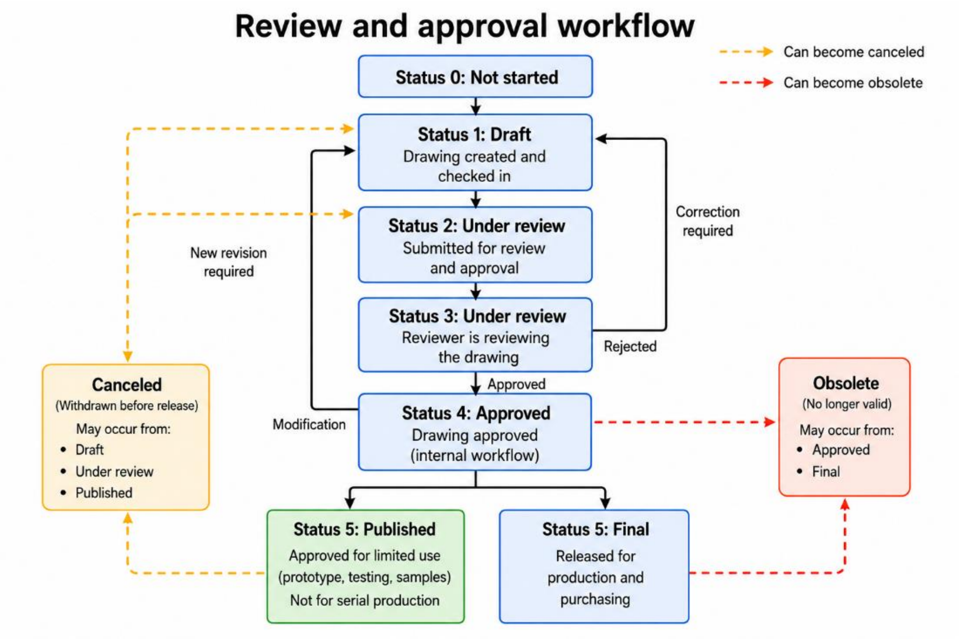


Figure 22: Review and approval workflow in Windchill.

Review and approval were identified as formally distinct activities within the workflow. A drawing may be submitted for review in the PLM system without proceeding through the full approval and release process, for example to obtain feedback during the development of more complex designs. Review activities focus on identifying errors and missing information, whereas approval represents a more formal confirmation that the drawing is considered complete and suitable for release. In practice, approval inherently involves some degree of review, and both activities are often performed by the same individual. Responsibility for the correctness of the drawing nevertheless remains with the drawing creator, even if errors are not detected during review or approval activities.

Although the workflow itself is formally standardized within the PLM system, the interviews indicated that the surrounding review practices differ depending on the context in which the drawing is used. While the system ensures that drawings formally pass through an approval step, the actual review practices may vary between departments and projects. A distinction was described between drawings used for on-site production and drawings created for purchasing from external suppliers.

4.2.10.2 Review of drawings for production

For drawings used in internal production, a dedicated reviewer from the production department is responsible for reviewing and approving new drawings. The process is performed through the Windchill where the drawing is assigned to the reviewer. The purpose of these reviews is primarily to verify that the drawings contain sufficient manufacturing information and that the design is feasible to produce. The review process was generally described positively by the participants, as it helps designers identify mistakes, improve drawing quality, and gradually establish more standardized drawing practices.

However, participants described that this review focused mainly on drawing-related details, such as formatting, spelling, and manufacturing clarity, rather than evaluating the overall product design such as product functionality and material choice. These engineering aspects were instead often reviewed informally by the designers themselves or discussed with colleagues during the design process. Several participants expressed that more systematic evaluation of such aspects could improve the review process further.

Production drawing reviews were described as contributing to improved drawing quality reducing the number of errors over time. However, it was noted that no documented review guidelines or formal review criteria existed. Since the review responsibility is concentrated to a single individual, the process depends heavily on individual judgement. This created uncertainty among designers regarding which aspects are expected to be checked during reviews, and which information should be included in the drawings. In certain cases, drawings that were previously approved were later rejected during subsequent reviews, further highlighting the need to delimit the review process through clearer review criteria.

Examples of common issues identified during reviews included bending radii below the minimum values specified in company technical information, missing notes regarding required tests, missing balloon references connected to the parts list, and unclear dimensioning where it was difficult to determine which feature the dimension referenced. Identifying such issues before release was noted as important, as they may otherwise result in products being manufactured incorrectly

4.2.10.3 Review of drawings for purchasing

For purchasing drawings, which are the majority of drawings, the review process was described as significantly more informal. No dedicated reviewer or formalized review procedure was identified for these drawings. Instead, the designers review their own drawings, have their drawings reviewed by colleagues, or discuss drawings together with the purchasing department to ensure that suppliers receive sufficient manufacturing information. Participants described that designers often review each other’s drawings informally as part of the daily design work, particularly when working with more complex components or assemblies. In the end, the designer is responsible for ensuring that drawings are complete before submission for approval.

All purchasing drawings go through the approval workflow in Windchill. The approval activity represents the formal confirmation that the drawing is considered complete. Purchasing drawings are intended to be approved by a colleague within the design department, preferably a more senior designer. However, no formally designated approver was identified for these drawings.

The findings showed that the absence of structured review procedures and documented guidelines results in substantial variation in how reviews and approvals are performed. Although drawings formally pass through the approval workflow in Windchill, the scope and thoroughness of the reviews were described as depending largely on the individual performing the review, available time, and prior experience. As a result, certain designers experienced uncertainty regarding what aspects of are important to include in the drawing.

Participants further considered that the lack of clearly defined review procedures created a risk that drawings with errors or missing information may be released into production. Several interviewees considered the relatively low number of observed drawing errors to depend more on the experience of the design engineers than on the structure of the review process itself. Some participants compared the situation to experiences from larger organizations where dedicated drawing review roles existed and viewed a similar function as a possible improvement.

4.2.11 PLM System and product data management

4.2.11.1 Role of the PLM system in drawing management

The organization uses the PLM system Windchill, which was identified as a central system for managing drawings and related product data throughout their lifecycle. The system is used to store, review, approve, and modify product data in a controlled manner. Through lifecycle management, Windchill ensures that the latest approved versions of drawings are identified as the valid versions for use in production and purchasing, while previous versions remain accessible in the system for traceability of modifications. Drawings are linked to related product data such as CAD models, Parts, assemblies, and BOM structures, enabling traceability between individual components and higher-level product structures.

4.2.11.2 Stored product objects and relationships

Several different object types are managed within Windchill, including 3D CAD Parts, 3D CAD Assemblies, CAD drawings, and Part objects. Within the system a distinction is made between CAD documents and Part objects. CAD documents represent the actual CAD files created in Creo, and they contain the geometric definition of the product. Part objects are created by Windchill and are used to manage product-related information such as lifecycle states, revisions and BOM structures. These object types are connected through relationships established within Windchill. Each CAD Part and assembly are linked to a corresponding Part object, while drawings are instead linked indirectly through references to the associated parts or assemblies.

For each object, users can access object-specific metadata and related views, including lifecycle states, change history, related objects, and structure views. Further details regarding this information are described in Section 4.2.11.4. Through the relationship and structure views, users can navigate between related objects and different levels of the product structure. The related information available for the main object types is summarized in Table 8.

Table 8: Relationships and accessible related information between object types Windchill.

Object type	Accessible related information in Windchill
Part	Corresponding CAD documents such as assembly or CAD Parts. For Parts related to assemblies, included Part objects and quantities can be viewed through the BOM.
CAD part	Corresponding Part object. Assemblies in which the part is used, including higher-level assembly structures. Related drawings referencing the CAD Part, including both its own drawing and higher-level assembly drawings.
CAD assembly	Corresponding Part object. CAD parts and subassemblies included in the assembly. Higher-level assemblies where the assembly is used as a subassembly.
CAD drawing	CAD Parts or assemblies shown in the drawing and their corresponding Part objects.

4.2.11.3 Integration between Creo and Windchill

The integration between Creo and Windchill is used continuously during design work. It enables information created in Creo to be transferred and managed within the Windchill, while information managed in Windchill can automatically populate model parameters and drawing title blocks in Creo. CAD models and drawings created in Creo are transferred to Windchill through check-in operations, during which the CAD file is stored together with associated metadata. S Some Creo parameters are automatically controlled through Windchill and are therefore locked from editing in Creo. This applies to certain title block fields, as previously discussed in Section 4.2.8.3.

Before a CAD document can be modified, it is checked out from Windchill, reserving it for editing and preventing conflicting modifications by other users. After modifications have been completed, the updated object is checked back into the system, and information is updated accordingly.

Currently, all models and drawings created in Creo are stored in Windchill through the integration between the systems. However, older legacy 2D drawings created in other systems are not stored within the PLM system.

4.2.11.4 Information stored

Each object stored in Windchill contains metadata and product-related attributes used for identification, lifecycle management, and traceability. The stored information includes object numbers, names, revisions, lifecycle states, creator and creation date, approver and approval date, change history, and storage location within the system, together with product attributes such as descriptions, material data, classifications, and manufacturing-related information.

4.2.11.5 Change management functionality

Interactions with the system showed that Windchill includes a functionality for change management based on change notices linked to product objects. These can be used to document the reason for a change, affected objects, implementation plans, responsible functions, and approvals, thereby maintaining traceability throughout the process.

However, the company's formal engineering change management is currently handled in a separate system described in Section 4.2.13. Changes approved through the external change management system that affect objects managed in Windchill may result in new drawing revisions being created in the PLM system, where the implemented changes and the reason for the change should be documented. In the current workflow, the Windchill change notice functionality is instead mainly used for submitting drawings and related product data for review and approval.

The technical management stated that it would be beneficial to manage formal engineering changes directly in Windchill, since the system already supports the required functionality. However, this is currently not feasible because not all departments within the organization have access to Windchill.

4.2.11.6 Identified challenges

Overall, Windchill was generally viewed positively and described as an important tool for management of drawings and product data. However, some participants describe the system as sometimes being difficult to navigate. The document analysis showed that internal guidelines and instructions for the use of Windchill are limited and not always well known within the organization. Existing instructions partly rely on references to online documentation rather than internally adapted guidelines.

Product data in Windchill is organized into different libraries, such as libraries for standard components, Backer-specific components, tools, projects, and different business areas. Observations performed in the system showed that the organization of objects within the libraries is only partially structured. While some data is organized into folder structures, many objects are stored directly at the library level without a clear hierarchy. Some participants expressed uncertainty regarding where new objects should be stored, and the current structure was described as making navigation unnecessarily difficult.

Additional challenges were identified regarding object naming and numbering practices within the system. Each object in Windchill is identified by both a *number* and a *name*. The number corresponds to the file name defined at the creation of a file, and it is used as the primary identifier within the system. This number shall be the article number generated in accordance with established internal conventions. In Windchill, the article number consists of an 8-digit number, while the corresponding article number in the ERP system consists of 10 digits. The two omitted digits form a prefix used to define the article type. Participants stated that it would be easier if the same numbering format was used in both systems.

The object name shall instead provide a descriptive representation of the product and should follow established naming conventions. However, for many product categories, naming conventions either did not exist or were not well known. As a result, object names were often relatively generic product descriptions, and several objects therefore had similar or identical names while being differentiated only by their numbers.

The findings further showed that both object numbers and names are entered manually, creating a risk of typing errors or incorrect numbering. Since the object number is linked to the ERP article number, such inconsistencies may make objects difficult to retrieve and trace between the systems. The technical management described the long-term goal as enabling products to be searched and identified through structured metadata and attributes rather than primarily through manually defined names and numbering conventions.

4.2.12 ERP System

The ERP system used within the organization is called Epicor. It is used for managing released product information and business-related data across different departments. In the context of drawing and product data management, Epicor functions as the primary system for handling released product information and making it accessible to downstream functions such as purchasing and production.

Released drawings and related product information are manually transferred from Windchill into Epicor. Once a drawing has been released, the drawing PDF is attached to the corresponding article in the ERP system, while related product information such as article descriptions and item classifications must be entered manually. In addition, BOM information must currently be entered manually into the ERP system.

Participants described the current workflow as involving unnecessary administrative work for design engineers, since information already available in drawings or the PLM system must be re-entered manually into Epicor. This was also described as introducing a risk of manual data entry errors and inconsistencies between systems. However, there are ongoing plans regarding a future implementation of a CAD link solution that could extract information directly from drawings or the PLM system and transfer it to Epicor automatically.

4.2.13 Change management

4.2.13.1 Change management process

Product changes are managed through a formal change management process defined in internal documentation. The process is intended to ensure that product changes are implemented in a controlled and traceable way.

Figure 23 illustrates the overall engineering change management process identified within the organization. The process starts with identification and evaluation of a proposed change, after which an Engineering Change Request (ECR) is created to document the proposed modification before approval, implementation, and release activities are carried out across affected functions. As part of the process, all affected product documentation, including drawings, CAD models, BOMs, parts lists, manufacturing documentation, and requirement specifications, may have to be updated to reflect the approved changes.

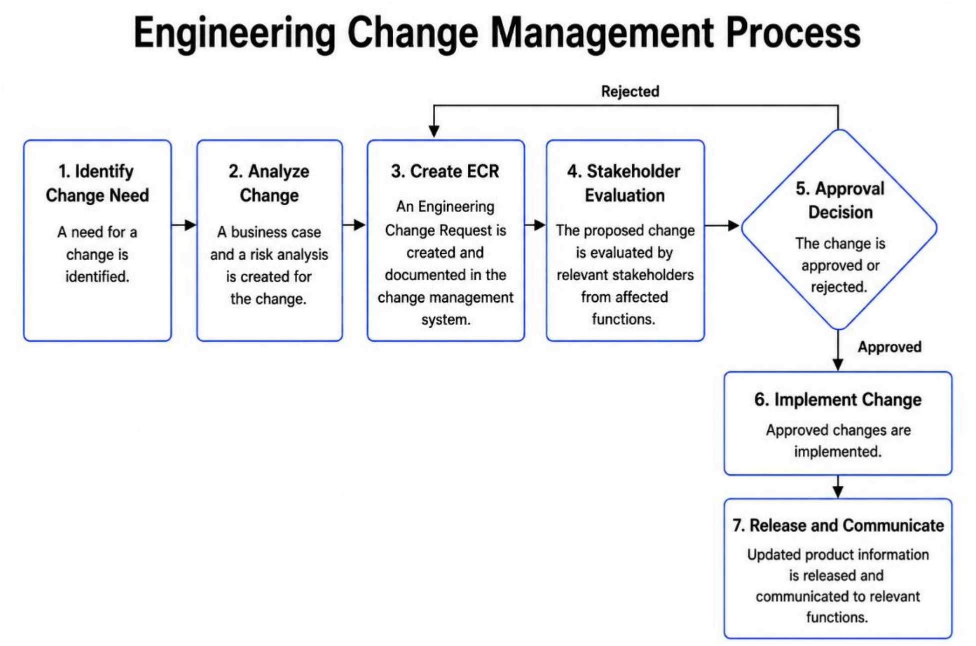


Figure 23: Illustration of the formal change management process.

The findings show that product changes are handled differently depending on the lifecycle stage and the degree of maturity of the product. During development, changes are managed more flexibly as part of the ongoing design process. In this phase, drawing and models that are not released may be modified directly. However, the extent to which modifications may be performed directly depends on how finalized the design is. Once the design has reached a more finalized stage of development, major design changes to the CAD model affecting product definitions, specifications, or related documentation are generally not to be implemented without formal handling, while purely drawing-related modifications such as layout adjustments, view changes, and documentation details may still be performed directly before release.

Once product data has been released, modifications shall be managed through the formal change management process previously described. Since released drawings represent the formal product definition, changes after release require formal handling.

The technical lead explained that for drawings used only internally, minor changes such as spelling or formatting corrections may in some cases be implemented for released drawings without creating a new revision by temporarily unlocking the revision to perform the correction. However, this approach was generally discouraged, especially for externally distributed drawings, as it may lead to inconsistencies between internally and externally distributed versions of the drawing. Formally, any change to a released drawing requires a new revision to be issued and redistributed to affected stakeholders. To avoid unnecessary updates, minor corrections are therefore recommended to be postponed and included in the next revision.

4.2.13.2 Change management system

As part of the engineering change management process, an ECR is registered in the dedicated change management system. It includes information regarding the proposed change, such as the reason for the change, feasibility, and expected impact. Each ECR is assigned a unique reference number that can later be used to link implemented changes to the affected product documentation.

When a drawing is updated as part of an approved change, the reference number should be included in the revision filed together with a brief description of the modification, as shown in Figure 18. This enables implemented drawing changes to be traced back to the corresponding change request. Revised drawings are thereafter resubmitted through the formal approval and release workflow in the PLM system.

The formal engineering change management process is intended to apply to all modifications of released products. However, interviewees described that the process is not always followed fully in practice for smaller changes. The change management process was described as time-consuming, since proposed changes must be reviewed by multiple departments before approval. Several participants stated that approvals may in some cases take several months, partly due to inconsistent use of the system and delayed handling of requests, which was described as discouraging further use of the system.

As a result, smaller changes are sometimes handled informally through direct communication between involved functions. In such situations, design engineers may update drawings directly and release new revisions without creating a formal change request. While this approach enables changes to be implemented more quickly, it reduces traceability. Although the systems show that an update has been performed, the underlying reason for the change and the exact modification implemented may not be clearly documented.

4.2.13.3 Revision and version management

Revision and version management in Windchill is used to distinguish between ongoing development work and formally released product definitions. During development, drawings and models in lifecycle states *Draft* and *Published* are managed through versions. These are indicated using a letter-number combination (e.g., A1, A2, B1). Multiple versions may exist simultaneously to represent different design alternatives under evaluation. Since these versions are still under development, they may be modified directly as part of the iterative design process. Published versions may then be used to manufacture samples for testing before a final design solution is selected.

Once a suitable version has been selected and approved, it is released to status *Final*. Released revisions are indicated using letters (e.g. A, B). A transition from one revision to another, for example from A to B, indicates that the released product definition has been modified. Such changes shall be handled through the formal change management process.

The relationship between versions, revisions, and article numbers is illustrated in Figure 24. The figure shows how different development versions may exist in parallel before one version is selected and released as the approved product definition. Subsequent modifications may then either result in a new revision of the existing article number or creation of a new article number.

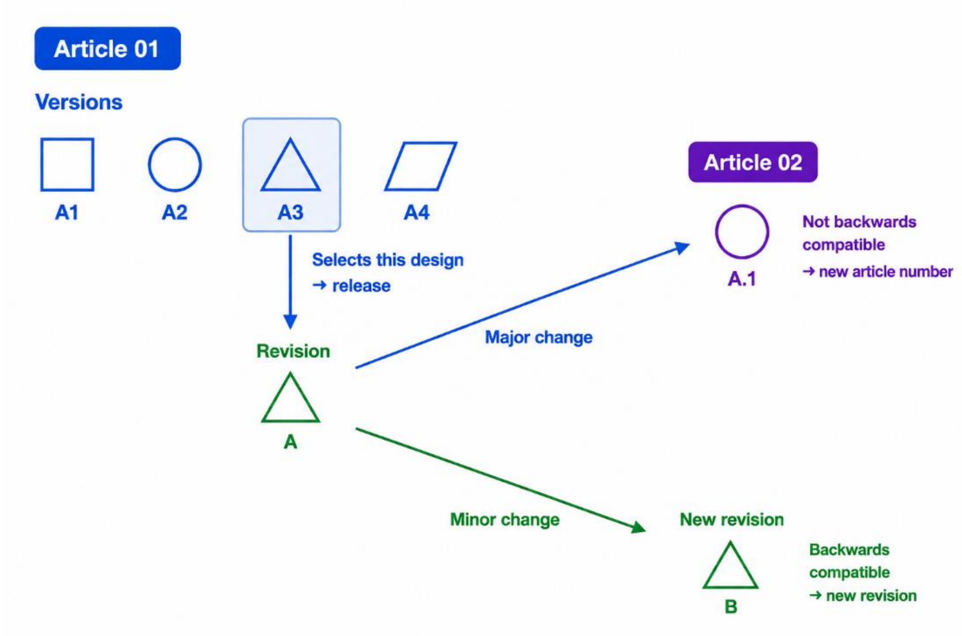


Figure 24: Example of revision management through versions, revisions and article numbers.

Depending on the scope of the change, a modification to a released revision may either result in a new revision or in creation of a new article number. If the change is minor, thus backwards compatible a new revision is created. Traceability is then maintained within the same article number as since all revisions are directly linked within the PLM system. If the change is major, a new article number must instead be created. Traceability must then be maintained by linking the new article to the previous article in the PLM system. This allows the product history to be followed even when the product identity changes.

4.2.13.4 Updating drawings

When a change is managed through creating a new revision, the drawing is revised in the PLM system based on the approved product definition. If a CAD model exists, the change shall be implemented in the model and not directly in the drawing. The drawing shall then be updated through the model to ensure consistency between the model and the drawing.

It was noted that many older legacy drawings exist only as 2D PDF drawings without associated 3D models. Interviewees explained that these legacy drawings may be relevant, for example, when a customer requests a product based on an older drawing. The findings showed that two main approaches are used when updating legacy drawings depending on the expected reuse of the drawing. One approach is to create a new 3D CAD model and associated drawing in Creo, resulting in a fully managed drawing package stored within Windchill, which supports future revisions and reuse. This approach was described as preferable for products intended for serial production or long-term use.

The second approach involves modifying the existing 2D drawing manually in a specific software without creating a 3D model. Participants described this as a faster and more practical solution for simpler updates, one-of-a-kind products, or projects where long-term reuse of the drawing is not expected.

4.2.14 Organizational working practices and knowledge transfer

4.2.14.1 Collaboration and responsibility

Several interviewees described the collaboration between design engineers and production as an important aspect of drawing creation. Since drawings are used directly in production, clear and understandable drawings were considered important to reduce misunderstandings.

Some interviewees described that different expectations may exist regarding responsibility for drawing-related problems. In certain situations, discussions arise regarding whether issues originate from the design itself or from how the drawing was interpreted during manufacturing. Some interviewees felt that operators should be able to interpret more complex information from the drawings, while others emphasized that drawings should clearly communicate all necessary information to avoid ambiguity.

4.2.14.2 Onboarding and introduction of new designers

The introduction process for new design engineers was described as relatively limited. Several interviewees explained that new employees are often expected to learn company practices, systems, and workflows largely through experience rather than through structured training or onboarding.

Participants noted that this may be manageable for experienced engineers but that it can be challenging for individuals with less experience or those unfamiliar with the specific processes. All participants stated that clearer documentation and guidelines for creation and management of drawings would help new engineers with understanding the processes.

4.2.14.3 Use of existing documentation

The findings showed that only limited information directly related to drawing creation is currently available in internal documentation. However, some related processes and requirements are documented, for example the engineering change management process and certain general design principles described in the existing design handbook.

It was noted that a lot of the current documentation is fragmented, where relevant information is distributed across multiple separate documents. Findings further showed that many existing documents are not widely known within the organization, making relevant information difficult to locate and use in practice.

The examination found that the current design handbook was incomplete and relatively poorly structured. Several interviewees emphasized the need for a more structured source of drawing-related information, where relevant requirements, working methods, and references to related processes are gathered within a single document.

4.2.14.4 Organizational culture and working practices

Several interviewees described the organization as relying on informal working methods, individual experience, and direct communication rather than formally documented procedures. While some participants viewed this flexibility as positive, many also considered the lack of structure to create challenges as the organization grows.

A recurring theme identified during the interviews was that much of the knowledge related to drawing practices exists primarily as tacit knowledge held by experienced employees. Historically, production personnel often relied on experience when interpreting drawings, which in some cases compensated for incomplete documentation. Interviewees explained that this became problematic when experienced personnel left the organization, since important manufacturing knowledge was not always documented in the drawings themselves. As a result, older drawings may sometimes be difficult to interpret without prior product knowledge.

Several participants therefore emphasized the increasing importance of clear drawings and structured documentation to preserve manufacturing knowledge within the organization. Some interviewees also described ongoing discussions within teams aimed at aligning drawing practices and clarifying expectations regarding drawing content. However, these discussions had not resulted in any formally documented guidelines.

Participants further noted that attempts to introduce drawing practices based on international standards may sometimes meet resistance if they differ from the methods production personnel are accustomed to, which may slow down implementation of new working practices.

All interviewees agreed that a drawing handbook would be beneficial, particularly for supporting new employees and creating a more consistent structure for drawing creation and management.

4.2.14.5 Language policy

The language used in drawings was also discussed during the interviews. Participants explained that drawings were historically in Swedish, after which the organization transitioned toward English to support international operations. More recently, a decision has been made to return to Swedish as the primary language for production drawings. However, findings indicated that the language policy is not clearly communicated, resulting in varying interpretations and mixed language usage.

For drawings used in production, Swedish was described as mandatory since operators may not be familiar with technical English terminology. This applies to free text which tells the operator what should be done. Title block headlines can be in English. Drawing in English have to be translated for use in production.

For purchasing drawings, English was generally preferred to support communication with international suppliers. Some interviewees further noted that both Swedish and English are sometimes used within the same drawing, which may improve communication, but it also makes drawings more crowded and difficult to read.

Participants further noted that existing organizational documentation currently exists partly in Swedish and partly in English. Some interviewees therefore suggested that the future drawing handbook could be developed either in Swedish or English, although English was considered beneficial for supporting employees who do not speak Swedish and for facilitating international collaboration.

4.2.14.6 Future development perspectives

Some interviewees also discussed possible future developments regarding technical documentation within the organization. Several participants believed that traditional 2D drawings may gradually be replaced by digital 3D models containing integrated product information. However, such a transition was considered a long-term possibility requiring significant organizational changes.

4.3 Organizational study discussion

4.3.1 Identified need for a drawing handbook

The elicitation activities revealed several recurring organizational patterns related to drawing creation and management. Many drawing processes were described as informal, only partly documented, or fragmented across different systems and documents. Several working methods relied on tacit knowledge and individual experience rather than standardized procedures.

Significant variation was identified in how different engineers create and manage drawings, including differences in layouts, dimensioning practices, review approaches, and interpretation of standards. This variation was largely connected to the absence of shared internal guidelines and contributed to inconsistencies, misunderstandings, and uncertainty regarding expected working methods.

The findings therefore strongly confirmed the need for a structured drawing handbook. The handbook provides an opportunity to gather key drawing processes and guidelines into a single structured source, while also referring to other applicable organizational documents and processes to increase awareness and accessibility of existing information.

The handbook also provides an opportunity for technical leadership to formally define working procedures that were identified as unclear, such as the language usage policy, thereby supporting more consistent organizational practices.

The findings further indicated that several identified challenges were related more to organizational working methods than to technical system limitations. Many inconsistencies originated from unclear procedures and differences in individual working practices. This was considered positive for the project, since such challenges can be addressed through standardized procedures within the handbook.

The findings further strengthened the identified intended user groups of the handbook. The relatively unstructured onboarding process for new design engineers increased the relevance of newly hired engineers as one of the primary target groups of the handbook. The handbook may therefore help address an identified gap by introducing relevant organizational processes and working methods.

The literature study in Chapter 3 provided important background for understanding the identified processes and evaluating current practices in relation to standards and recommendations. The findings from this chapter will further be used in Chapter 5 to translate identified organizational needs into formal handbook requirements.

4.3.2 Identification of key drawing related processes

The elicitation activities were considered successful in identifying and mapping the key processes related to drawing creation and management within the organization. The results summarized in Figure 16, showed that drawing activities are closely connected to several broader organizational processes such as review activities, production, purchasing, and product data management. Highlighting that technical drawings are not isolated engineering documents but interact with multiple surrounding organizational functions and workflows.

The gathered information provided an important foundation for development of the handbook content by creating an understanding of how drawings are created and managed within the organization, including applied standards, system usage, review practices, and interactions between departments. The findings also helped identify areas where working methods were unclear or inconsistently applied, allowing these aspects to be clarified in the handbook. The process mapping further highlighted that development of drawing guidelines requires understanding not only technical drawing standards, but also how drawings interact with surrounding organizational processes and responsibilities.

The process mapping may also have relevance beyond the specific organizational context. The key processes and interactions summarized in Figure 16 provide an overview of aspects relevant to examine when analyzing drawing creation and management within an organization. This may be particularly relevant for similar organizations, i.e. medium-sized manufacturing organizations combining internal production with purchasing from external suppliers and operating with a similar degree of digital maturity, since more model-based approaches such as MBD may alter the workflows. The identified processes may support such organizations in understanding their drawing workflows and developing drawing guidelines adapted to their own organizational environment.

4.3.3 Handbook content derived

A broad range of areas considered important to include in the handbook were identified. Since the amount of identified content was extensive, all findings cannot be discussed in detail within this section. However, all the identified key processes should be addressed to some extent within the handbook. Some examples of areas identified as particularly important to include within the handbook are discussed below.

One example is the application of the Backer standard tolerancing practices, which was described as difficult for new engineers to understand. Particularly regarding when internal tolerancing practices should be applied in relation to customer drawings and external communication. Another important area is the distinction between production drawings and purchasing drawings, as this is currently mainly an informal distinction. Including this distinction in the handbook would help formalize it and clarify the intended purpose of different drawing types, while also increasing awareness regarding unnecessary information in drawings.

The handbook should also describe how drawings are used by different departments in order to help drawing creators understand what information is considered necessary in different contexts. Related to this, the handbook will also include a recommendation regarding avoiding duplication of information in drawings. However, the findings showed that opinions differed regarding how much information should be included directly in the drawing, particularly from a production perspective. The handbook therefore aims to reduce unnecessary duplication while still retaining information considered important for production activities.

Clearer guidance regarding the relevant ISO standards, described in Chapter 3.2, is also considered important, since awareness and application differed between engineers. Guidance related to Creo and Windchill workflows is relevant to include. However, detailed system-specific instructions were considered outside the scope of this project and could instead form the basis for separate future documentation focused specifically on Creo and Windchill usage.

The same guidelines will be applied across all three business segments, even though one segment was described as having higher requirements regarding drawing quality and documentation. No specific differences were identified that motivated separate guidelines, and the organization was considered too small to justify separate drawing practices between business areas.

4.3.4 Issues outside of the scope of the handbook

Naturally, many of the issues identified cannot be addressed directly by guidelines in a handbook. They instead require implementation of new organizational processes, investments in new technologies and systems, and management decisions. Such aspects are therefore considered outside the direct scope of the handbook.

Drawings are part of broader organizational processes involving product development, production, purchasing, review procedures, product data management, and change management. The handbook may support more consistent working methods, but the quality of drawings is also dependent on the surrounding organizational structures.

However, one aim of the study was also to identify challenges associated with drawing-related activities and processes. It is therefore still relevant to discuss identified gaps, inconsistencies, and potential improvement areas, even when such aspects extend beyond the direct scope of the handbook. Some examples and recommendations for potential future improvements are therefore discussed below.

4.3.4.1 Improvements to title block structure

The title block is currently used inconsistently, with fields being completed differently or left empty. The primary way to address this is through clearer guidance in the handbook regarding what each field should contain and whether the information is entered manually or automatically

Additionally, it could be beneficial to remove certain fields from the title block. Reducing the number of fields would make the title block easier to overview, while some information may instead be more appropriately managed within the PLM system rather than appearing on the drawing.

Table 6 presents the title block fields and compared them to the governing standard ISO 7200 [38]. It should however be noted that ISO 7200 defines fields for technical product documentation in general and not specifically for technical drawings. As a result, some drawing-specific fields are not described in the standard. Field such as projection method, scale, tolerancing, and surface requirements, are still considered relevant to include.

The comparison indicated that some fields may be unnecessary or could be restructured. ISO 7200 identifies creator and approver as mandatory fields, while reviewer is not mentioned. The reviewer field could therefore potentially be removed, as review is not a formally required step and the reviewer and approver are often the same person. If separate reviews are performed, this information is already traceable within the PLM system. In contrast, the manufacturing standard field could benefit from being divided into separate fields for manufacturing standard and test requirements, since missing test codes were described as a recurring issue.

The use of the notes field should either be clarified, or the field could potentially be removed, since it is used inconsistently and similar information is instead often entered directly on the drawing sheet. The necessity of keeping the scale field could also be discussed, since scale has become less important as drawings are increasingly viewed digitally. However, since printed drawings are still used in production, the field is still considered useful to include.

4.3.4.2 Review process improvements

The findings indicated a need for formally defined review criteria for both production drawings and purchasing drawings. Clearer review guidelines could help define what aspects the review should focus on, what information drawings are expected to contain, and reduce the dependence on personal interpretation during review activities.

The study also indicated a need for clearer review responsibilities and designated reviewers for purchasing drawings, where the current review process was described as highly informal and largely dependent on available time and personal initiative. In addition, designated reviewers focusing on design-related aspects should exist for both types of drawings, in order to evaluate aspects such as functionality, design suitability, and material selection rather than primarily manufacturing-related aspects and drawing presentation.

4.3.4.3 Improved PLM organization and metadata usage

The findings also indicated a need for improved organization of the PLM libraries in order to simplify navigation and retrieval of objects. In addition, naming conventions should be clarified and more consistently applied, since many objects currently have similar names and are primarily differentiated through their object numbers.

Over time, the organization should also strive toward more systematic classification and description of parts, rather than depending mainly on generic manually entered names and numbers. This could improve searchability, support reuse of existing parts, and make internal standardization more efficient. AI-based tools may also provide support for part classification and metadata generation, reducing the manual effort required to improve product data quality.

Additional long-term system improvements were also identified. One example is implementing formal engineering change management directly within the PLM system to create a more integrated and consistent workflow. Another is implementing a CAD–ERP integration to reduce the amount of manual transfer of product information performed by design engineers, thereby reducing administrative work and the data entry errors. Given the potential benefits, continued development of the planned integration is highly recommended.

4.3.5 Limitations of the elicitation

Overall, the elicitation process was considered successful in identifying key drawing-related processes. One limitation was that no interviews were conducted with personnel from the purchasing department due to project time constraints, as production personnel and design engineers were considered more central to the project scope.

The study also placed limited focus on the ERP system, since it was not considered directly related to drawing creation itself, represents a significantly broader system area, and is currently undergoing organizational changes.

In addition, the study did not include long-term observation of day-to-day working practices, meaning that some findings may reflect how the workflows were described by participants rather than how they are consistently performed in practice. However, the findings were continuously discussed with multiple participants and supported through practical interactions with the systems and workflows throughout the project, which helped strengthen the credibility of the identified workflows.

The results are further based on a single organizational context, meaning that some identified practices and challenges may be company-specific. However, many of the identified processes and organizational patterns are likely relevant on a more general level.

5 Requirements development

5.1 Method

The identified organizational needs were translated into requirements for the handbook. The following sections describe the conventions used for requirement formulation, as well as how the requirements were derived and structured into the requirements table.

5.1.1 Requirement formulation conventions

Well-formulated requirements are essential for ensuring that stakeholder needs are clearly translated into a handbook that can be developed and verified. The requirements serve as the primary means of communicating what the handbook must achieve and guide subsequent development, implementation, and verification activities.

The International Council on Systems Engineering (INCOSE) defines several characteristics that well-formulated requirements should possess, in their guide to writing requirements [50]. Based on this, the following principles were considered during requirement formulation.

- **Necessary** – addresses an identified need.
- **Appropriate** – defined at a suitable level of detail.
- **Singular** – addresses one capability or constraint only.
- **Correct** – reflects the underlying need accurately.
- **Conforming** – follows consistent structure and wording.
- **Unambiguous** – allows only one interpretation.
- **Complete** – provides sufficient information.
- **Feasible** – realistically implementable within project constraints.
- **Verifiable** – can later be evaluated or tested.

The guide also includes recommendations regarding wording, structure, and terminology consistency, several of which were applied within the handbook. The following examples illustrate some practical applications. For example, vague terms such as “approximately” or “if necessary” were avoided to increase accuracy. The use of negations was minimized to improve clarity. Absolute terms as “always” or “never” were avoided in order to promote realism.

To clarify the level of obligation in the requirement specification, modal verbs were used following the same conventions as used in ISO documentation [51]. *Shall* denote a mandatory requirement, while *should* indicate a recommendation or best practice. Permissions are expressed using *may,* while *can* indicate possibility. These conventions were applied consistently throughout the requirement list.

5.1.2 Requirement derivation

The requirements were derived from the needs identified in the organizational study presented in Chapter 4, based on interviews, document analysis, and observations of current drawing practices. The requirements were formulated with the intention of covering all identified organizational needs considered to be within the defined project scope, thereby ensuring that the handbook addressed the relevant aspects of drawing processes.

Requirements were formulated for all identified key drawing-related processes. However, greater focus was placed on areas directly related to drawing creation, content and management, which therefore resulted in a larger number of requirements within these areas. For broader organizational processes that were already described in existing organizational documentation, the handbook requirements mainly focused on the drawing-related aspects in order to maintain the focus of the handbook on drawings rather than describing complete organizational workflows.

In addition to requirements directly related to identified organizational needs some requirements were also introduced to support the handbook's intended function as a practical support and learning tool. Such requirements addressed aspects including handbook structure, explanation level, and use of examples.

5.1.3 Requirement specification structure

The requirements were organized into a structured requirement specification. Each requirement was assigned a unique reference number and categorized according to the aspect of the drawing process it addressed, for example drawing creation, drawing review, system interaction, or handbook structure. The requirement categories were partly based on the key processes identified in Chapter 4, while also including more specific and handbook-related categories where needed.

The INCOSE guide [50] emphasizes that the underlying analysis from which requirements are derived is important for requirement quality, and that requirements should therefore be traceable to the analysis that motivated them. A rationale was therefore provided for each requirement to clarify the underlying need it addressed. The rationale briefly describes why the requirement is necessary, including the problem it addresses or the intended benefit for the handbook.

In addition, each requirement was assigned a proposed verification method describing how compliance could later be assessed. To support traceability and individual verification, some closely related requirements were kept separate rather than combined into broader requirement statements. However, closely connected aspects with the same purpose that would be fulfilled simultaneously were sometimes included within the same requirement. The verification methods used in the project are described further in Section 7.1. Finally, to support prioritization during handbook development, each requirement was assigned a priority level from 1 to 3, where 3 represented the highest priority.

The structure of the requirements specification was selected to balance readability with the inclusion of supporting information and therefore did not include additional attributes such as responsible departments. Individual requirement sources were also not included, since many requirements were derived from multiple overlapping sources, described in Section 4.2.

As the handbook constitutes a document-based product, the requirements primarily define the handbook content and scope. The requirements specified what information and guidance the handbook should include, but not how the information should be presented. For example, the requirements did not specify the exact structure, wording, or use of figures, but focused on ensuring that the necessary information was included.

Once the requirement list had been completed, it was reviewed together with a representative from technical management to obtain feedback regarding the coverage of relevant subject areas.

5.2 Result

5.2.1 Overview of requirements

The requirement development process resulted in a structured set of 69 handbook requirements. The complete requirement specification is presented in Appendix D. The requirements were divided into 12 categories based on the aspect of the drawing process they addressed. The categories containing the largest number of requirements were drawing creation, handbook structure, drawing review, and change management. Examples of formulated requirements are given below:

- The handbook shall describe the standardized workflow for creating drawings from 3D models in the CAD system. *(Drawing creation)*
- The handbook shall describe how drawings are checked into the PLM system and which drawing information is stored in the system. (*System interaction*)

- The handbook shall describe how relevant ISO standards are applied in drawing creation. (*Tolerances and standards*)
- The handbook shall describe how the title block should be completed and explain the purpose of each field. (*Title block*)
- The handbook shall describe the company's language policy for drawings. (*Language*)

5.2.2 Requirement categories

The following sections present the requirement categories and summarize the types of requirements included within each category.

5.2.2.1 Handbook structure

This category includes requirements related to the overall structure and usability of the handbook. The requirements emphasize clarity and logical structure to support navigation and information retrieval. A high degree of explanation is required, supported by illustrative examples, typical company drawings and examples of common mistakes. In addition, the handbook is intended to function as a standalone document and provide consistent guidelines across business segments. The category also includes requirements related to the possible inclusion of CAD-specific guidelines and multiple handbook languages.

5.2.2.2 Supporting information

This category covers requirements related to supporting documentation and resources connected to the drawing process. The requirements specify that the handbook shall describe and reference relevant company documentation, explain how drawing templates are accessed, and describe how drawings are stored and managed. In addition, the handbook shall explain the purpose of key supporting elements such as data cards, operation lists, and Bills of Materials.

5.2.2.3 Drawing creation

This category includes requirements stating that the handbook shall describe standardized workflows for creating and managing drawings from 3D models. In addition, the requirements specify which drawing conventions the handbook shall define related to projection methods, scales, formats, font sizes, drawing layout, dimensioning principles, including that critical and manufacturing-relevant dimensions should be specified.

5.2.2.4 Drawing content

This category focuses on requirements related to the information that shall be included in drawings. The requirements specify that the handbook shall describe the different types of drawings used within the company, including assembly and detail drawings, as well as the distinction between production and customer drawings. Furthermore, the requirements state that the handbook shall define what information is required to ensure drawing completeness and address the risks associated with ambiguous drawings and duplication of information.

5.2.2.5 Tolerances and standards

This category includes requirements related to the application of standards and tolerancing in drawings. The requirements specify that the handbook shall present relevant ISO standards and describe how they are applied in drawing creation. They also specify that the handbook shall describe general tolerancing principles, including the distinction between the use of the Backer standard tolerancing table and general ISO tolerances.

5.2.2.6 Title block

The requirements in this category specify that the handbook shall describe how the title block is completed, explain the purpose of each field, and distinguish between mandatory and optional fields.

5.2.2.7 Drawing review

This category covers requirements related to the review and approval of drawings. The requirements specify that the handbook shall describe the review workflows for both production and purchasing drawings, including the associated workflow within the PLM system. Furthermore, they emphasize the inclusion of review criteria, examples of common mistakes identified during reviews, and an explanation of the purpose and benefits of structured drawing reviews.

5.2.2.8 Change management

This category includes requirements related to the control and management of drawing changes. The requirements state that the handbook shall describe the general change management process, the use of the change management system, handling of revisions and minor corrections, as well as guidance for updating existing and legacy drawings.

5.2.2.9 System interaction

This category includes requirements stating that the handbook shall describe the interaction between drawings and related company systems, including the purpose of the PLM and ERP systems, how drawing-related information is transferred between them, and what drawing information is managed within each system.

5.2.2.10 Drawing use

This category includes requirements stating that the handbook shall describe how drawings are used in production and purchasing contexts. The requirements specify that the handbook shall address the consequences of using printed drawings, describe principles that support clear interpretation by production personnel, and explain the role of the drawing as the governing manufacturing document.

5.2.2.11 Roles and onboarding

This category includes requirements stating that the handbook shall describe the roles and responsibilities of departments involved in the drawing process. The requirements also specify that the handbook shall support onboarding of new design engineers by explaining company-specific practices and providing examples suitable for users with limited experience of working with drawings.

5.2.2.12 Language

This category includes requirements stating that the handbook shall describe the company's language policy, including the use of Swedish for production drawings, English for purchasing drawings, and situations where both languages may be used within the same drawing.

5.3 Requirements development discussion

5.3.1 Reflections on the requirement derivation process

The requirement development process helped translate the organizational practices and needs identified in Chapter 4 into tangible handbook requirements. This supported the transformation of broad organizational findings and observations into more concrete and structured handbook topics, representing an important step between the organizational study and the actual handbook development. The identified key processes provided a useful foundation for the requirement categorization, which in turn contributed to the overall handbook structure.

However, an important realization during this stage was that transforming organizational information into a usable handbook required more than simply identifying what information should be included. Unlike development of a traditional technical product, the handbook also required consideration of how the information should be structured, explained, and presented to the user. Additional handbook-related requirements therefore had to be introduced to address aspects such as handbook structure, explanation level, and use of examples. This required several important decisions regarding how the handbook should function as a support and learning tool. As one of the primary intended user groups consisted of newly employed design engineers, it was decided that the handbook should contain a high degree of explanation supported by illustrations and company-specific examples. This was intended to support both users who were new to the organization and users with limited prior experience of technical drawing principles.

Translating these organizational findings into handbook requirements also introduced challenges. Many findings were broad, interconnected, and not always directly suitable to formulate as concrete handbook requirements. In addition, many inconsistencies identified during the organizational study could not realistically be resolved through the handbook itself and therefore had to be excluded from the requirement scope. Different stakeholders also sometimes expressed different opinions regarding how certain activities should be performed. In cases where processes or practices were unclear, discussions with technical management were used to clarify which procedures the handbook should describe.

5.3.2 Scope, strengths and limitations of requirements

Overall, the requirements are considered to cover the majority of the relevant aspects. This was also supported during a review of the requirements by a representative from technical management, who originally identified the need for the handbook, where the requirements were considered to cover the intended subject areas and organizational needs. Since the requirements were derived from interviews, observations, document analysis, and standards, they reflected both standardized technical practices and practical organizational workflows. The broad organizational coverage contributed to a requirement set relevant to multiple stakeholders involved in the drawing process.

The use of rationales for each requirement supported traceability to the underlying organizational needs and findings. One possible way to further strengthen this traceability could have been to first establish a more formalized list of identified organizational needs before translating them into requirements.

At the same time, the scope of the requirement list had to be limited to maintain the usability of both the requirement specification and the handbook itself. Including too many detailed requirements would have made the specification more difficult to overview and use, while also increasing the risk of producing an unnecessarily extensive handbook. Therefore, some requirements were intentionally formulated more broadly to allow flexibility in the exact content within a subject area, while requirements describing content that had to be included, such as specific standardized conventions, were formulated more specifically. Overall, the requirement scope primarily focused on aspects considered practically relevant for the creation, understanding, review, and management of drawings within the organization.

Overall, the requirements were considered sufficiently concrete to support verification, as the majority described content that the handbook should include. The inclusion of proposed verification methods also supported this process. However, some of the broader requirements may still be more difficult to verify strictly. These requirements are primarily intended to be verified through expert review and therefore still involve a degree of personal judgement.

5.3.3 Use of requirements during handbook development

The requirements provided an important structural foundation during the handbook development, where many requirements directly resulted in handbook headings or subheadings. As the handbook content and understanding of the organizational processes developed further, a small number of requirements were discovered to be less central than initially expected, for example use of language in drawings. In addition, new interconnected topics emerged that could potentially also have been formulated as requirements. For example, the distinction between drawing review and approval. However, the requirement specification was not intended to define every individual aspect of the handbook content, but rather the information and subject areas that the handbook should address.

6 Handbook development

6.1 Method

This chapter describes the development of the handbook based on the previously defined requirements. The objective of this phase was to transform the defined requirements into a complete handbook by developing and organizing the content into a structured and understandable format. While the requirements defined what areas the handbook should contain, this phase focused on how the information should be formulated, structured, and presented to support understanding and practical use.

6.1.1 Principles for formulating technical content

6.1.1.1 Linguistic and communicative principles

An important part of the handbook development was establishing principles for how the technical content should be formulated. Since the handbook is intended to support practical work, the content needed to be easy to interpret to support users in performing various drawing-related tasks.

The development of the handbook content was guided by established principles from technical communication literature, such as *Technical writing essentials* by Suzan Last [52]. A central concept emphasized in the book is reader-centered writing, meaning that the content should be adapted to the intended users, their prior knowledge, and their purpose of using the document. Since the handbook is intended to support newly hired engineers working with drawings, the content was formulated assuming limited prior experience with engineering drawings and company-specific drawing practices. Since the handbook was also intended for more experienced engineers, recommended procedures and their purpose were clearly described to support a standardized way of working.

The handbook was written using a professional and neutral technical writing style based on recommendations from the literature, including maintaining an objective tone, avoiding unnecessary emotional language, and using constructive phrasing with positively formulated explanations. [52]

In addition, the handbook content was guided by the "7 Cs" of technical communication described by Last [52]. This describes that a strong technical writing style can be characterized by the 7 Cs, clear, coherent, concise, concrete, correct, complete, courteous. This includes ensuring that each sentence conveys a distinct idea, that information is logically structured and follows naturally between sections, and that ideas are expressed using as few words as possible avoiding unnecessary complexity or redundancy.

When applying these principles, clarity was prioritized when trade-offs were necessary. Practical application of these principles included replacing abstract nouns with verbs to formulate ideas more concisely, for example using *acquire* instead of *acquisition*. In addition, the use of intensifiers, such as *absolutely* and *highly*, and qualifiers, such as *apparently* and *generally*, was limited to avoid unnecessary emphasis and vague phrasing

6.1.1.2 Use of visual elements

The use of visual elements is particularly important in technical communication, as visual representations can support understanding and retention of complex information by helping users identify patterns and relationships between concepts. As discussed by Bobek and Tversky [53] this may be explained by the fact that visual explanations can promote deeper cognitive processing and support the development of more complete mental models. Their study also suggested that visual explanations can often be more efficient than verbal explanations, since structures and relationships can be represented more directly than through text. This can make complex information easier to interpret and inconsistencies easier to identify.

Accordingly, clear and consistent visual elements were included primarily in sections where textual explanations alone were considered insufficient, particularly for illustrating workflows, relationships between concepts, and applications of standards and procedures.

6.1.1.3 Content structure and navigation

To support clarity and usability, the handbook content was organized into smaller topic-specific sections and arranged in a logical order, either from general to specific topics or as step-by-step instructions. Consistent terminology was used throughout the handbook, supported by clear definitions of key terms. Cross-references and a table of contents were also included to improve navigation, while important information, such as warnings and recommendations, was highlighted where appropriate.

To support consistency, a common overall structure was applied throughout the handbook. Most sections included brief introductory explanations followed by instructions and practical guidance, while examples and notes on common mistakes were included where relevant.

6.1.2 Development of handbook structure

The next step in the development process was to establish a structure for the handbook. The handbook structure was developed primarily based on the categories defined in the requirement specification together with the key processes identified in the organizational study. This allowed the structure to reflect both the formal requirements and the practical context in which the handbook will be used. In addition, sections describing the purpose, scope, and use of the handbook were added to support usability.

Based on these inputs, a high-level structure resembling a table of contents was established, where the main sections followed the overall workflow and lifecycle of drawings, including creation, drawing content, review and approval, use, system interaction, and change management. The individual requirements were then placed into the most appropriate sections, while additional subheadings were introduced where necessary to further structure the content.

The resulting outline functioned as a working table of contents throughout the development process by defining where content related to different requirements should be developed and by providing a structured overview of the handbook. In this way, each section covered one or more related requirements, ensuring that each requirement was addressed in an organized manner.

The overall structure remained largely consistent during the development phase, but minor adjustments were made where necessary, to ensure a balanced distribution of contents and to reduce overlaps between sections.

6.1.3 Development of handbook content

Once the handbook structure had been established, content for each section was developed based on the findings from the literature review and organization study. As both these studies were broad and included large amounts of information, the requirement specification functioned as a filter for determining which findings should be included in the handbook. This section describes how the findings were used, while detailed descriptions of the standards and processes investigated are presented in Chapters 3 and 4.

The literature review provided much of the technical content used in the handbook, particularly through the reviewed ISO standards. Relevant parts of this material were selected and reformulated into practical handbook content. In many areas, the organization already followed ISO standards through existing ways of working and the use of CAD, even if this was not always explicitly recognized. The handbook therefore clarified the relevant ISO standards already being applied. In areas where no clearly defined process existed, the handbook referred to and explained the relevant ISO standards. Where company-specific practices differed from ISO standards, such as the Backer standard, these were described instead.

The organizational study contributed to the company-specific parts of the handbook, including workflows, system usage and responsibilities. Relevant findings were reformulated into instructional handbook content focused on describing the intended organizational processes, rather than the variations in current working methods or individual opinions identified.

Unlike most requirements, specified content that should or shall be included, two requirements were formulated as possibilities. Requirement R10 stated that the handbook may in either Swedish or English. The handbook was developed in English to support accessibility for employees who primarily speak English, as well as to support increasing globalization. Similarly, R9 stated that the handbook can include guidelines for Creo. Based on this, basic instructions for the use of Creo and Windchill were included, describing how certain drawing-related tasks should be performed within the systems.

6.2 Result

The result of the development process was the handbook *Engineering Drawing Creation and Management Handbook*. The complete handbook is presented in Appendix E. This section summarizes the overall handbook structure and key content characteristics.

6.2.1 Overall structure of the final handbook

The structure of the final handbook is presented in Table 9. The table outlines the main sections and selected subheadings together with their main content and the requirements they address. Requirements are mapped at the most detailed level to avoid duplication and clearly indicate where each requirement is addressed.

Table 9: Overall structure of the developed handbook, including main content areas and their relation to the defined requirements.

Section	Main content	Covered reqs.
Overall handbook	Overall handbook structure, usability, language, and standardized drawing practices	R1, R2, R4-R8, R10
1. Introduction	Context, purpose and use of handbook	
1.1 Purpose of the handbook	Objective and intended outcome of the handbook	R3, R4
1.2 Scope	Scope and limitations	R8
1.3 Use of handbook	Target audience and usage	R63-R65

1.4 Related documents	Relevant company documentation and external sources	R9, R11
2. Overview of drawing practices	Fundamental concepts, drawing types, standards	
2.1 Role of drawings in the company	The role of drawings as the governing document	R59
2.2 Importance of standardized drawing practices	Benefits of standardization	R3
2.3 Applicable standards	Relevant ISO standards	R34
2.4.1 Types of drawings based on content	Production and purchasing drawings	R30
2.4.2 Types of drawings based on use	Assembly, detail, and other technical drawing types	R29
3. Roles and responsibilities	Responsibilities of stakeholders in the drawing process	
3.1 Design engineers and reviewers	Responsibilities for creating and reviewing drawings	R62
3.2 Production and purchasing	Responsibilities for interpreting and using drawings	R62
4. Drawing creation	Creation workflow, layout and technical principles	
4.1 Workflow for creating drawings from 3D models	Drawing creation workflow in CAD	R9, R17
4.2 Templates and formatting	Templates, formatting and text elements	
4.2.1 Drawing templates	Access and use of templates	R12
4.2.2 Format and sheet size	Drawing formats and sheets sizes	R21
4.2.3 Lettering and text size	Recommended font sizes	R22
4.3 Views, projections and layout	Arrangement of view and graphically elements	
4.3.1 Projection method	European projection method	R19
4.3.2 Line types and line widths	Basic line types and widths	
4.3.3 Use of views	Selection of views, sectional views	R25
4.3.4 Scale selection	Use of standard scales	R20
4.3.5 Placement of views	Consistent positioning of views	R23
4.3.6 Placement of text elements	Consistent positioning of text elements	R24, R26
4.4 Dimensioning	Principles for dimensioning	R27,28
4.5 Dimensional tolerancing	Principles for tolerancing	
4.5.1 Purpose and principles	Geneal tolerancing approaches	R35, R38
4.5.2 Numerical tolerances	Use of numerical tolerances according to ISO	R35
4.5.3 ISO tolerance classes	Use of ISO tolerance classes	R35
3.5.3 General tolerances	Application of general tolerances, ISO 2768	R37
4.5.4 Backer Standard	Company-specific tolerancing practices	R36
4.6 Geometrical tolerancing	Different types of geometrical tolerances	R35
4.7 Surface roughness	Selection of surface roughness value	
5. Drawing content	Included information and its structure	

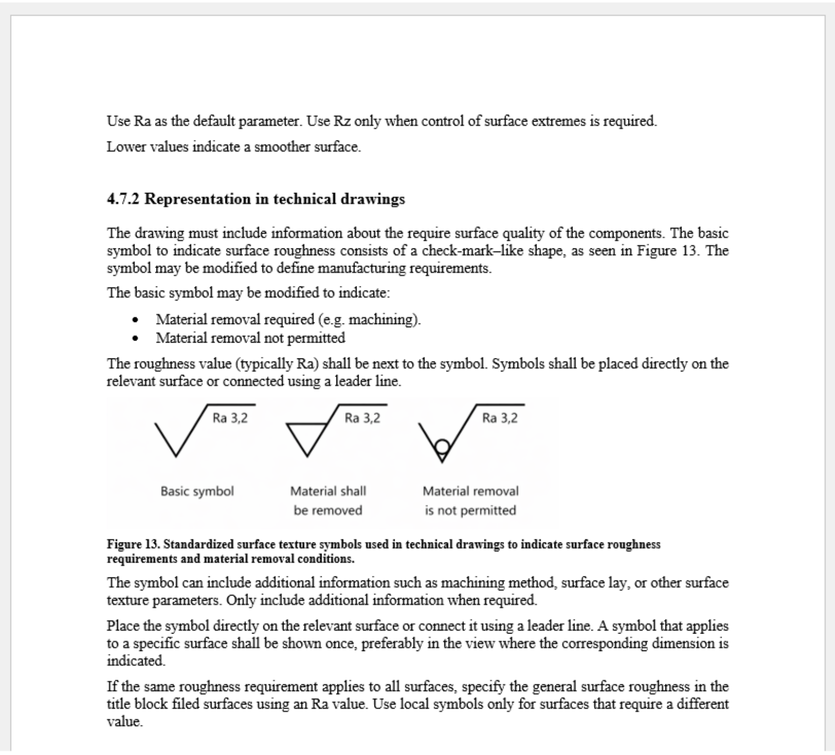
5.1 Required information in drawings	Mandatory information needed for manufacturing and interpretation	R31
5.2 Completeness and clarity of drawings	Avoidance of ambiguity and missing information	R32, R33
5.3 Title block content	Title block fields, their source and required entries	R39, R40
5.4 Parts list	Purpose and information included	R16
5.5 Related documentation	Supporting documents related to drawings	
5.5.1 Data card	Content and purpose of data card	R14
5.5.2 Operations list	Content and purpose of operations list	R15
5.6 Language policy	Language use depending on drawing context	R66-R69
6. Use of drawings	Use of drawings in operational contexts	
6.1 Use in production	Use for manufacturing and inspection	R57, R58
6.2 Use in purchasing	Use for purchasing and supplier communication	R60, R61
7. Drawing review and approval	Review workflows, review criteria	
7.1 Purpose and benefits of drawing review	Importance of reviews for quality and consistency	R46
7.2 Review and approval in PLM	Formal review process within PLM	R43
7.3 Review of production drawings	Review workflow for production drawings	R41
7.4 Review for purchasing drawings	Review workflow for purchasing drawings	R42
7.5 Review criteria	Minimum criteria for drawing reviews	R44
7.6 Common mistakes identified during drawing review	Typical issues found during reviews	R45, R7
8. Systems supporting drawing management	Systems used to store, manage and transfer drawing data	
8.1 PLM system	System purpose and drawing management in Windchill	R13, R18, R53, R54
8.1.1 Purpose of the system		R13, R53
8.1.2 Object types and relationships	Types of objects stored in Windchill	R13
8.1.3 Data transfer from CAD	Description of connection between Creo and Windchill	R18
8.1.4 Information stored	Metadata and product related attributes stored	R54
8.2 ERP system	System purpose and drawing related data in Epicor	R55, R56
9. Change management	Handling of drawing changes and revisions	
9.1 Purpose of change management	Purpose and importance of controlled changes	R47
9.2 Change management process	Overall process for implementing changes	R18, R47
9.2.1 Change management system	Use of change management system	R49
9.2.2 Handling of minor corrections	Process for minor adjustments	R51

9.3 Revision management	Revision numbering and revision handling	R48, R50
9.4 Updating existing drawings	Updating and modifying existing drawings	
9.4.1 General procedure for updating drawings	Principles for modifying drawings	R52
9.4.2 Legacy drawings	Handling and updating legacy drawings	R52

The table shows that the handbook structure covers all the defined requirements. Further discussions on requirement coverage and fulfilment are presented in Chapter 7.

6.2.2 Content characteristics

The developed handbook combines instructional descriptions of organizational processes with explanations of relevant technical drawing principles, standards and system usage. The handbook uses an instructional style intended to support practical task execution. The handbook is relatively extensive, consisting of approximately 60 pages, and therefore combines continuous text with bullet lists, tables, figures, and bold text to improve readability. An example of this is shown in Figure 25.



Use Ra as the default parameter. Use Rz only when control of surface extremes is required.

Lower values indicate a smoother surface.

4.7.2 Representation in technical drawings

The drawing must include information about the require surface quality of the components. The basic symbol to indicate surface roughness consists of a check-mark–like shape, as seen in Figure 13. The symbol may be modified to define manufacturing requirements.

The basic symbol may be modified to indicate:

- Material removal required (e.g. machining).
- Material removal not permitted

The roughness value (typically Ra) shall be next to the symbol. Symbols shall be placed directly on the relevant surface or connected using a leader line.

Figure 13. Standardized surface texture symbols used in technical drawings to indicate surface roughness requirements and material removal conditions.

The symbol can include additional information such as machining method, surface lay, or other surface texture parameters. Only include additional information when required.

Place the symbol directly on the relevant surface or connect it using a leader line. A symbol that applies to a specific surface shall be shown once, preferably in the view where the corresponding dimension is indicated.

If the same roughness requirement applies to all surfaces, specify the general surface roughness in the title block filed surfaces using an Ra value. Use local symbols only for surfaces that require a different value.

Figure 25: Example section from the developed handbook illustrating instructional content and visual elements.

Workflow diagrams are included to illustrate organizational processes and relationships between activities while reducing the need for extensive textual explanations, with examples shown in Figure 22 and Figure 24. The handbook also contains examples from existing company drawings to illustrate how information should be presented in practice, such as completion of title blocks. Textual examples were also included, such as issues identified during drawing reviews, including missing balloons and use of bending radii above the allowed limit. Relevant sections also include basic guidance for Creo and Windchill, describing how certain drawing-related activities are performed within the systems, while more detailed instructions are left to external documentation.

The handbook largely functions as a standalone document by gathering relevant information in one place, while still referring to related company documents describing broader organizational processes to avoid unnecessary overlap.

6.3 Handbook development discussion

6.3.1 Handbook structure and usability

The developed handbook attempts to balance completeness and usability within a single document. Since the handbook is intended both to explain drawing-related practices and to support engineers during daily drawing work, trade-offs regarding the level of detail had to be made between providing sufficient practical information and avoiding unnecessary information overload to maintain usability. At times, the handbook therefore becomes relatively detailed, which was considered necessary since practical details are important for making the handbook useful rather than overly generic.

The chosen level of detail also resulted in inclusion of several basic topics, such as projection methods and line types. These topics may appear obvious to experienced engineers, but they provide important context and support for less experienced users who may be unfamiliar with these practices. Even if many of these aspects are handled automatically within CAD systems, it was still considered important to explain the underlying principles, both to improve understanding of the practices themselves and to support interpretation of drawings.

The handbook is relatively extensive, which comes with a risk of becoming overwhelming. This was nevertheless considered necessary in order to gather dispersed information and cover the relevant topics within a single document. Otherwise, the handbook would risk becoming another fragmented source of information, further contributing to the existing problem of relevant information being scattered across multiple documents and sources.

To support usability the content combines continuous text with bullet lists, examples, and visual elements. The handbook structure also follows a natural workflow to support navigation, beginning with the role of drawings and responsibilities, continuing through drawing creation, layout, dimensioning and tolerancing, and further into review, approval, system interaction, and change management. This structure naturally guides the user through the overall drawing process. Clear topic-specific headings support the user when searching for particular information through the table of contents.

6.3.2 Scope and maintainability

Technical drawings are involved in many organizational processes and affect several functions, even in cases where this may not be immediately obvious. The scope of the handbook therefore had to be relatively broad in order to cover the relevant processes. This was supported by the mapping of organizational processes, which showed how drawings are involved throughout large parts of the product lifecycle. One example is change management, where organizational changes may ultimately result in updates to the drawings. This illustrates how drawings are closely connected to broader organizational processes and therefore cannot be viewed as isolated documents that can simply be modified independently. Providing context regarding these surrounding processes was therefore considered important to support understanding of how drawings are managed within the organization.

The large scope however makes maintainability more difficult. Organizational processes may change, standards may be updated, systems such as PLM and ERP may evolve or be replaced, and new company guidelines may be introduced. The handbook should therefore be regarded as a living document requiring continuous review and update in order to remain useful and reflect current organizational practices. At the same time, avoiding relevant topics simply to simplify maintenance was not considered appropriate, since this would reduce the practical usefulness of the handbook.

Certain decisions were nevertheless made to improve maintainability. For example, the handbook contains less details regarding ERP usage, partly because of ongoing discissions of possible changes, which could otherwise cause the handbook to become outdated quickly. Specific software names such as Creo, Windchill, and Epicor are also mainly used only in sections specifically discussing those systems. In other sections, more general terms such as CAD, PLM, and ERP systems are used to reduce the need for future revisions in case systems are replaced. To further support maintainability, unnecessary overlap with broader organizational procedures was avoided by referring to existing company documents where appropriate. This reduces both the update burden and the risk of inconsistencies between documents.

The handbook only remains useful if it is continuously updated and if responsibility for maintaining the document is clearly defined. The handbook should therefore have a clearly assigned owner responsible for reviewing and updating the content. Revision of the document should be controlled and reviewed before implementation. Otherwise, there is a risk that the handbook becomes outdated and inconsistent with actual processes, reducing both trust in and practical use of the document.

The handbook structure was also designed to support future additions and modifications through a modular section structure. This allows new procedures, standards, and practices to be integrated into relevant sections without requiring major restructuring of the document.

6.3.3 Future refinements

Although the handbook covers the identified core processes related to technical drawings, some areas could be further expanded in the future. Due to the broad scope of the handbook and the complexity of the organizational processes involved, it was not considered realistic to fully develop all areas to the same level of detail. As the handbook is used in daily work, it will likely require iterative refinement after longer organizational use, where practical use may reveal unclear sections or missing guidance.

The handbook could also benefit from additional examples of common drawing mistakes and more specific visual examples illustrating areas that users frequently find difficult to interpret. Such examples could be added continuously as new recurring issues are identified.

Future refinements could include more detailed Creo and Windchill guidance, since this was identified as a need during the organizational study. It is also recommended that more formalized review criteria and requirements for drawing content are developed and later integrated into the handbook. The handbook could also be expanded with guidance for welded drawings and electrical drawings, since these are also used within the organization.

In the future, the handbook should also be expanded with more guidance related to specific products, departments, and complex technical drawing situations, since many of the current examples primarily illustrate more general drawing principles. It is however not recommended to expand the handbook with broader engineering design guidance, such as strength calculations, material selection, and product performance considerations, since this would shift focus away from technical drawing creation and management. Such content would instead be more suitable for a separate engineering design handbook.

Even if future developments in CAD software reduce the amount of manual work involved in drawing creation, clear drawing guidelines will still play an important role. Emerging AI-based functionality for automatic generation of technical drawings from 3D models may influence future drawing workflows. For example, SOLIDWORKS has introduced a beta feature for automatic generation of drawings of parts and assemblies [54]. Similar functionality is likely to become available in most 3D modelling softwares in the future. However, such systems would still require guidelines for drawing creation, both for the AI system generating the drawing and for the engineer responsible for reviewing and approving it. Clear drawing guidelines could therefore continue to play an important role in both automated and manual drawing workflows.

7 Verification and validation

7.1 Method

After completion of the handbook verification and validation activities were performed. Verification was performed to assess whether the developed handbook fulfilled the defined requirements presented in Chapter 5. As part of the requirement specification, each requirement was assigned at least one proposed verification method indicating how fulfillment of the requirement was to be assessed. Depending on the nature of the requirement, verification was performed through requirement inspection, standards analysis, or expert review.

Requirement inspection was performed for all requirements and served as the primary verification method for requirements where fulfillment could be directly assessed through review of the handbook itself. This was performed by reviewing the handbook content against the defined requirements and assessing whether the identified requirements had been addressed. As part of this activity, all requirements were mapped against the handbook structure, including chapters and subchapters, to evaluate requirement coverage and completeness.

Standards analysis was used to verify requirements related to standards compliance or requirements covered by ISO standards. This activity involved reviewing whether standards identified during the literature study were appropriately referenced and described within the handbook.

Expert review was used to verify requirements related to organizational processes, where correctness could not be sufficiently assessed through document inspection alone. These activities were performed together with the company technical lead, who first reviewed the handbook independently and later reviewed and discussed the handbook together with the author. The review included assessment of whether organizational processes had been described accurately in order to verify fulfillment of related requirements.

Validation was performed to assess whether the handbook fulfilled its intended purpose and was considered suitable for organizational use. During the review sessions, the company technical lead assessed the usefulness, clarity, and practical applicability of the handbook in relation to its intended organizational purpose.

The handbook was also distributed to several design engineers within the organization for review and feedback. However, no substantial feedback was received within the project timeframe. In addition, a practical validation activity involving direct application of the handbook during drawing creation was initially planned as part of the project. However, due to project time limitations, this activity could not be completed within the scope of the project.

Based on the results of the performed verification and validation activities, minor refinements and clarifications were made to the handbook, while the majority of the structure and content remained unchanged.

7.2 Result

7.2.1 Requirement inspection

The requirement mapping in Table 9 shows that all the requirements are covered by the handbook structure. Most requirements could be mapped to a single primary section, while some requirements related to broader practices were addressed across multiple sections due to their scope. In addition, some requirements were mapped to the handbook as a whole, particularly requirements related to handbook structure, level of detail, and use of examples.

Through detailed review of the handbook content against the defined requirements, the requirements were considered to be sufficiently addressed within the handbook. Most requirements were relatively specific and could be directly assessed through inspection of the handbook content. However, some broader requirements could not be fully assessed through requirement inspection alone and also relied on the expert review.

7.2.2 Standards analysis

The literature review identified approximately 18 relevant standards. The standards analysis showed that all but two of these standards were referenced within the handbook. One of the omitted references concerned a specific part related to orthographic representation within the standard for projection methods, where the overall standard was still referenced within the handbook. The second omitted reference concerned presentation of linear size tolerances for numerical tolerances.

The review confirmed that the referenced standards were included within appropriate handbook sections and that the descriptions of the standards were considered consistent with the content presented in the literature study. The standards references were also considered appropriately incorporated within the handbook without unnecessarily increasing complexity or reducing readability.

7.2.3 Expert review

The expert review indicated that the majority of the described organizational processes were accurately described. Only a few areas required additional clarification during the review sessions. These concerned the change management process, where it was clarified that the use of formal change management procedures depends on the maturity of the project, and the distinction between review and formal approval. These distinctions were further clarified within the handbook.

Overall, based on feedback from the company technical lead, the validation activities indicated that the handbook fulfilled its intended purpose, provided good coverage of the intended organizational processes, and had good usability. The combination of descriptive text, bullet lists, and visual examples was considered to support readability.

7.3 Verification and validation discussion

Systematically mapping all requirements against the handbook structure was useful, since it supported structured verification that all identified requirements had been explicitly addressed within the handbook. The requirement inspection showed good overall requirement coverage within the handbook. However, requirement fulfillment alone does not necessarily mean that the handbook fully satisfies organizational needs, since this also depends on how well the defined requirements reflect the actual needs of the organization. As discussed in Section 5.3, the requirement set was argued to provide relatively comprehensive coverage of the identified organizational needs, which strengthens the credibility of these results.

The standards analysis helped improve consistency with relevant standards and reduced the risk of missing or incorrectly referenced standards. This was important for supporting the technical credibility of the handbook. The standards analysis showed good overall standards coverage. This evaluation is considered relatively credible due to the more objective nature of comparing handbook content against identified standards.

A major limitation was that a large part of the verification activities consisted of reviews performed by the author. This introduces a risk of bias and limits the ability to draw conclusions regarding the completeness and practical effectiveness of the handbook content. However, conclusions could still be drawn regarding requirement coverage and consistency with the identified standards.

Using a representative from technical management as expert reviewer was beneficial due to the person’s strong knowledge of organizational processes and responsibility for defining these processes. This was particularly valuable for assessing process-oriented requirements that could not be sufficiently verified through document inspection alone. The positive results from the expert review and validation activities indicate that the handbook is reasonably aligned with the intended use. However, these conclusions remain limited due to the limitations of the validation. Only having one reviewer limits the credibility of the validation, since the evaluation becomes dependent on the opinions of a single person

Another important limitation was the limited amount of user feedback received. Although the handbook was distributed to several design engineers for review, no feedback was received due to limited reviewer availability. Additional feedback from multiple users would have strengthened the validation by identifying further inconsistencies, improvement areas, and usability-related issues. In future work, the review activities could benefit from earlier coordination with reviewers to better allocate time for handbook evaluation activities.

The validation activities were also limited by the absence of practical application testing. All performed activities were based on review of the handbook itself rather than evaluation during actual engineering work. While this is partly a natural limitation for a document-based deliverable compared to a physical technical product with measurable performance characteristics, it still limits the ability to evaluate how effectively the handbook supports practical work activities.

As part of the original project plan, a practical validation activity had been planned in which a technical drawing would be created from an existing 3D model using the handbook as support, followed by review through the normal drawing review process. However, this activity could not be completed within the project timeframe. Both this activity and evaluation involving multiple users performing practical tasks using the handbook would have strengthened the validation.

Another limitation is that the handbook was not implemented and evaluated over a longer period of time within the organization. Since no statistics have been developed regarding drawing quality it also would not be possible to quantitatively evaluate potential improvements resulting from the handbook implementation.

Overall, the performed activities provided useful support for evaluation of the handbook, although broader validation and practical implementation would be required to more fully assess the handbook’s effectiveness in practice.

8 Overall discussion

8.1 Process and methods

The project combined literature review, organizational study, requirements development, handbook development, and verification and validation to investigate drawing creation and management. One strength of the methodology was that the project combined technical standards, organizational processes, and practical input from both engineering and production. The combination of theoretical standards and practical organizational needs was important for developing a handbook that was both technically credible and organizationally relevant. The literature review provided a foundation for understanding technical drawing principles, while the organizational study provided important insight into existing workflows and practical challenges.

The requirements-based approach supported structured handbook development and improved traceability between the identified organizational needs and handbook content. The different project activities also complemented and built upon each other throughout the project. Findings from the literature review and organizational study formed the basis for the requirements development, where identified needs were translated into measurable objectives. These requirements then guided the handbook development, while the verification and validation activities were later used to evaluate the resulting handbook. However, as discussed in Chapter 7 the validation activities were limited in scope, and further practical validation is recommended.

The project showed that there are challenges associated with investigating organizational practices and translating them into unified guidelines. Working methods may differ both between individuals and departments, while some important knowledge exists mainly as tacit knowledge rather than formally documented procedures. Developing common guidelines therefore required balancing and integrating these different perspectives into a standardized way of working. In addition, relevant international standards also needed to be incorporated alongside existing organizational practices.

8.2 General results

One of the main outcomes of the project was the handbook developed to support drawing creation and management. The handbook covers a wide range of topics related to technical drawings. It is expected to contribute to a more unified way of working with drawings and improved drawing quality. This is expected to reduce misunderstandings and errors due to incorrect drawings, thereby reducing the risk of production delays. Another main purpose of the handbook is to support the onboarding of new design engineers. By covering multiple relevant processes, it is intended to give the person a basic understanding of relevant organizational processes. This way, the project may contribute to social and organizational sustainability by supporting knowledge preservation, clearer guidance, and more structured engineering processes. The handbook functions as a centralized source of information by gathering relevant standards and organizational processes while still referring to existing documentation where appropriate.

The project also identified different examples of drawing-related organizational challenges which cannot be fully solved through a handbook alone This included fragmented documentation, lack of standardized guidelines, lack of criteria for drawing reviews and unclear review responsibilities. A handbook can support improvement, but it cannot independently solve all organizational issues. However, identifying these issues is still valuable as they can serve as examples of issues other organizations should investigate when evaluating drawing related processes.

On a more general level the project helped identify what processes are relevant when an organisation wants to investigate their drawing related processes. These processes are summarized in Figure 16. It shows that the workflow consists of different product development activities leading to drawing creation, which is supported by standards, templates, guidelines for content and tolerancing principles, followed by storage of product data in PLM, review and approval of drawings, use of drawings, and change management. All these processes are influenced by the organizational attitudes, and one also needs to investigate the existing related documentation.

This can be useful for similar types of organizations that want to reduce drawing-related challenges through development of a drawing handbook. In this context, similar organizations refer to medium-sized companies with both internal production and externally sourced components. While many of the observations can be transferable one should keep in mind that this study has been conducted at a single company and that some processes and challenges identified may be unique for that organisation. The general applicability also depends on the organisation’s technical maturity. The handbook is based on traditional drawing-based workflows with documentation managed through PLM systems. Organizations using MBD may require different documentation practices.

8.3 Further development

As previously discussed, the validation of the handbook was limited. The next step in the development process would therefore be to gather more feedback from design engineers with varying tenure within the organization. This would be combined with practical validation tasks, as mentioned in Section 7.3. Then the handbook would have to be validated during more long-term use, to evaluate how it supports day-to-day engineering work. Possible future development of the handbook content itself has previously been discussed in Section 6.3.3.

The next step after the handbook has been validated further is to implement the handbook in the organization. In order for the intended benefits to be realized the handbook must be well known among the employees and integrated into the working routines. Some implementation challenges may arise due to attitudes towards change. The employees must therefore be well informed about the handbook and its purpose, otherwise there is a risk that it will not be actively used. The handbook will be uploaded to the company's business system to make it accessible to relevant employees. Internal communication and presentation activities will also support awareness and adoption of the handbook. Once it has been implemented it has to continuously be maintained to keep the content up to date with the current practices, as discussed in Section 6.3.2.

After implementation, the handbook should be evaluated to assess how well it is adopted and used in practice. One should investigate long term effects on drawing workflows, and address areas where issues remain. It would also be relevant to, before implementation, produce statistics over the current drawing related errors, in order to be able to measure the effects on drawing workflows in the future.

9 Conclusion

The purpose of this thesis was to investigate what processes influence technical drawing creation and management, what challenges are associated with these processes, and how a handbook can support improvements related to the identified challenges. The study further aimed to investigate how international standards, engineering practices, and organizational processes can be integrated into a unified framework through the development of a handbook for drawing creation and management.

The study identified a set of interconnected organizational processes related to technical drawings, influencing drawing creation, lifecycle management, review, and change handling. Investigating these processes provides a comprehensive understanding of an organization's drawing-related practices. The identified process structure may support similar organizations when investigating drawing related practices, especially organizations with similar workflows and documentation practices

The investigation identified several challenges related to the identified drawing-related processes. These included inconsistent practices, dependency on tacit knowledge, fragmented documentation, unstructured onboarding, unclear responsibilities, and lack of criteria for drawing content and drawing reviews. These challenges create risks related to drawing quality, traceability, and communication between departments.

The thesis demonstrated how organizational processes and standards can be integrated into a unified handbook framework. This entailed adapting the standards to the organizational context to support practical organizational use of the handbook. The developed handbook supports consistent drawing creation, which contributes to reducing drawing related errors and facilitate onboarding of new design engineers.

The work can be expanded further through long term validation and implementation of the handbook to evaluate its practical effects within the organization. It can also be expanded by examining different types of organizations, preferably one with a higher degree of technical maturity, to investigate how drawing-related processes differ.

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Appendix A Project plan and outcome

Figure A.1 presents the original planned project timeline established at the beginning of the project, while Figure A.2 presents the approximate timeline of the activities as they were performed in practice.

The earlier project phases generally followed the original project plan relatively well. However, the current state analysis and interview activities extended somewhat longer than initially planned, partly due to scheduling and availability of interview participants. In addition, literature review activities continued throughout middle stages of the project when additional information and standards needed to be investigated during handbook development, although at a lower intensity than during the main literature review phase.

Handbook development required more time than initially anticipated due to the extensive amount of technical content and writing work involved. In addition, report writing activities occupied a significant amount of time during the later stages of the project, particularly during the period originally allocated for verification and validation. Consequently, less time than planned could be allocated to verification, validation and refinement activities. The originally planned practical validation task was therefore not performed, and validation instead mainly consisted of reviews and feedback

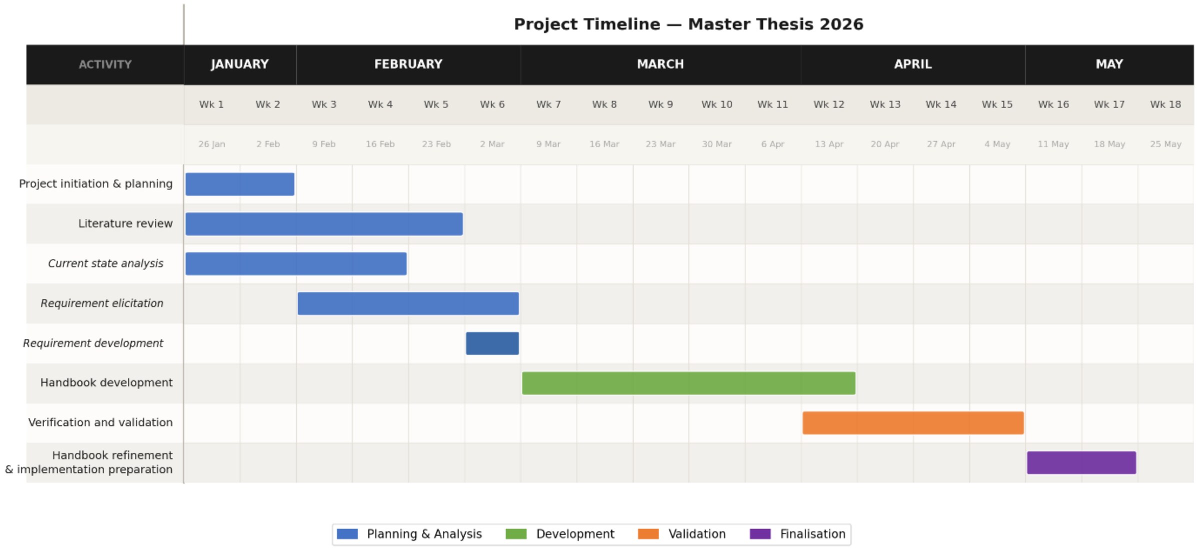

Figure A.1: Gantt chart illustrating the planned project timeline.

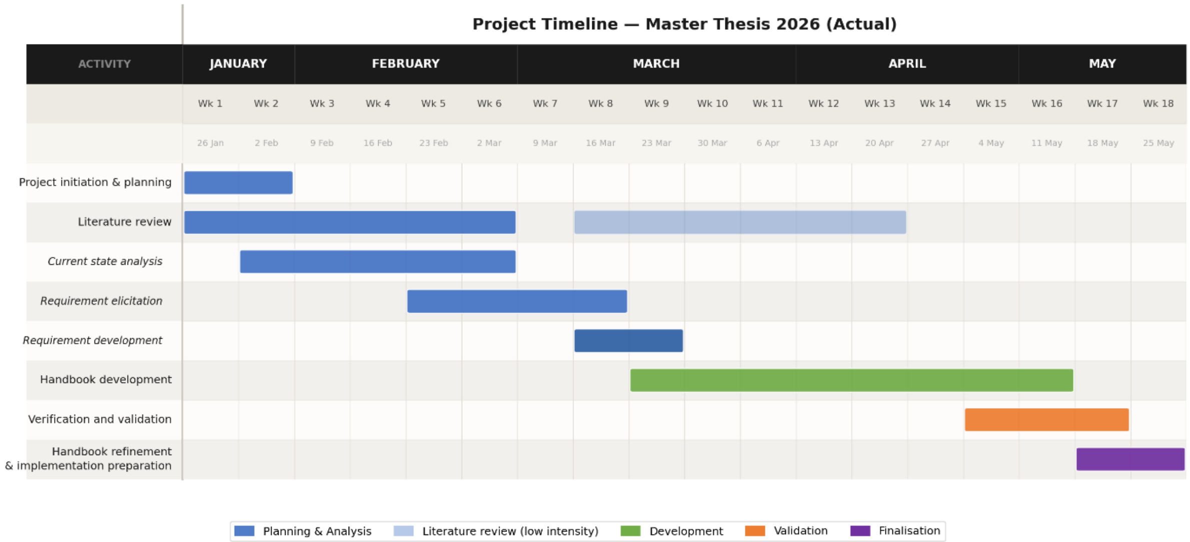

Figure A.2: Gantt chart illustrating the actual project outcome.

Appendix B Interview guide for the first round of interviews

B.1 Interview guide first round of interviews

B.1.1 Creation of drawings

- How are drawings created?
- What CAD software is used?
- Are the current drawing practices causing any issues, if so, which? (E.g. unclarities with notes, dimensioning, and manufacturing requirements)
- Do you have any drawing guidelines you follow, company specific or personal?
- Any ideas about things that it would be important to include in the guidelines?
- What works well today and should not be changed?
- Do you see differences between how different design engineers work? If so, what consequences does this have?

B.1.2 Use of drawings

- How and where are the released drawings stored?
- What format is used for end users of the drawings? Is it PDF of 2D drawings, 3D PDF models that enable reading of dimensions from the models, or paper versions of the documents?
- How is the drawing lifecycle organized?
- Who approves the drawings and how?
- What stages are there in the life cycle? Is it implemented in the PLM system as a workflow?
- There are different types of drawings, ex. production and customer drawings, what separates them?

- How do you ensure manufacturability when creating drawings?
- How are templates managed and updated?

B.1.3 Engineering change management

- What is the procedure in case of engineering change management? Is it implemented in PLM?
- What steps have to be taken to edit a drawing for correction?
- What is the biggest bottleneck in the change process?
- How are urgent changes handled?

B.1.4 Drawing content & standards

- What activities are important when creating drawings? (e.g. dimensioning principles, welding notations, views, paper size)
- Which data fields are there in the current drawing title block? Which are mandatory, optional, should be added, or needs clarification?
- What language is used for drawings?
- What manufacturing standards and tests should be noted in drawings?
- What issues related to tolerancing are there?
- What common misunderstandings with production exist due to missing information?

B.1.5 PLM

- What PLM system is used?
- What information is stored in the PLM system?
- How is information transferred from the drawing program to PLM? Is there any issue with this transfer?
- Does changes of property values in PLM automatically update the drawing, or does it have to be done manually?
- Are BOMs managed in PLM or CAD?
- How easy is it to find old projects?
- Are revision histories clearly understandable?
- Are drawings and related 3D models both stored in PLM?

B.1.6 Model based definition (MBD)

- Is there any use of model-based definition and product information management (PMI), i.e. using 3D objects to display important information?
- What advantages do you see with using this as the main method of communication design intent? Would it accelerate the creation of drawings?
- What challenges do you see with using it?
- Would production be ready to work directly from 3D models?

B.1.7 Drawing reviews

- What is the process when reviewing the work of another constructor?
- What are the most common errors found in these reviews?
- What is the process for drawing reviews performed by production?
- What are the most common things that need to be corrected based on production reviews?
- How long does a typical review cycle take?

B.1.8 Collaboration between the different departments

- Who is the user of the drawings? (Production, sales, purchasing?)
- How are the drawings used in respective department?
- How are the drawings used in production? In paper form? Passed around between the operators?
- What programs do they use to view the drawings (viewer vs full CAD)?
- How well does collaboration and communication between departments work?
- Where do misunderstandings most often occur?
- What department is responsible for what? Are responsibilities clearly defined?
- Do all departments follow the same drawing standards?

Appendix C Interview guide for the second round of interviews.

C.1 Interview guide second round of interviews

C.1.1 Structure & Scope of the handbook

Standardization and interpretation

- What should always be mandatory when creating a drawing?
- Which elements of drawing creation should never be left to personal interpretation?
- In which parts of the drawing process do engineers tend to solve things differently?
- Why does this variation occur?
- What topics should the handbook definitely cover?
- What level of detail should the handbook have (principles vs. step-by-step)?

Onboarding & Core Knowledge

- If a new design engineer starts tomorrow, what must they know to create correct drawings?
- Which parts of the drawing process are most difficult for new engineers?
- How is this knowledge currently transferred (formal vs informal)?
- Why do misunderstandings typically occur in these areas?
- When in the process do these knowledge gaps become visible?

Alignment with Existing Documents

- What existing internal documents would overlap with this drawing handbook?
- Which of these documents should be referenced by the handbook, and which could potentially be replaced by it?

- Should the handbook be included in the existing design handbook, or be a standalone document?

C.1.2 Drawing creation standards

Dimensioning and tolerancing

- What should be standardized regarding dimensioning and tolerancing?
- Which tolerancing practices differ most between engineers?
- How are tolerances currently selected?
- What is Backer specific tolerance table? Where is it used, and why?
- Why do tolerancing misunderstandings occur?
- When are tolerance-related errors typically discovered (design, review, production)?

Views, projections & scales

- What should be standardized regarding views, projections, and scales?
- How should these standards be documented in the handbook?
- Which drawing elements most often create confusion in production?
- Where are layout inconsistencies typically detected?

Standards & Exceptions

- What ISO standards should explicitly be stated in the handbook?
- Which product-specific exception needs to be documented?
- How should special processes (e.g. welding, testing) be documented?
- Why have these exceptions caused issues in the past?

C.1.3 Templates & Layout

- What information must always appear in the title block? Optional, mandatory fields?
- Which information currently included in the title block is unnecessary?
- Which title block fields create confusion?
- What textual information is necessary and not necessary in the drawing?
- Who is responsible for updating drawing templates?
- When were the templates last updated?

C.1.4 Language policy

- What language rules are formally defined?
- Which types of drawings are most sensitive to language ambiguity?
- When is English acceptable?
- How should translation or mixed-language drawings be handled?

C.1.5 Review & Approval process

- What does the formal review process look like?
- Who is responsible at each stage of the review process?
- What criteria define that a drawing is ready for review?
- Which types of errors are most commonly identified during reviews?
- When is a drawing considered ready for release?
- Should review criteria be included in the handbook?
- Should responsibilities for approval be clarified in the handbook?

C.1.6 Engineering change management

Revisions

- What responsibilities are defined during change management?
- When must a new revision be created?
- Which types of changes create the most confusion?
- How are revisions managed?

Minor adjustments

- What qualifies as a minor adjustment?
- Who has authority to approve minor adjustments?
- Why have minor adjustments led to errors in the past?

C.1.7 Interaction with PLM & ERP

- What PLM and ERP steps should be described to prevent mistakes?
- How is information transferred between Creo → Windchill → Epicor?
- What manual steps today create risks?

- Should the handbook include a simple workflow overview (Creo->Windchill->Epicor)?
- What metadata must always be correctly entered before release?
- When are system-related errors typically discovered?

C.1.8 Collaboration & Responsibilities

- What drawing related misunderstandings between departments occur most often?
- What should engineers be responsible for?
- What knowledge should production reasonably be expected to have?
- How are roles and responsibilities explicitly defined?
- How is feedback from production formally handled?

C.1.9 Future considerations

- Should the handbook prepare for possible future use of MBD?
- Which current practices would conflict with MBD?
- Should parametric modeling practices be included?
- Who would be responsible for maintaining the handbook over time? How?

Appendix D Requirement specification

The requirement specification is presented in this appendix. Due to the width of the table, it has been divided into two parts to improve readability. Table 10 contains the requirement identifiers, categories and requirement descriptions, while Table 11 contains the corresponding rationales, verifications methods, and priorities. The tables are linked together through the requirement ID.

Table 10: Requirement specification, including requirements ID, category and requirement

Req ID	Category	Requirement
R1	Handbook structure	The handbook shall be structured in a clear and logically organized manner to facilitate navigation and information retrieval
R2	Handbook structure	The handbook shall include a high degree of explanation
R3	Handbook structure	The handbook shall describe the benefits of following standardized drawing procedures
R4	Handbook structure	The handbook shall function as a standalone document
R5	Handbook structure	The handbook shall include illustrative examples and explanatory images of concepts when necessary
R6	Handbook structure	The handbook shall include examples of typical drawings used within the company
R7	Handbook structure	The handbook shall include examples of common drawing mistakes
R8	Handbook structure	The handbook shall provide the same guidelines for all three business segments
R9	Handbook structure	The handbook can include guidelines for the use of Creo
R10	Handbook structure	The handbook may be in developed in Swedish, English, or both languages

R11	Supporting information	The handbook shall describe existing company documentation related to drawing creation and reference these documents where applicable
R12	Supporting information	The handbook shall describe where and how drawing templates are accessed within the company's CAD system
R13	Supporting information	The handbook shall describe how drawings are stored and managed after creation within the company's systems
R14	Supporting information	The handbook shall describe the purpose and content of the data card and how it is used together with the drawing
R15	Supporting information	The handbook shall describe the purpose of the operation list and how it is used together with the drawing
R16	Supporting information	The handbook shall describe what information is included in the parts list and BOM
R17	Drawing creation	The handbook shall describe the standardized workflow for creating drawings from 3D models in the CAD system
R18	Drawing creation	The handbook shall describe the standardized workflow for managing drawings
R19	Drawing creation	The handbook shall describe the use of the European projection method in drawings
R20	Drawing creation	The handbook shall describe the use of standard scales such as 1:1, 1:2, and 1:5
R21	Drawing creation	The handbook shall describe the use of A3 format for printed drawings
R22	Drawing creation	The handbook shall specify recommend font sizes for text elements in drawings
R23	Drawing creation	The handbook shall describe a standardized placement of views within drawings
R24	Drawing creation	The handbook shall describe a standardized placement of textual elements within drawings
R25	Drawing creation	The handbook should recommend using at least three views per drawing, where applicable
R26	Drawing creation	The handbook should recommend using additional drawing pages when all information cannot fit on a single page
R27	Drawing creation	The handbook shall describe that all critical measurements should be dimensioned on the drawing
R28	Drawing creation	The handbook should emphasize dimensioning measurements that are relevant for manufacturing
R29	Drawing content	The handbook shall describe common technical drawing types used within the company (assembly drawings and detail drawings)

R30	Drawing content	The handbook shall describe the distinction between production drawings and customer drawings, based on their purpose
R31	Drawing content	The handbook shall describe the information that the drawing must include
R32	Drawing content	The handbook shall explain the risks associated with ambiguous or incomplete drawings
R33	Drawing content	The handbook shall explain why duplication of information across drawings and other documents should be minimized
R34	Tolerances and standards	The handbook shall describe how relevant ISO standards are applied in drawing creation
R35	Tolerances and standards	The handbook shall describe tolerancing principles used within the company, including how deviations from standard tolerancing are handled
R36	Tolerances and standards	The handbook shall describe the use of the Backer standard tolerance table for drawings used in internal production
R37	Tolerances and standards	The handbook shall describe the use of ISO 2768 for tolerancing for external drawings
R38	Tolerances and standards	The handbook shall explain the implications of specifying unnecessarily thigh tolerances
R39	Title block	The handbook shall describe how the title block should be completed and explain the purpose of each field
R40	Title block	The handbook shall specify which title block fields are mandatory and which are optional
R41	Drawing review	The handbook shall describe the workflow for reviewing production drawings
R42	Drawing review	The handbook shall describe the workflow for reviewing purchasing drawings
R43	Drawing review	The handbook shall describe the drawing review and approval workflow in the PLM system, including how rejected drawings are handled.
R44	Drawing review	The handbook should describe review criteria used when reviewing drawings
R45	Drawing review	The handbook shall describe common mistakes identified during drawing reviews
R46	Drawing review	The handbook shall explain the purpose and benefits of performing drawing reviews
R47	Change management	The handbook shall describe the change management process for drawings and explain why changes must be controlled and approved

R48	Change management	The handbook shall describe the revision and version numbering used for drawings (e.g., A1, A2, A, B)
R49	Change management	The handbook shall describe the change management system used within the company
R50	Change management	The handbook shall explain the difference between revisions for serial and one-of-a-kind products
R51	Change management	The handbook should describe the procedure for handling minor adjustments
R52	Change management	The handbook shall describe the process for updating existing drawings, including legacy drawings created in BricsCAD
R53	System interaction	The handbook shall describe the purpose of the PLM system
R54	System interaction	The handbook shall describe how drawings are checked into the PLM system and which drawing information is stored in the PLM system
R55	System interaction	The handbook shall describe the purpose of the ERP system
R56	System interaction	The handbook shall describe how drawing information is transferred to the ERP system and which drawing-related information is stored in the ERP system
R57	Drawing use	The handbook shall describe how drawings are used in production, including implications of using printed drawings
R58	Drawing use	The handbook shall promote drawing practices that ensure drawings are easily interpretable by production personnel
R59	Drawing use	The handbook shall explain the role of the drawing as the governing document
R60	Drawing use	The handbook shall describe how drawings are used for purchasing and how communication with purchasing and suppliers should be conducted when creating purchasing drawings
R61	Drawing use	The handbook shall emphasize that all necessary manufacturing information shall be included in the drawing rather than only in external correspondence
R62	Roles and onboarding	The handbook shall describe the roles and responsibilities of departments involved in the drawing process
R63	Roles and onboarding	The handbook shall facilitate onboarding of new design engineers by explaining company-specific drawing practices and processes
R64	Roles and onboarding	The handbook shall provide explanations suitable for design engineers with limited prior experience of working with drawings

R65	Roles and onboarding	The handbook shall include examples that are understandable to newly hired design engineers
R66	Language	The handbook shall describe the company's language policy for drawings
R67	Language	The handbook shall specify how drawings used in production shall be written in Swedish, including which fields may be in English still
R68	Language	The handbook shall specify how drawings used for purchasing shall be written in English
R69	Language	The handbook shall describe how Swedish and English may be used within the same drawing

Table 11: Requirement specification, including requirement ID, rationale, verification method, and priority

Req ID	Rationale	Verification method	Priority
R1	Information about drawing practices is currently not defined or scattered across sources	I,R	3
R2	Parts of the existing documentation was described as difficult to understand	I,R	2
R3	Designers currently use individual working methods, which lead to variation in drawings	I	2
R4	Interviewees indicated that current documentation is difficult to navigate because information is spread across multiple sources	I	2
R5	Visual examples support understanding of drawing practices	I	3
R6	Designers currently rely on personal experience to understand expected drawing formats	I, R	3
R7	Similar drawing errors were mentioned repeatedly during interviews	I, R	3
R8	Drawing practices vary between business segments, leading to inconsistencies in how drawings are created and interpreted	I	3
R9	Some designers described the CAD system Creo as complex to work with	I	1
R10	Company documentation is currently either in Swedish or English	I	1
R11	Existing documentation is not widely known among engineers	I, R	3

R12	It is not documented where templates are located	I	3
R13	The storage location of drawings is not clearly documented	I	3
R14	The relationship between drawings and data cards is not clearly documented, information is sometimes duplicated	I, R	2
R15	The relationship between drawings and operation list is not clearly documented, important information is sometimes missing	I, R	3
R16	The information contained in the parts list and BOM is not clearly documented	I, R	3
R17	Interviews revealed significant variation in how engineers create drawings	I, R	3
R18	The process for managing drawings across systems was described as unclear	I, R	3
R19	Incorrect projection methods have previously been used in some cases	I, A	3
R20	Inconsistent scaling can reduce readability of printed drawings	I, A	3
R21	Printed drawings primarily use the A3 format	I, R	1
R22	Automatically generated text may become too small when drawings are printed	I, A	2
R23	It was described that people place things according to personal preferences, creating confusion	I, R	2
R24	It was described that people place things according to personal preferences, creating confusion	I, R	2
R25	Insufficient views can make drawings difficult to understand	I	1
R26	Overcrowded drawings reduce readability	I	2
R27	Missing dimensions may cause errors and misunderstandings in production	I, R	3
R28	Some dimensions specified in drawings are difficult to measure in practice	I	3
R29	Different types of drawings are not clearly documented	I	2
R30	The distinction between production and customer drawings is not formally defined or applied in practice	I	2
R31	Some drawings lack information required for production	I, R	3

R32	Ambiguous drawings are leading to misunderstandings and additional communication	I	2
R33	Duplication of information increases the risk of inconsistencies when updates are made	I	2
R34	Designers have different awareness about standards, and apply them differently	I, A	3
R35	General principles for how tolerances should be defined are not clearly documented	I, R	3
R36	The Backer tolerance table is used in production, but its purpose is not clearly documented	I, A	3
R37	External suppliers may not understand the internal tolerance table	I, A	3
R38	Tight tolerances increase manufacturing cost and complexity	I	1
R39	Engineers reported uncertainty about the purpose of certain fields	I, R	3
R40	Important information is sometimes missing from the drawings, and fields are used inconsistently	I, R	3
R41	The production drawing review process lacks documented procedures	I, R	3
R42	The purchasing drawings are currently reviewed informally, and lacks documented procedures	I, R	3
R43	The workflow in Windchill is not clearly documented	I, R	3
R44	Designers reported uncertainty about what is evaluated during reviews	I, R	3
R45	Similar drawing errors were found repeatedly during drawing reviews	I, R	2
R46	The importance of drawing reviews is not clearly communicated	I	1
R47	The process for handling drawing changes is perceived as unclear, uncontrolled changes reduce traceability	I, R	3
R48	The revision and version numbering is not clearly documented	I	2
R49	The formal change management system is not always used in practice	I, R	3

R50	Different revision practices exist for different product types	I	1
R51	Small changes are sometimes implemented informally	I, R	2
R52	Older drawings are updated inconsistently. Some legacy drawings exist only as PDF files	I, R	2
R53	The role of the PLM system in drawing management is not clearly communicated	I	2
R54	Designers expressed uncertainty about PLM procedures. The separation of information between systems is not clearly documented	I, R	3
R55	The role of the ERP system in drawing management is not clearly communicated	I	2
R56	Information must currently be entered manually into the ERP system	I, R	3
R57	Drawings are used directly in production but are sometimes difficult to interpret. Production relies on printed drawings rather than digital models	I, R	3
R58	Unclear drawings lead to questions and misunderstandings in production	I	3
R59	The importance of drawings as the primary manufacturing reference is not always emphasized	I	2
R60	Purchasing drawings have different requirements than production, they are often developed through informal communication with suppliers	I, R	3
R61	Important manufacturing information is sometimes only communicated only through emails or other sources	I	2
R62	Roles in the drawing process are not clearly defined, leading to disagreements about responsibilities	I, R	3
R63	New engineers currently learn drawing practices mainly through experience	I, R	3
R64	Some engineers may lack prior experience of working with drawings	I, R	3
R65	Practical examples support learning for inexperienced designers	I, R	3
R66	Language rules are interpreted in different ways	I, R	3

R67	Production personnel may not be familiar with technical English terminology	I	3
R68	Suppliers are often international and require English documentation	I	3
R69	Mixed language use currently occurs without clear guidelines	I	2

Appendix E Final handbook

The final handbook developed as part of the project is presented in this appendix.

Engineering Drawing Creation and Management Handbook

Contents

1 Introduction

1.1 Purpose of the handbook

The purpose of this handbook is to define and standardize the practices for creating, managing and using technical drawings within the company. It provides guidelines that support the development of consistent and high-quality drawings by ensuring that all drawings are clear, consistent, and compliant with applicable standards and internal requirements.

By establishing a common framework, the handbook aims to:

- Reduce errors and misinterpretations in drawings.
- Improve communication between design, production, and purchasing functions.
- Ensure efficient handling of drawings and changes to drawings throughout their lifecycle.
- Support high product quality and traceability.

The intended outcome is a uniform approach to technical documentation that ensures drawings are reliable, easy to understand, and suitable for their intended use throughout the product lifecycle.

1.2 Scope

This handbook applies to all technical drawings created, modified, or used within the company. It covers the full lifecycle of drawings, from creation based on 3D models to their use, review, approval, and revision.

The handbook defines principles and guidelines for key aspects of drawing work, including:

- **Drawing layout and formatting**, including templates, sheet formats, and general presentation rules.
- **Views and projections**, including selection of views, projection methods, and scale usage.
- **Dimensioning practices**, including dimensioning methods, placement, and readability.
- **Tolerancing**, including general tolerances, geometrical tolerancing, and surface roughness.
- **Drawing content**, including required information, title blocks, parts lists, and references to related documentation.
- **Drawing review and approval**, including review processes and responsibilities.
- **Use of drawings**, including application in production and purchasing contexts.
- **Drawing management in systems**, including handling in CAD, PLM, and ERP, as well as change management.

This handbook does not include detailed, step-by-step instructions for working in specific systems (e.g. CAD, PLM, and ERP), nor does it cover broader processes beyond drawing-related activities. Some basic guidance on drawing creation in PTC Creo is provided in Chapter 4. For more detailed instructions, users are referred to external resources and the documents listed in Section 1.4.

1.3 Use of the handbook

The handbook establishes a common way of working with drawings to ensure a consistent, clear, and efficient approach across the organization.

It is primarily intended for design engineers and serves as a practical guide in their daily work. It is especially relevant for users who are new to the company as part of the onboarding process, or to users who have limited practical experience in working with drawings, providing support and understanding for how drawings are created and managed in practice.

The handbook may also be used by reviewers as guidance during the review and approval process. However, it is not intended to serve as a formal checklist for drawing approval, and compliance shall not be assessed solely based on this document.

In addition, the handbook may be used as a reference by personnel in production and purchasing, or any other department, who need to interpret drawing information and understand drawing structure and content.

1.4 Related documents

1.4.1 Internal documents

This handbook focuses on drawing-related practices. However, drawings are part of a larger product development and product lifecycle process which is covered in other company documents.

The following documents provide additional information on related processes and shall be used when relevant:

- **”Konstruktionshandbok” – BS-1436**
  Provides guidelines and standardized practices for design work, to support a consistent way of working across engineering activities.
- **”Produktutveckling rutin” – BS-1477**
  Describes the company’s product development process, including planning, execution, documentation, and review of product development activities.
- **”Checklista för konstruktionsgranskning”- A-40075**
  Provides a checklist for self-review during design work, supporting verification of drawings and product documentation before formal approval and release.
- **”Teknisk Information” – Backer business managementsystem**
  Provides technical data for element design, including material selection, material properties, and detailed design parameters.
- **”Elementkonstruktion” – BS-1437**
  Provides supporting data for the design of tubular heating elements, including general and element-specific information such as tables, formulas and diagrams.
- **“Engineering Change process” – R-40040**
  Describes the company’s process for engineering changes, including initiation, evaluation, approval, and implementation, as well as requirements for updating product documentation.

1.4.2 External documents

The systems used for drawing creation and management include PTC Creo (CAD), PTC Windchill (PLM), and Epicor ERP (ERP). The CAD system is used for creating 3D models and technical drawings, the PLM systems is used for managing drawings, revisions, and approval workflows, and the ERP system is used for production, purchasing, and management of product-related data.

The role and use of PLM and ERP systems in drawing management are described in Section 8. The use of CAD systems in drawing creation is described throughout Section 4.

Detailed, step-by-step instructions for how to use these systems in practice are not included in this handbook. Comprehensive guidelines, user documentation, and support material are available through respective system providers’ official websites ad shall be used when guidance on system functionality or usage is required. Some support material and links for Creo and Windchill are available through the Backer AB tab within the Creo interface.

2 Overview of Drawing Practices

2.1 Role of drawing in the company

Technical drawings are a central part of the product definition. During development, the product is defined through activities such as requirement specification, analysis of previous designs, and risk assessment. These activities form the basis for the design work. This description is general, detailed product development workflows are described in the document *Produktutveckling rutin.*

Based on the agreed specification and the outcomes of the preceding development activities, a 3D model is created or adapted, often using existing designs or components as a starting point. Based on the 3D model, the drawing and related product structure, such as the bill of materials (BOM), are then created.

The drawing defines the geometry, dimensions, tolerances, and general specifications of the product and serves as the authoritative source for how the product is intended to be realized. In case of ambiguity, the drawing is the governing document for product definition. It represents the agreed definition of the product between the company and the customer and forms the basis for manufacturing, purchasing, inspection and verification of the final product. The drawing is a controlled document, meaning that only approved versions are valid and changes are managed through a defined revision process. The drawing shall be approved by the customer, including any changes made to it. Further guidance on completeness and consistency of drawings and related documents is provided in Section 5.2.

As part of the development process, the drawing is reviewed and approved internally to ensure that it fulfils both customer and company requirements.

The drawing also serves as a key communication tool between design, production, purchasing and other departments. It shall provide clear and unambiguous information that supports interpretation and decision-making throughout the product lifecycle. In on-site production, the drawing is used directly as a reference during manufacturing. As such, the drawing functions as a common technical language across different functions. It also supports reuse of existing designs and can be used as a basis when developing similar products.

2.2 Importance of standardized drawing practices

Standardized drawing principles ensure that technical drawings are clear, consistent, and easy to interpret. By following the guidelines in this handbook, drawings are created and managed in a uniform way, supporting effective collaboration and reliable use across the organization.

Following standardized drawing principles:

- **Enable clear communication**
  Provide a common visual language using standardized symbols, dimensioning, and layouts, allowing everyone to interpret drawings consistently across departments, functions, and global locations.
- **Reduce misunderstanding and rework**
  Following a uniform way of working reduces the risk of misinterpretation, design errors, and rework, saving time and avoiding unnecessary corrections.
- **Improve quality and efficiency**

Support faster creation and use of drawings by applying consistent templates, symbols, and conventions. In CAD environments, these standardized approaches enable structured workflows and improve overall efficiency.

- **Support accurate manufacturing**
  Use standardized notations to clearly communicate design intent, ensuring that components are produced according to specification.
- **Ensure traceability and documentation control**
  Standardized practices recommend a structured organization of information in title blocks and revision tables, providing metadata that enables drawings to be traced and supports consistent documentation of design changes over time.

2.3 Applicable standards

Technical drawing are largely governed by standards published by the International Organization for Standardization (ISO). These standards define key aspects of drawing creations, including presentation, dimensioning, tolerancing, and layout, and provide a common basis for consistent and unambiguous interpretation.

Relevant ISO standards shall be followed when creating drawings. In addition, company-specific requirements and practices complement these standards to ensure a consistent way of working within the organization.

The following standard frameworks define the overall system and fundamental aspects of drawing creation:

- **ISO GPS (Geometrical Product Specifications)** - Provides the overall system for specifying product geometry, including size, form, orientation, location, and surface characteristics.
- **ISO 128** - General rules for drawing presentation (views, lines, sections).
- **ISO 129** - Rules for dimensioning and indication of dimensions.

These frameworks are complemented by supporting standards that define specific aspects of drawing content and layout

- **ISO 2768** - General tolerances
- **ISO 1101** - Geometrical tolerancing
- **ISO 5456** - Projection methods
- **ISO 5457** - Sheet formats and layout
- **ISO 7200** -Title block content
- **ISO 3098** - Lettering
- **ISO 21920** - Surface roughness
- **ISO 5455** - Scales
- **ISO 7573** - Parts list

Guidance on the application of these standards is provided in the relevant sections of this handbook.

2.3.1 Deviations from standards

Relevant ISO standards shall be followed when creating drawings. Deviations from ISO standards shall only be made through company-specific requirements and practices defined in internal documents. Where company-specific requirements or practices define solutions that differ from external standards, these shall take precedence over the corresponding standard.

2.4 Types of drawings

2.4.1 Types of drawings based on content

The main types of drawings used are detail drawings, assembly drawings, and combined drawings.

2.4.1.1 Detail drawing

Detail drawings shall provide all information required to manufacture a part. This shall include, where applicable:

- Dimensions
- Tolerances
- Material specifications
- Surface requirements
- Required treatments

A detail drawing may represent a single part or a group of similar parts. For similar parts, a collective detail drawing may be used, where common geometry is shown once and variations are defined in a table, for example for bolts or nuts.

Detail drawings form the basis of manufacturing and process planning.

2.4.1.2 Assembly drawing

Assembly drawings show how multiple components are fitted together for a product or sub-assembly. It shall contain all information required for assembly, but generally includes limited dimensional information.

Assembly drawings may be presented in different forms:

- **Assembly drawing** – Shows a specific assembly or sub-assembly consisting of defined components.
- **Collective assembly drawing** – Shows a group of similar assemblies in a single drawing, with common structure but minor variations (e.g. size or configuration).

Assembly drawings shall be accompanied by a parts list. The parts list shall identify all components and their quantities, see Section 5.4. for further details. It may be included in the drawing or provided as a separate document.

Standard company templates are available for both assembly and detail drawings, as described in Section 4.2.1.

2.4.1.3 Combined drawing

A combined drawings may include both assembly information and detailed dimensions for individual components, together with a parts list. This type of drawing may be used for simpler products to reduce the need for separate drawings.

2.4.2 Types of drawings based on use

In addition to the classification of drawings based on content, see Section 2.4.1, drawings can also be distinguished based on their intended use.

A single drawing format is used across all applications within the company. However, drawings shall be distinguished based on their intended use. The two main categories are production drawings and customer drawings. The purpose of the drawing shall determine its content, so that unnecessary information is avoided.

2.4.2.1 Production drawings

Production drawings are used internally to support operators in performing the required operations. These drawings shall only include information necessary for production. Information not directly relevant for manufacturing, such as the overall application of the product, is generally not required. The required content shall be determined based on the product and how it is intended to be manufactured, in line with principles of the production department.

2.4.2.2 Customer drawings

Customer drawings are used for communication with customers or external suppliers. When a customer provides a drawing, the design engineer shall assess whether specified requirements, such as tolerances, can be fulfilled based on internal capabilities, and revise the drawing accordingly to reflect achievable requirements. When drawings are created for suppliers, they shall define the requirements that the supplier must meet. In both cases, they shall include relevant technical information, such as dimensions and tolerances, and shall include all information necessary to define the product or requirements for external communication.

3 Roles and responsibilities

3.1 Design engineers and reviewers

3.1.1 Design engineer

The design engineer is responsible for creating the drawing and ensuring that it is complete, correct and suitable for its intended use.

This includes:

- Defining all required information, such as dimensions, tolerances, and specifications, in accordance with agreed customer specifications and company requirements.
- Ensuring compliance with applicable ISO standards and company requirements, for example Technical Information (TI), where defined limits and values shall not be exceeded.
- Ensuring that agreed customer requirements and company requirements are documented and available to relevant stakeholders, including internal departments and suppliers.
- Ensuring that correct and required information is registered and consistent across all relevant systems (e.g. PLM, ERP).
- Ensuring that the drawing can be correctly interpreted by production and purchasing.

The design engineer retains full responsibility for the drawing content, including any errors or missing information, regardless of review and approval performed by others.

3.1.2 Reviewer and approver

The reviewer verifies that the drawing meets the required quality before release.

This includes:

- Checking correctness and completeness.
- Verifying compliance with standards and company requirements.
- Identifying errors and missing information.

A drawing may be sent for review to receive feedback without requesting approval. Reviewers act as a supporting function in the design process by providing feedback and identifying potential issues.

Approval is a separate step and provides formal confirmation that the drawing is ready for release.

- Approval shall be performed by designated reviewers with the required authority.
- A design engineer cannot approve their own drawing, as this is restricted by the system to ensure an independent and objective review.
- For simpler drawings, review and approval may be performed by the same person.

Both review and approval are performed to ensure drawing quality before release.

The reviewer and approver depend on the type of drawing:

- Customer drawings are reviewed and approved by designated designers with the required authority, with a focus on design correctness and compliance with standards and agreed requirements
- Production drawings are reviewed and approved by a designated reviewer with manufacturing knowledge. The responsibilities of this reviewer are described in Section 3.2.1.

The detailed review and approval process is described in Section 7.

3.2 Production and purchasing

3.2.1 Production

The production department is responsible for planning and executing the manufacturing of components, based on the information defined in the drawing.

This includes:
• Determining appropriate manufacturing methods and processes.
• Creating and maintaining operation lists.
• Manufacturing components in accordance with the drawing and defined processes.
• Identifying and communicating issues related to manufacturability or design.

As part of this responsibility, production supports the design process by reviewing drawings from a manufacturing perspective.

This includes:

- Assessing manufacturability and feasibility using available production methods.
- Identifying errors, missing information, or unclear specifications
- Identifying production-related risks or issues.

Production drawings shall be reviewed and approved by the designated reviewer from the production department.

The production reviewer acts as a link between design and production by contributing practical manufacturing knowledge during the review. Additional review by design engineers may be performed when needed but is not required for approval.

Feedback from production shall be considered by the design engineer and incorporated where necessary to ensure that the design is suitable for manufacturing.

3.2.2 Purchasing

The purchasing department ensures that drawings are suitable for external suppliers.

This includes:

- Verifying that all supplier requirements are defined.
- Ensuring that the drawing is complete and unambiguous for external use.
- Communicating with suppliers regarding technical requirements.

Feedback from purchasing and suppliers shall be considered by the design engineer and incorporated where necessary to ensure that the drawing is suitable for procurement.

4 Drawing creation

4.1 Workflow for creating drawings from 3D models

The creation of technical drawings in PTC Creo shall follow a structured workflow to ensure consistency and clarity. It should be noted that there are multiple ways to perform tasks within the CAD system. The approach described here only represents a basic workflow.

This section provides general guidance on drawing creation in the CAD environment, including commonly used tools and methods. The subsequent sections of Chapter 4 define requirements for projection methods, view selection and placement, dimensioning principles, tolerancing, and surface specifications, and do not describe how the majority of these tasks are performed in the CAD system. Detailed instructions for the use of CAD tools shall be obtained from PTC online documentation.

The overall workflow includes the following key steps:

Model completion → Drawing creation → View creation → Dimensioning → Addition of tolerances and notes → Review → Approval.

Drawings are associative to the 3D model, meaning that changes to the model will propagate to the drawing and shall be reviewed before release.

4.1.1 3D model preparation

Drawings are generated from completed 3D models. All relevant geometry shall be defined prior to drawing creation. When creating a 3D model and its associated drawing, both files shall be assigned the same file name corresponding to the article number, in accordance with the established naming conventions. Further guidance regarding naming conventions is provided in 8.1.4.

Material properties shall be assigned to bodies within a part using the material directory available under the *Design Item* definition. The material database includes different materials and their mechanical and thermal properties such as Young's modulus, Poisson's ratio, density, stress–strain relationships, and thermal characteristics.

Before creating a new drawing, relevant model and drawing information shall be completed in the *Parameters* tool in the *Tools* tab in Creo. This information is used to populate title block fields and other drawing information. Further description of required parameters is provided in Section 5.3.

4.1.2 Drawing setup using templates

A new drawing is created based on an existing model and shall utilize predefined company templates. This ensures that drawings comply with company standards without requiring manual setup.

Company templates are available and shall be selected based on required sheet size and format, as described in Section 4.2.1.

4.1.3 Creation of primary view

Once a new drawing has been created the primary view is created using the *General View* function in the *Layout* tab.

The orientation of the view is selected from predefined orientations (e.g. front, top, right) within the *View Type* category. The selected orientation shall:

- Clearly represent the geometry.
- Minimize the use of hidden lines.
- Reflect functional or manufacturing orientation where applicable.

4.1.4 View display and representation

The visual representation of views is controlled through the *Drawing View*, which becomes available when a view is created or selected. This window contains the primary settings for view configuration, including orientation (*View Type*), display style (*View Display*), and scale, as seen in Figure 1.

The selected display style shall support clarity. For standard views, hidden line or no hidden line representations are typically used. Shaded representations may be used for isometric 3D views to improve visual understanding.

The scale of each view is defined within the *Drawing View* window. The default scale defined in the template shall be used in most cases. This ensures consistency across the drawing and reduces the need for manual adjustments. Custom scales may be applied, when necessary, for example in detail views or when the geometry cannot be clearly represented at the default scale.

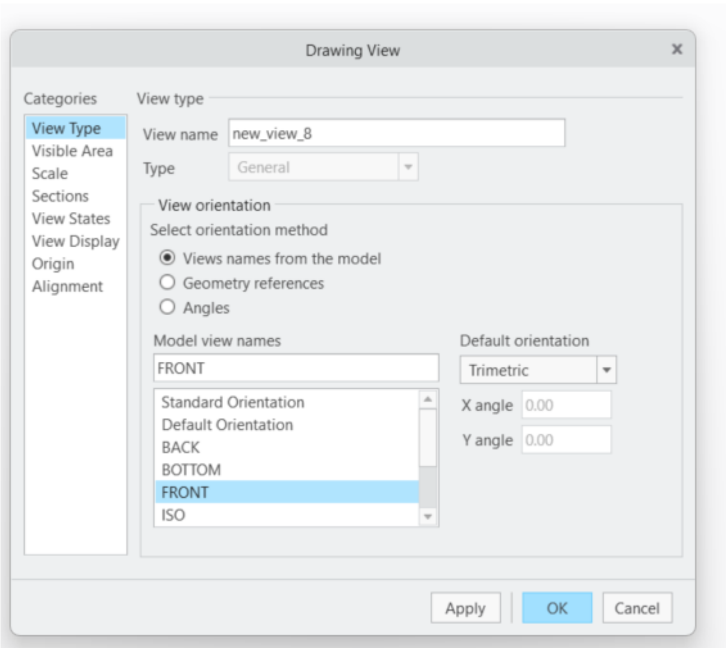

Figure 1: Drawing view window in PTC Creo.

4.1.5 Generation of additional views

Additional views are created using the *Projected View* function. Projected views are placed relative to the primary view and are automatically aligned in accordance with the selected projection method.

First angle projection is defined as default by the drawing template and shall not be modified. In first angle projection, views are positioned opposite to their logical direction relative to the primary view, for example the top view is placed below the primary view.

Projected views shall be used in preference to creating independent views, as they ensure consistency and alignment.

Isometric views, i.e. a 3D representation of the component, may be added using the *General View* function to provide a visual representation of the component. Custom orientations for such views may be defined in the model environment using the *View Manager* and saved for reuse in the drawing. Isometric views are intended for visualization purposes only and shall not replace dimensioned views.

4.1.6 View placement and layout

Views are positioned on the drawing sheet in CAD using either coordinate-based placement via the *Origin* settings in the *Drawing View* window, or by manual positioning.

Manual positioning is performed by temporarily disabling the *Lock View Movement* option in the *Layout* tab, after which views can be repositioned by dragging.

Although the CAD system allows free placement, views shall:

- Remain aligned horizontally and vertically.
- Be spaced consistently.
- Avoid overlapping or overcrowding.

When a primary view is repositioned, associated projected views remain aligned. However, repositioning may be required to maintain consistent spacing and a balanced layout on the drawing sheet.

4.1.7 Dimensioning

Dimensioning is performed in the *Annotate* tab and may be created manually or by using *Model Annotations*.

Manual dimensioning is created using the *Dimension* tool in the *Annotate* tab, where the appropriate reference type is selected and corresponding geometric references (e.g. edges, surfaces, or axes) are defined. The dimension is then placed in the desired location within the view.

Model Annotations are accessed by selecting a view, where all associated model dimensions can be reviewed and selectively displayed. This allows predefined dimensions from the 3D model to be reused instead of being recreated manually.

The use of model annotations is recommended where appropriate, as it enables reuse of dimensions defined in the 3D model and improves consistency between model and drawing. In practice, a combination of both methods is typically used, where model annotations are supplemented with manually added dimensions when required.

Regardless of method, all dimensions shall be reviewed by the designer to ensure correctness, completeness, and clarity.

Dimensions shall be arranged to maintain readability, with consistent spacing and without unnecessary duplication.

4.1.8 Addition of tolerances and notes

Tolerances and notes are added in the *Annotate* tab using annotation tools such as notes, symbols, and geometrical tolerancing features.

Numerical tolerances are applied by selecting a dimension, after which tolerance values can be defined in the *Dimension* tab.

4.1.9 Finalization

The drawing is completed by verifying:

- Correct view layout and spacing.
- Appropriate scale usage.
- Complete and clear dimensioning.
- Compliance with applicable standards.

After completion, the drawing shall be checked into the PLM system and stored in the appropriate library according to the applicable project, and business area. Further information regarding management in the PLM system is provided in section 8.1.

4.2 Templates and formatting

4.2.1 Drawing template

The drawing template defines the standardized layout used in CAD drawings. It contains predefined areas that organize graphical and administrative information.

A range of different company specific drawing templates are available in Creo, under the *Backer Darwing* tab, when a new drawing has been created. The drawing template controls predefined drawing settings such as sheet format, title block layout, projection method, default scale, and certain drawing display settings. These settings shall not be changed manually unless required by an approved drawing procedure.

Different templates are provided depending on the type of drawing. For the first sheet, templates are available for both **assembly drawings** and **detail drawings**. Assembly drawing templates include a parts list, while detail drawing templates do not.

For drawings consisting of multiple sheets, separate templates are used for subsequent pages. These are referred to as **N-assembly** and **N-detail** templates and are used for the second sheet and onwards. These templates do not include a parts list, regardless of drawing type.

An overview of the available drawing templates is shown in Figure 2.

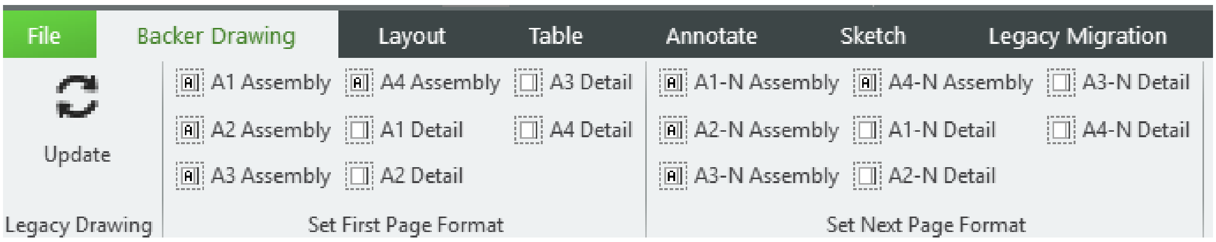

Figure 2: Overview of available drawing templates.

An example of an A3 Assembly template is shown in Figure 3, illustrating the main fields included in the template, such as the title block, parts list, revision field, and drawing field.

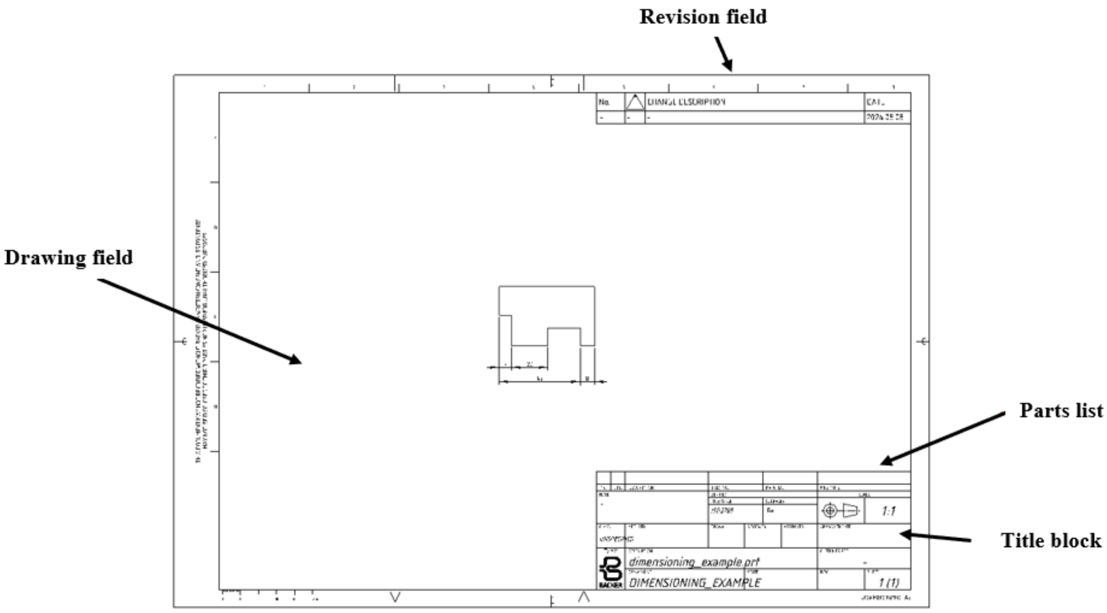

Figure 3: A3 Assembly drawing template showing the drawing field, revision field, parts list, and title block.

4.2.1.1 Drawing field

The drawing field contains the graphical representation of the component or assembly. All views, dimensions and annotations required to define the design is placed in this area.

Additional instructions may also be included to specify manufacturing requirements and ensure that the component conforms to the intended design. For recommendation for placement of such information, see Section 4.3.6.

4.2.1.2 Revision field

The revision field contains a record of changes made to the drawing. When a modification is introduced, the previous value or information is recorded in the revision field together with an identifying number. This number corresponds to a unique reference assigned through the change management system, enabling traceability between the drawing update and the approved change request. See Chapter 9 for further details on the change management process.

The corresponding change in the drawing field shall be marked with a revision symbol (e.g. a triangle) placed adjacent to the updated information when the change is directly related to specific geometry, dimensions, or annotations, linking the change to its description and ensuring traceability. An example of the revision field, and the corresponding change marked in the drawing is illustrated in Figure 4 and Figure 5.

No.	△	CHANGE DESCRIPTION	DATE
1953	B	Changed from press to solder nipple	2024-03-05

Figure 4: Revision field showing change reference number, description, and date.

	No.	QTY.	DESCRIPTION	PART NO.	MATERIAL	MFG. NOTE
	5	2	Nut	40482319	EN 1.4305	Pr 18.6
B	4	2	Nipple	40544903	AISI 303	
	3	2	Gasket	51326903	Micalit_F	27x18,8x1,5
	2	1	EL 1.4404 1500/230 140 L591	5052159001	EN_1.4404	591±10
	1	2	Collar washer	60070201	Brass_Ni_pl	NV 10

Figure 5: Parts list with revision symbol (triangle) indicating the modified item, corresponding to the entry in the revision field shown in Figure 4.

4.2.1.3 Title block

The title block contains identification and administrative information for the drawing. Required information shall be entered according to Section 5.3.

4.2.1.4 Parts list

The parts list contains information about components included in an assembly. Each item is assigned a position number that corresponds to its graphical representation in the drawing field. For more information, see Section 5.4.

4.2.2 Format and sheet size

Drawing sheet sizes and formats shall follow ISO 5457. The drawing shall be created on the smallest sheet size that permits sufficient clarity and readability. As a general guideline, A3 format should be used. Other sheets sizes may be used when required. The designation of the sheet size is placed at the bottom right-hand corner of the drawing sheet.

4.2.3 Lettering and text size

Lettering, i.e. the text used to convey non-graphical information such as notes, dimensions, and titles, shall be applied in accordance with ISO 3098.

Text heights shall be selected from the following values: **1.8 mm, 2.5 mm, 3.5 mm, 5 mm, 7 mm, 10 mm, 14 mm, and 20 mm**.

The purpose of standardized lettering is to ensure that all non-graphical information is clear, consistent and legible, enabling correct interpretation of the drawing.

The following text heights are provided as a general recommendation and may vary depending on the sheet size, scale and purpose of the drawing.

- 2.5 mm for descriptive text, general notes, and dimensions
- 3.5 mm for labels and names of structures
- 5.0 mm for main titles
- 7.0 mm for extra-large text or emphasized information

The selected text height shall ensure that all information is clearly readable both digitally and when the drawing is reproduced or printed. It is the responsibility of the user to verify that the chosen text sizes provide sufficient readability for the intended use.

Lettering shall be consistent in style, size, proportions and spacing throughout the drawing. Uppercase lettering should be used for text on drawings to enhance clarity and reduce the risk of misinterpretation.

4.3 Views, projections and layout

4.3.1 Projection method

Projection methods used in technical drawings are covered by ISO 5456, to provide a standardized way of representing three-dimensional objects on two-dimensional media. Technical drawings are created using orthographic representation, where a three-dimensional object is described using multiple two-dimensional views. The projection method defines how these views are arranged relative to each other, in order to ensure consistent arrangement and interpretation of views.

First angle projection, also known as European projection, shall be used for all drawings. The projection method, shall be indicated in the drawing title block using the standardized symbol, see Figure 6.

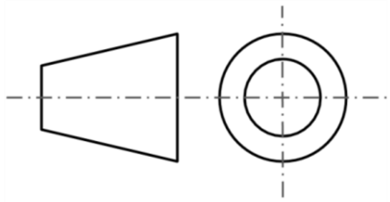

Figure 6: Symbol for first-angle projection

The projection method is defined by the drawing template in the CAD system. First-angle projection is therefore applied automatically when projected views are created from the principal view. An understanding of the projection method is however required for correct interpretation of drawings.

In first-angle projection, views are arranged relative to the principal view and are placed on the opposite side from where they are observed. For example, the top view is placed below the front view, and the right-side view is placed on the left. The principal view, typically the front view, shall be selected to show the object in its most informative orientation, such as its functional, manufacturing or mounting position. This is illustrated in Figure 7.

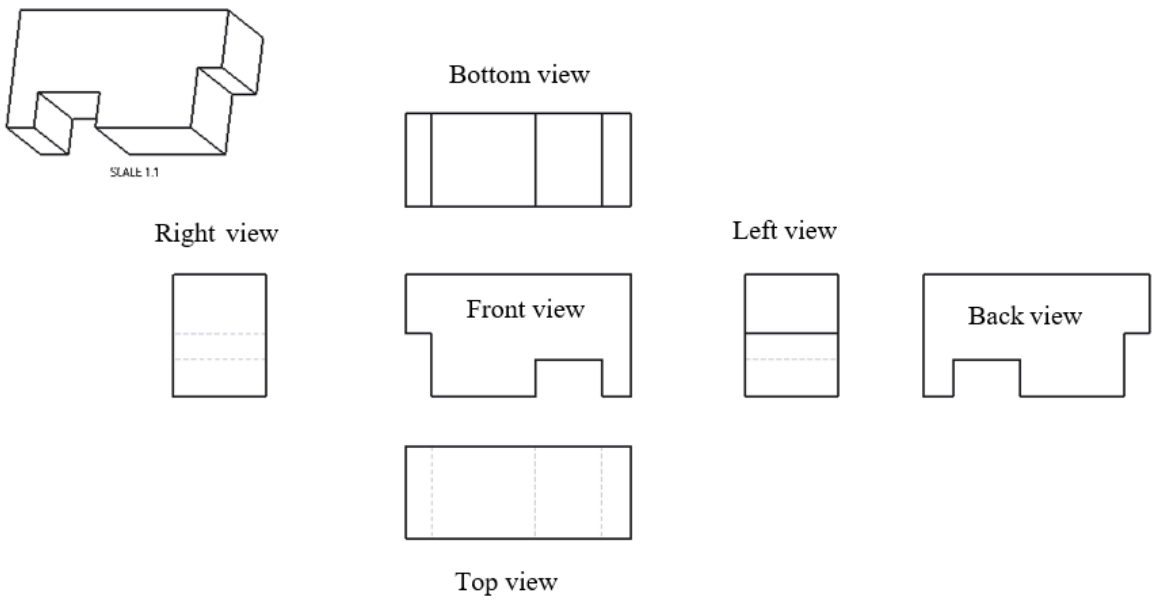

Figure 7: Illustration of view placement according to first-angle projection, showing the relationship between the different views of a component. An isometric view is included for reference.

The principal view shall be used as the main reference. The selection and representation of views are described in Section 4.3.3.

Isometric views may be included to support understanding of the object geometry. They provide a three-dimensional visualization of the object as it would appear to the observer and can aid interpretation of orthographic views, but shall not replace them. See for Figure 7 an example of an isometric view.

4.3.2 Line types and line widths

The interpretation of technical drawings relies on standardized line types in accordance with ISO 128-2. These define how different features are represented, such as visible edges, hidden features, center lines, and other graphical elements. The main line types used in technical drawings are summarized in Table 1.

Table 1: Line types, appearance, and typical use in technical drawings, based on ISO 128-2.

Line type	***Apperance***	***Use***
Continuous wide line		Visible contours (edges and outlines)
Continuous narrow line		Dimension, extension and auxiliary lines
Dashed narrow line		Hidden contours (not visible in the view)
Dashed wide line		Hidden contours (not visible in the view)
Long-dashed dotted narrow line		Centre lines and lines of symmetry
Long-dashed dotted wide line		Position of cutting planes

Different line types convey specific information about the geometry of an object and shall be interpreted consistently across all views.

4.3.2.1 Line widths

A standardized set of line widths is defined (0.13 mm, 0.18 mm, 0.25 mm, 0.35 mm, 0.5 mm, 0.7 mm, 1 mm, 1.4 mm, and 2 mm), and values shall be selected based on the type, size, and scale of the drawing. In practice, two line widths are typically used within a drawing:

- **Wide lines**
- **Narrow lines**

The terms wide and narrow refer to relative line widths within the drawing. A ratio of approximately 1:2 shall be maintained, where narrow lines are drawn at about half the width of wide lines. A third category, extra-wide, exists, following a 1:2:4 ratio, but is rarely used in mechanical drawings.

4.3.2.2 Interpretation

Line types are particularly important when interpreting multiple views. The same feature may be represented differently depending on the viewing direction. For example, a feature that is visible in one view may appear as a dashed line in another.

Corresponding features in different views are aligned, meaning they are positioned at the same height or location across views, even if their representation differs.

In the CAD system, line types are generated automatically based on predefined settings and shall not be modified manually. An understanding of their meaning is nevertheless essential for correct interpretation of drawings.

4.3.3 Use of views

4.3.3.1 Selection of views

The principal view, usually the front views, shall be selected to show the object in its most informative orientation, such as its functional, manufacturing, or mounting position, in accordance with ISO 128-3.

Additional views, sections, or cuts shall be selected based on the object geometry to clearly represent all relevant features, while keeping the number of views to a minimum and avoiding unnecessary repetition of details.

Views should be chosen to minimize the use of hidden lines. Where internal features are difficult to interpret, sectional views shall be used instead.

4.3.3.2 Sections and cuts

Sectional views shall be used to improve clarity and reduce the use of hidden lines. A section represents the object as if it were cut along a defined plane, revealing internal features that would otherwise not be visible.

The position of the cut shall be indicated by a cutting plane line, which is drawn as a long-dashed dotted wide line, with thickened ends and arrows indicating the viewing direction. The cutting plane shall be identified by capital letters at each end (e.g. A), and the corresponding section shall be labeled using the same designation (e.g. A–A).

Cut surfaces shall be indicated by hatching lines, drawn as thin continuous lines, typically at an angle (e.g. 45°). Areas of the same component shall be hatched in the same way, while adjacent components shall be hatched using different directions or spacing.

As a general principle, dimensioning of hidden contours should be avoided. Sectional views are therefore preferred for representing internal features such as holes (e.g. countersinks, counterbores, and blind holes). An example of a sectional views illustrating this is found in Figure 8. Hidden lines are consequently generally not drawn in sectional views.

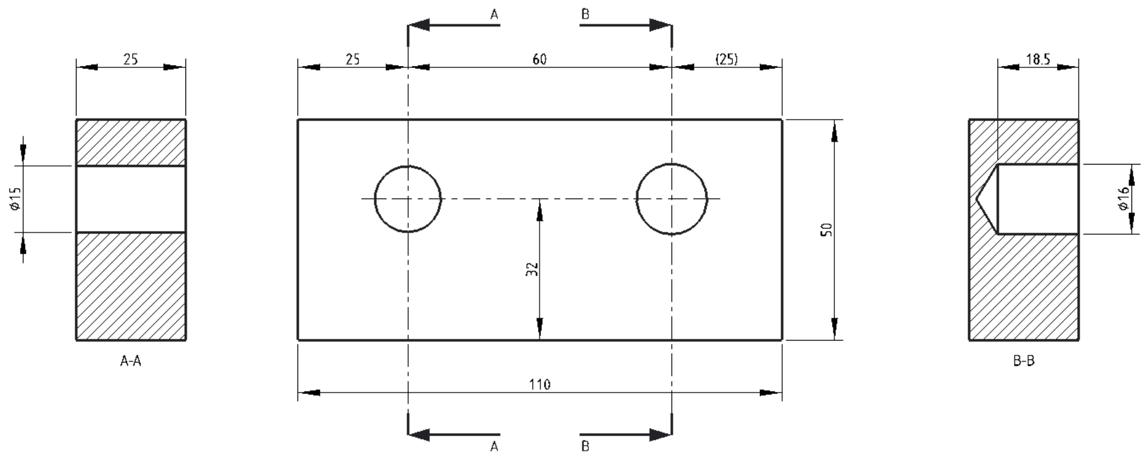

Figure 8: Example of sectional views (A-A and B-B), showing a through hole and a drilled hole.

Different types of sectional representations may be used.

Sections shown as separate views:

- **Full section** - The object is completely cut along a single plane
- **Offset section** - The cutting plane is bent to pass through multiple features (e.g. several holes), and the bends are indicated by thicker line segments, allowing them to be shown in a single section view.

Sections shown within an existing view:

- **Half section** - Used for symmetrical objects, where one half of the view is shown in section and the other half as an external view. Each half is interpreted independently.
- **Local section** - Only a limited area of the object is sectioned within the same view to reveal specific internal features, avoiding the need for a separate section view.

To create a simple sectional view in Creo, open the *View Manager* in the model and create a new section under *Sections*, assigning it a name (e.g. A, B). In the drawing, select the view to be sectioned and open the *Drawing View Manager*. Under *Sections*, add a new 2D cross-section using the previously defined section. Reference arrows can be added from the *Layout* tab by selecting *Arrows*, then first selecting the section view and finally the principal view.

4.3.3.3 Simplified views

To improve clarity and reduce unnecessary detail, simplified representations may be used where appropriate.

- **Half or quarter view** – Used for symmetrical objects, where only a portion of the geometry is shown, as the remaining part can be understood from symmetry. This reduces drawing space.
- **Partial view -** Used to show specific features that do not require a full view. The view is limited to the area of interest and bounded by a continuous narrow zigzag line.
- **Auxiliary view -** Used to represent features not parallel to the main projection planes. The view is taken from an oblique direction, and the viewing direction shall be indicated by arrows.

To create a half or partial view in Creo, open the *Drawing View Manager* and under *Visible Area* select the desired *View Visibility* option, such as full, half, or partial view.

4.3.3.4 Identification of views (arrow method)

The arrow method shall be used for views that are not placed according to the standard projection arrangement, as well as for section views and other special views. These views shall be identified using a capital letter placed next to a reference arrow in the principle view, indicating the viewing direction, with the same letter repeated on the corresponding view. An example with identification of sectional views can be found in Figure 8.

The arrow method allows views to be positioned independently of standard projection conventions, as the viewing direction is explicitly indicated. However, views shall still be arranged according to first-angle projection, as unrestricted placement may reduce clarity. The arrow method, may also be applied to views arranged according to first-angle projection where additional clarity is required.

4.3.4 Scale selection

The use and designation of scales in technical drawings shall follow ISO 5455. A scale expresses the ratio between a dimension shown on the drawing and the corresponding real dimension of the object.

A scale of 1:1 represents full size. Enlargement scales are expressed as X:1, while reduction scales are expressed as 1:X. The scale applied to the drawing shall be indicated in the title block, and is denoted as SCALE X:X. The word SCALE may be omitted if the meaning is clear and cannot be misunderstood. If multiple scales are used, the main scale shall be stated in the title block, while additional scales shall be indicated near the relevant view, detail, or section, as in Figure 9.

Figure 9:Example of a detail for which the scale differs from the main scale

The recommended scales, according to ISO 5455, shall be used to ensure consistency:

- Enlargement: 2:1, 5:1, 10:1, 20:1 and 100:1
- Reduction: 1:2, 1:5, 1:10, 1:20, 1:100

When a larger or smaller scale is necessary, the scales may be extended by factors of 10. In exceptional cases, intermediate scales may be applied if required for functional reasons.

The scale shall be chosen based on the size and the complexity of the object. The selected scale shall be large enough to ensure that the information is presented clearly and is easy to interpret. Features that cannot be clearly represented at the main scale shall be shown in detail views or sections using a larger scale. An example of a detail view is found in Figure 10. For small objects shown at a large scale, an additional simplified full-size view may be included to provide an overall reference of the object's form.

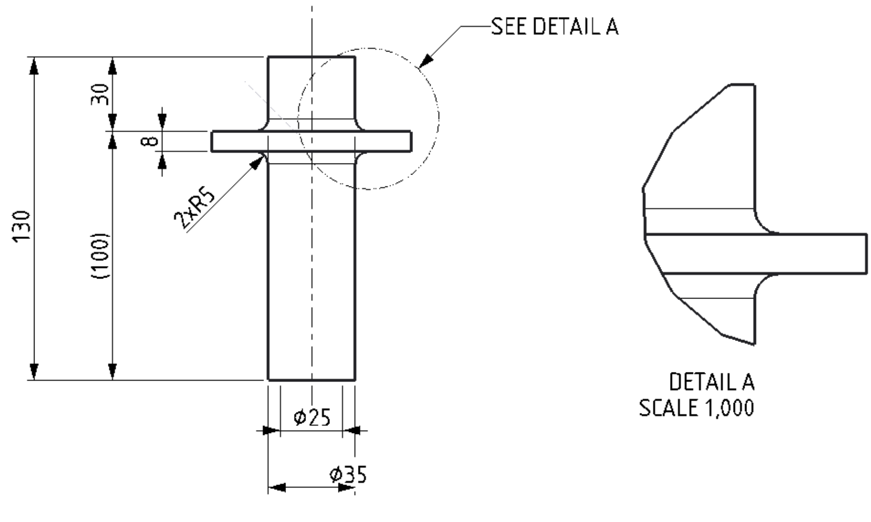

Figure 10: Example of a detail view.

Use of scale in practice

Scale is used to control the layout and readability of the drawing. It determines how views, dimensions, and text are arranged on the sheet so that the information can be interpreted correctly.

Dimensions shall always be taken from stated values, and not by measuring from the drawing. The scale of a printed or reproduced drawing may differ from that of the original drawing, which can alter the size of the output.

Drawings should be printed on the intended sheet size and preferably at 100% scale in order to preserve the defined layout and scale. The scale used shall be large enough to ensure that the drawing is clear and readable when printed. Settings such as *"fit to page"* can result in a scaled print where the stated scale is no longer accurate, and should be avoided where possible.

4.3.5 Placement of views

This section describes how views are placed on the drawing sheet relative to the principal view. Views shall be arranged to provide a clear and logical layout on the drawing sheet. The arrangement shall follow the selected projection method, with views aligned relative to the principal view.

Views shall be positioned to maintain consistent spacing and alignment, ensuring that corresponding features can be easily identified across views.

The layout shall avoid overlapping views and unnecessary crowding. Where the required views cannot be clearly arranged on a single sheet, additional sheets shall be used. Additional sheets are identified in the title block field "Sheet" using the format 1(2), 2(2), etc., where the first number indicates the sheet number and the second the total number of sheets, ensuring that the correct sheet order can be identified, particularly when printed.

4.3.6 Use and placement of textual elements

Textual elements in a drawing, such as instructions and notes, refer to free text placed in the drawing field. These shall be placed in a clear and structured manner to support readability and correct interpretation.

Text shall be kept concise, unambiguous and relevant. Avoid unnecessary wording and ensure that each note serves a clear purpose. Avoid duplication of information, by not stating information that is already defined elsewhere in the drawing or in another system, as this may lead to inconsistencies and errors, as explained further in Section 5.2.

4.3.6.1 General principles

- Avoid overlap with geometry, dimensions, or other text.
- Group related information together.
- Keep sufficient spacing to maintain readability.
- Use appropriate font size to ensure readability. See Section 4.2.3 font size recommendations.
- Information that applies to the entire component shall be placed in a dedicated area, separated from the geometry (e.g. near the title block).
- General notes may also be placed in the notes field of the title block when appropriate.
- Notes that are clearly related to a specific feature shall be placed close to the relevant geometry or connected using leader lines.

4.3.6.2 Placement recommendations

The following recommendations describe typical placement for commonly occurring textual elements in drawings. Consistent placement improves readability and makes drawings easier to interpret. Similar types of information should follow the same principles to maintain a clear and predictable structure.

The placement of text shall consider both clarity and the amount of space required. Larger elements shall be placed in defined areas to avoid overcrowding the drawing the drawing.

- Bend charts shall, where possible, be placed in the upper right corner of the drawing.
- A note containing information that applies to the entire component, including heat treatment, sealing material, temperature limits, and inactive length, shall be placed above the parts list when possible.

4.4 Dimensioning

Dimensioning defines the size, geometry, and spatial relationships of a component and shall ensure that the design can be manufactured, assembled and inspected.

Only the dimensions necessary to define the nominal geometry shall be shown. Each dimension shall be indicated once using a dimension line and a dimension value, in accordance with ISO 129-1. Duplicate dimensions shall be avoided unless clearly identified as auxiliary dimensions.

Dimensions shall be used together with other specifications, such as tolerances and surface requirements, to fully define the product. The drawing is the authoritative source for all dimensions, and the geometry shall be defined by the specified dimensions, not by measuring the drawing.

Basic terminology:

- **Auxiliary dimension –** A dimension given for information only, indicated in parentheses. It shall not be used for manufacturing or inspection and shall not be toleranced.
- **Theoretically exact dimension** – A dimension indicated by a rectangular frame, defining an exact value. It is not toleranced, and any permissible variation is specified using geometrical tolerancing.

4.4.1 Dimensioning principles

The following principles shall be applied:

- **Completeness –** All dimensions necessary to define the geometry shall be provided.
- **Avoid redundancy –** Dimensions shall not be duplicated, unless clearly identified as auxiliary.
- **Functional dimensioning -** Critical dimensions shall be defined directly and related to function.
- **Clarity and grouping –** Dimensions shall be arranged logically and grouped to improve readability.

4.4.2 Dimensioning methods

The arrangement of dimensions shall reflect the design intent. Different method may be used. Dimensioning shall prioritize features that are critical for function and manufacturing. Important dimensions shall be stated directly and not need to be calculated from other dimensions, for example distances to the center of a hole, while less critical dimensions may be given as auxiliary dimensions.

4.4.2.1 Chain dimensioning

Dimensions are arranged sequentially, where each dimension starts from the end of the previous one. This creates a chain of dependent dimensions. Since each dimension defines the spacing from one feature to the next, this method is suitable when the distances between adjacent features are most important. An example of chain dimensioning can be found in Figure 11.

4.4.2.2 Parallel dimensioning

All dimensions are taken from a common reference, and the dimension lines are arranged parallel to each other, as seen in Figure 11. These dimensions may be aligned in one or more directions, or arranged concentrically in the case of circular features. This method provides clear and independent dimensions, but may require more space on the drawing, due to the number of parallel dimension lines. This method is suitable when the position of features relative to a common reference is important, for example distances to a datum or the center of a hole.

4.4.2.3 Running dimensioning

A simplified form of parallel dimensioning, where all dimensions are given from a common origin along a single line. This reduces the number of dimension lines and improves clarity. The starting point is indicated by an origin symbol, from which all dimensions are given along the same line, and each dimension represents the distance from the origin to the feature rather than the distance between features. To create running dimensions in Creo use the *Ordinate Dimension* tool. An example can be seen in Figure 11.

4.4.2.4 Combined dimensioning

In practice, different methods are often used together within the same drawing. The selected approach shall ensure that critical dimensions are stated directly and do not need to be calculated from other dimension. An example of combined dimensioning can be found in Figure 11.

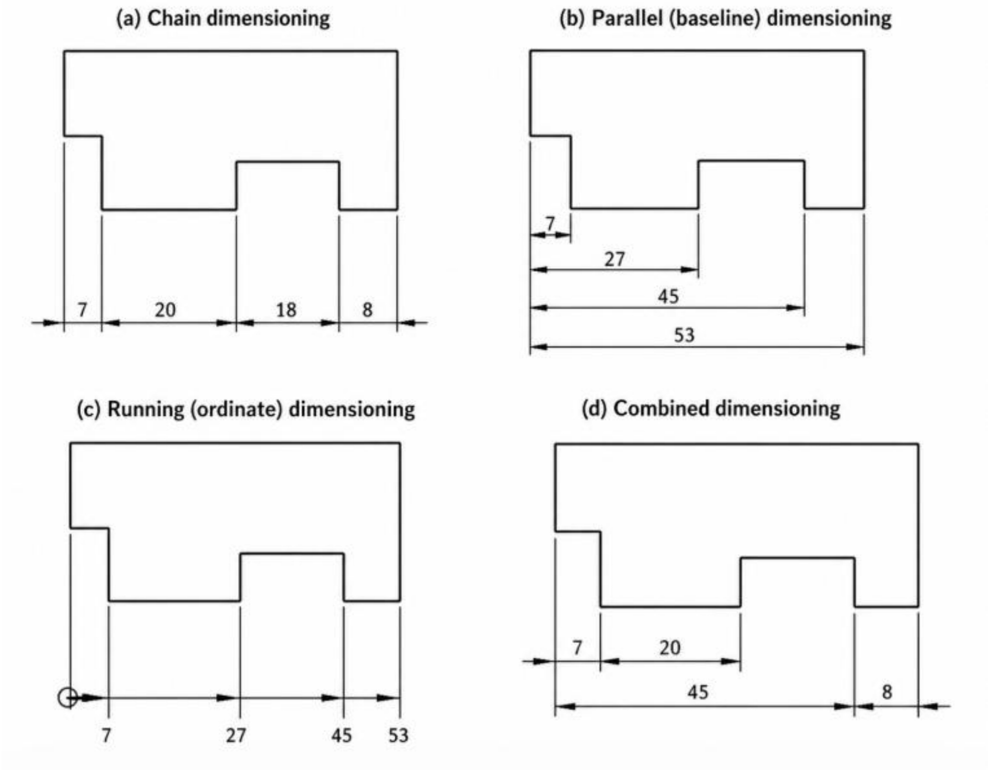

Figure 11: Comparison of dimensioning methods: (a) chain, (b) parallel (baseline), (c) running (ordinate), and (d) combined.

4.4.3 Placement and readability

Dimensions shall be placed in the view where the feature is shown most clearly.

- Dimensions should be placed outside the contour of the object where possible.
- Dimensioning of hidden features should be avoided unless absolutely necessary.
- Dimension lines and values shall be arranged to avoid overlapping and crossing.
- Related dimensions shall be grouped together.
- Internal and external dimensions should, where possible, be separated

Dimension values shall be placed above the dimension line and oriented so that they can be read from the bottom or right-hand side of the drawing. For vertical dimensions, the values shall be placed to the left of the dimension line. Dimension values shall be placed parallel to their dimension lines and shall not be crossed or obscured by other lines.

If crossing cannot be avoided, the dimension line shall remain continuous, while the intersecting line may be interrupted.

Where several features are located close to each other, dimensions shall be grouped according to feature or function to improve clarity.

For linear dimensions, units (typically mm) may be omitted if specified elsewhere on the drawing. Angular dimensions shall always include their unit. If a different unit is used, it shall be explicitly stated.

4.4.4 Graphical representation

Dimensioning shall follow standardized conventions for dimension lines, extension lines, and symbols.

- **Dimension lines** – A continuous thin line indication the extent of a dimension
- **Terminator-** Usually an arrowhead, indicating the limits of the dimension
- **Extension line –** A line extending from a feature to define where the dimension applies
- **Property indicator –** Symbols such as Ø (diameter) and R (radius), used to describe the shape of a feature, placed directly before the dimensional value.

Repeated features: may be dimensioned using simplified notation to avoid duplication. This may be done by indicating the number of identical features followed by the dimension (e.g. 2× ⌀18), or by using a reference line connecting the features with a single dimension.

Chamfers: are typically dimensioned using one linear dimension and an angle (e.g. 2 × 45°).

Symmetry: When symmetry exists, only part of the geometry may be shown. In such cases, dimensions shall be given as full values and referenced to a centerline, indicating that the geometry is mirrored about that line.

4.5 Dimensional tolerancing

4.5.1 Purpose and principles

Tolerances define the allowable variation in size and geometry of a component to ensure proper function, while enabling economic manufacturing.

Dimensional tolerances define the allowable variation in the size of features, such as lengths, diameters, and distances. All dimensions shall be toleranced either individually or through general tolerances. No requirement shall be left to interpretation.

Tolerances shall be defined based on the requirements from the customer as defined in the specification for the product.

Dimensional tolerances shall be applied using one of the following methods:

- **Numerical tolerances** - A tolerance value is stated directly on individual dimension, using ± values or limit values.
- **Tolerance classes** - A standardized tolerance designation is applied to an individual dimension, typically for fits.
- **General tolerances** - Applied to dimensions that are not individually toleranced, providing standard permissible deviations based on size ranges.

Company-specific tolerance table, Backer standard, is used as a form of general tolerances for internal production drawings.

Overly tight tolerances increase production cost and complexity, while unnecessarily loose tolerances may compromise functionality. Tolerances shall therefore be selected based on functional requirements and manufacturing capability.

4.5.2 Numerical tolerances

Numerical tolerances define allowable deviations directly on an individual dimension and are the most direct way of specifying dimensional variation.

A numerical tolerance is typically expressed as a nominal dimension with an associated tolerance, for example **54 ± 0.4 mm**, where ±0.4 mm defines the permissible variation.

The upper and lower limits of size define the acceptable range of the dimension. In this example, the limits are 54.4 mm and 53.6 mm. The difference between these limits is the tolerance width.

Tolerances may also be asymmetric, for example $\mathbf{16^{+0,5}_{+0,1}}$, where the permissible range is not centered around the nominal value.

Numerical tolerances shall be used where specific functional, or manufacturing requirements require tighter or more controlled limits than those provided by general tolerances.

4.5.3 ISO tolerance classes

ISO tolerance classes provide a standardized method for specifying tolerances on individual dimensions in accordance with ISO 286.

A tolerance class is indicated by a nominal dimension followed by a letter and a number, for example **Ø8H7**. The number (IT grade) defines the tolerance width, i.e. the difference between the maximum and minimum permissible size, while the letter defines the position of the tolerance interval relative to the nominal size. Lower IT grades correspond to smaller tolerance widths, i.e. higher precision.

Tolerance classes can be applied to individual features, as well as to other geometries such as distances between parallel surfaces. However, they are primarily used to define fits between mating components, such as a hole and a shaft. Tolerance classes shall be used when a standardized fit between components is required.

ISO tolerances ensure consistent fits and interchangeability of components produced in different manufacturing environments.

Tolerance values are defined in standardized tables based on nominal size and tolerance class. Table 2 shows an example of how such values are presented.

Table 2: Example of ISO tolerance classes for holes

Nominal size (mm)	Limit deviation (µm)			
	F7		F8	
	Upper	Lower	Upper	Lower
(1) – 3	+16	+6	+20	+6
(3)- 6	+22	+10	+28	+10
(6) -10	+28	+13	+35	+13

Tolerances for holes and other internal dimensions are indicated by uppercase letters (e.g. H7), while tolerances for shafts and other external dimensions are indicated by lowercase letters (e.g. h7). On the drawing, the tolerance is normally indicated by only the tolerance class designation (e.g. Ø8H7).

Alternatively, the corresponding limit values may be shown together with the dimension, for example $\text{Ø}8F7^{+0,028}_{+0,013}$.

The resulting fit shall be determined by comparing the tolerance intervals of the mating components. The type of fit depends on the relative positions of the tolerance zones:

- **Clearance fit -** Use when easy assembly or relative movement between components is required. The tolerance zones do not overlap, meaning the hole is always larger than the shaft.
- **Transition fit** – Use when accurate positioning is required and either a small clearance or slight interference is acceptable. The tolerance zones partially overlap, meaning the fit may result in either clearance or interference depending on the actual sizes of the components.
- **Interference fit -** Use when a permanent or rigid connection is required. The tolerance zones fully overlap, meaning the shaft is always larger than the hole, and assembly requires force or special methods.

The selection of tolerance class and fit shall be made based on functional requirements. In practice, the corresponding limit values are obtained automatically in the CAD system based on the selected tolerance class.

4.5.4 General tolerances (ISO 2768)

For external drawings, general tolerances according to ISO 2768 should normally be used, as they provide a simple and efficient way of specifying tolerances. This method shall only be applied to external drawings. For production drawings, the Backer standard tolerance table shall be used instead (see Chapter 4.5.5).

General tolerances according to ISO 2768 are applied when no individual tolerances are specified on a drawing. They define the allowable variation in dimensions by assigning standard tolerance values based on the size of the feature and the selected tolerance class (fine, medium, coarse, or very coarse). This allows dimensions to be controlled without specifying a tolerance for each individual feature, simplifying drawings while ensuring consistent manufacturing accuracy.

When applying general tolerances:

- Use a tolerance class (f, m, c, v) that reflects the manufacturing capability of the workshop
- Indicate the use of general tolerances in the tolerance field of the title block, e.g. ISO 2768-m
- Specify individual tolerances when tighter limits are required
- Specify individual tolerances when larger deviations are acceptable and beneficial

General tolerances are based on typical manufacturing capability. Increasing tolerances beyond these values does not normally provide economic benefit. Furthermore, workpieces exceeding general tolerances should not automatically be rejected if their function is not impaired.

The selection of tolerance class is based on the following considerations:

The selected tolerance class shall correspond to the expected manufacturing capability. The term customary workshop accuracy refers to the level of precision that can be consistently achieved under normal production conditions. A tolerance class should therefore only be used if its values can be achieved in practice. However, tolerances shall always be selected based on the functional requirements of the component, and individual tolerances shall be specified where necessary to ensure proper function.

The use of general tolerances offers serval advantages. They reduce the need for detailed tolerance specification, making drawings easier to create and interpret. Inspection efforts can be reduced, as features requiring higher precision are clearly identified through individually specified tolerances.

4.5.4.1 Linear dimensions

General tolerances for linear dimensions apply to features such as lengths, diameters, radii and distances, and are used when no individual tolerances are specified. Dimensions smaller than 0.5 mm are not covered and must therefore be specified individually on the drawing. The permissible deviations for different nominal size ranges and their respective tolerance classes are given in Table 3.

Table 3: General tolerances for linear dimensions, adapted from ISO 2768-1.

Tolerance class	***Permissible deviations for basic size ranges***								
Designation	Description	0.5 up to 3	over 3 up to 6	over 6 up to 30	over 30 up to 120	over 120 up to 400	over 400 up to 1000	over 1000 up to 2000	over 2000 up to 4000
F	fine	±0,05	± 0,05	± 0,1	± 0,15	± 0,2	± 0,3	± 0,5	-
M	medium	± 0,1	± 0,1	± 0,2	± 0,3	± 0,5	± 0,8	± 1,2	± 2
C	coarse	± 0,2	± 0,3	± 0,5	± 0,8	± 1,2	± 2	± 3	± 4
V	very coarse	-	± 0,5	± 1	± 1,5	± 2,5	± 4	± 6	± 8

The standard also includes a separate tolerance table for broken edges (e.g. chamfer heights and external radii), which are not included here.

4.5.4.2 Angular dimensions

Angular tolerances define allowable deviations in the orientation of features, but do not control form deviations. The permissible deviation depends on the length of the shorter side forming the angle, where larger dimensions allow greater angular deviation. The corresponding permissible deviations for angular dimensions are presented in Table 4.

Table 4: General tolerances for angular dimensions, adapted from ISO 2768-1

<table>
<tr><td>Tolerance class</td><td colspan="6">Permissible deviations for ranges of lengths in millimeters of the shorter side of the angle concerned</td></tr>
<tr><td>Designation</td><td>Description</td><td>0.5 up to 3</td><td>over 3 up to 6</td><td>over 6 up to 30</td><td>over 30 up to 120</td><td>over 120 up to 400</td></tr>
<tr><td>F</td><td>fine</td><td rowspan="2">±1 °</td><td rowspan="2">± 0°30</td><td rowspan="2">± 0°20</td><td rowspan="2">± 0°10</td><td rowspan="2">± 0°5</td></tr>
<tr><td>M</td><td>medium</td></tr>
<tr><td>C</td><td>coarse</td><td>± 1 ° 30</td><td>± 1°</td><td>± 0°30</td><td>± 0°15</td><td>± 0°10</td></tr>
<tr><td>V</td><td>very coarse</td><td>± 3°</td><td>± 2°</td><td>± 1°</td><td>± 0°30</td><td>± 0°20</td></tr>
</table>

4.5.5 Backer standard

The company-specific tolerance table, referred to as Backer standard, is used for drawings for on-site production. The standard defines tolerances that are considered feasible within the company's manufacturing process, and it is based on experience from production. It represents a company-specific application of general tolerances, where the same principles are applied, but with a Backer-specific tolerance table and values adapted to internal manufacturing capabilities.

The Backer standard is used for internal production drawings, for heating elements and cartridges, in place for general ISO standards. Its application supports efficient interpretation of drawings, as the production personnel are familiar with the standard. It is not applied to drawings for purchased components.

The tolerance table shall be included on all drawings intended for on-site production. It shall be placed in the lower left corner of the drawing sheet, outside the drawing frame. When used the Backer standard should be referenced in the tolerance field in the title block, see section 5.3, by indicating that the tolerances are specified in the tolerance table on the drawing, e.g. see Backer standard table.

The Backer standard table is shown in Table 5. The table defines general tolerances based on nominal dimension ranges. The first column specifies the size range of the dimension ("over/up to"), while the corresponding tolerance column defines the permissible deviation (±) for each range. The tolerances apply unless otherwise specified on the drawing. Where individual tolerances are defined, these shall take precedence over the general tolerances defined in the Backer standard.

Table 5. Backer standard tolerance table

Backer standard		
Nom. measure mm & grades		***Tol.***
Over	Up to	±
(1) (6) (30)	6 30 100	0,5 1,0 2,0
(100) (300) (1000)	300 1000 2000	3,0 5,0 7,0
(2000)	4000	10,0

A drawing with tolerances provided by a customer can be interpreted as defining the customer's requirements for the product. All drawings received from customers for production shall be recreated within the company and assigned an internal drawing number. They shall be evaluated against the Backer standard to verify that the specified tolerances are achievable within the company's capabilities. Where tolerances are not achievable, they shall be adjusted to align with internal manufacturing capabilities. The resulting drawing shall be submitted to the customer for review and approval.

Separate drawings are maintained for customer communication and internal production. The Backer standard shall not be included or referenced on drawings issued to customers. Instead, drawings issued to customers for approval shall specify all tolerances explicitly as numerical values on the drawing or, where applicable, by using general tolerances, while internally being based on the Backer standard. Internal production drawings shall instead reference the Backer standard and are used for manufacturing. These drawings shall be assigned separate drawing numbers and managed as related documents.

4.6 Geometrical tolerancing

Geometrical tolerances are defined according to ISO 1101 and are used to control the allowable variation in the **form, orientation, and location** of features. While dimensional tolerances control size, geometrical tolerances ensure that features have the correct shape and spatial relationship to function as intended.

Geometrical tolerances shall be applied where necessary to ensure function, assembly, or performance. As they are more complex to define and verify than dimensional tolerances, they should be used with care and only where there is a clear purpose.

A key concept in geometrical tolerancing is the **tolerance zone**, which defines the region within which a feature is permitted to vary. The region is bounded by ideal geometric elements, such as lines, planes, or surfaces, and its size is determined by the specified tolerance value. The shape and size of this zone depend on the type of tolerance applied. For instance, in the case of circularity, the permitted variation is represented by the area between two concentric circles.

4.6.1 Types of geometrical tolerances

Geometrical tolerances control different aspects of a feature's deviation and are defined by a set of standardized symbol. These tolerances are grouped into different categories depending on the type of variation they control:

- **Form tolerances –** Define the allowable deviation of a feature from its ideal shape (e.g. straightness, flatness, circularity). Do not require datums.
- **Orientation tolerances –** Define the allowable deviation in the angular relationship of a feature relative to a datum (e.g. parallelism, perpendicularity). Require datums.
- **Location tolerances –** Define the allowable deviation of a feature's location relative to one or more datums (e.g. position, symmetry). Require datums.
- **Runout tolerances –** Define the allowable variation of a feature during rotation about a datum axis (e.g. circular runout, total runout). Require datums.

An overview of the most common geometrical tolerances, their classification, symbols, and datum requirements is provided in Table 6.

Table 6: Overview of geometrical tolerances and their classification

Tolerance	***Characteristics***	***Symbol***	***Datum needed***
Form	Straightness	⏤	no
	Flatness	⏥	no
	Circularity	○	no
	Cylindricity	⌭	no
	Line profile	⌒	no
	Surface profile	⌓	no
Orientation	Parallelism	//	yes
	Perpendicularity	⊥	yes
	Angularity	∠	yes
Location	Position	⌖	yes
	Concentricity	◎	yes
	Symmetry	⌯	yes
Run-out	Circular runout	↗	yes
	Total runout	⌰	yes

Geometrical tolerances are often defined relative to datums, which represent theoretically exact reference features such as planes, axes, or points. Datums establish a reference system used to evaluate features in relation to one another.

4.6.2 Representation in drawings

Geometrical tolerances are specified using a tolerance indicator, which consists of a rectangular box divided into sections:

- The first section contains the tolerance symbol.
- The second section contains the tolerance value.
- The third section (optional) specifies datum references.

An example is shown in Figure 12.

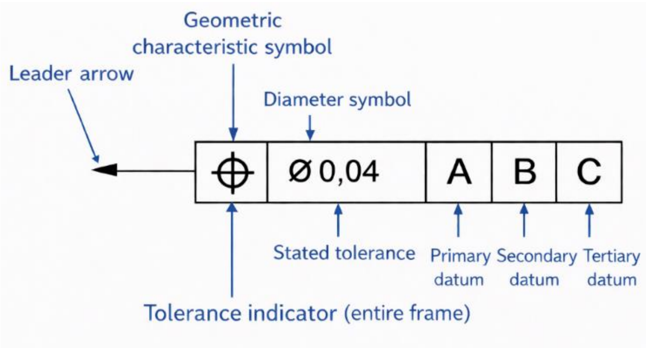

Figure 12: Example of a tolerance indicator showing a position tolerance.

4.6.3 Form tolerances

- **Straightness –** Defines the allowable deviation of a line element from a perfectly straight line. Use when a feature must mate with or align along a straight path, such as sealing or guiding surfaces.
- **Flatness –** Defines the allowable deviation of a surface from a perfectly flat plane. Use when a surface must mate evenly without gaps, but where orientation is not important.
- **Circularity –** Defines the allowable deviation of a circular feature from a perfect circle. Use for features that must be sufficiently round to ensure proper function, such as shafts and holes in rotating or mating components, to maintain consistent clearance and prevent vibration or uneven wear.
- **Cylindricity –** Defines the allowable deviation of a surface from a perfect cylinder. Use for cylindrical features that must maintain uniform contact along their length for example in sliding or rotating applications, such as shafts or pins.

4.6.4 Orientation tolerances

- **Parallelism -** Defines the allowable deviation of a feature from being parallel to a datum. Use when two features must maintain a constant alignment or spacing. Use when features must maintain consistent alignment or distance relative to each other.
- **Perpendicularity -** Defines the allowable deviation of a feature from being perpendicular (90°) to a datum. Use for features that must meet at a right angle to ensure proper alignment or contact.
- **Angularity -** Defines the allowable deviation of a feature from a specified angle relative to a datum. Use for features that must be oriented at a defined angle.

4.6.5 Location tolerances

- **Position -** Defines the allowable deviation of a feature from its theoretically exact location relative to datums. Use when the precise placement of features such as holes or pins is critical.
- **Symmetry -** Defines the allowable deviation of a feature from symmetrical distribution about a datum plane. Use when equal distribution about a center plane is required.

4.6.6 Runout tolerances

- **Circular runout -** Defines the allowable variation of a feature during rotation about a datum axis at individual cross-sections, limiting how much the surface deviates (wobbles) relative to the axis. Use for rotating or mating components where variation can cause vibration, noise, or uneven wear.
- **Total runout -** Defines the allowable variation of a feature during rotation about a datum axis over the entire surface, limiting the overall wobble along the full length of the feature. Use for rotating parts where the entire surface must be controlled.

Geometrical tolerances should be selected based on functional requirements. Where possible, use dimensional or simpler geometrical tolerances, such as form and orientation tolerances. More complex tolerances, such as location and runout tolerances, should only be applied when necessary, and additional information should be consulted before use.

4.7 Surface roughness

Surface roughness describes the microscopic texture of a surface, consisting of small peaks and valleys. It is used in technical drawings to specify how smooth or rough a surface must be for proper function.

Surface roughness affects properties such as friction, wear, lubrication, and sealing. Surface roughness shall be specified based on functional requirements. Avoid specifying unnecessarily low roughness values, as smoother surfaces increase manufacturing time and cost.

Surface roughness is defined and indicated according to ISO 21920.

4.7.1 Surface roughness parameters

Surface roughness is specified using standardized parameters. The most commonly used parameter is **Ra** (arithmetical mean roughness). It represents the average deviation of the surface profile and is used for general specification in technical drawings.

Rz (mean roughness depth) describes the average height difference between peaks and valleys. It is more sensitive to individual surface irregularities.

Use Ra as the default parameter. Use Rz only when control of surface extremes is required.

Lower values indicate a smoother surface.

4.7.2 Representation in technical drawings

The drawing must include information about the require surface quality of the components. The basic symbol to indicate surface roughness consists of a check-mark–like shape, as seen in Figure 13. The symbol may be modified to define manufacturing requirements.

The basic symbol may be modified to indicate:

- Material removal required (e.g. machining).
- Material removal not permitted

The roughness value (typically Ra) shall be next to the symbol. Symbols shall be placed directly on the relevant surface or connected using a leader line.

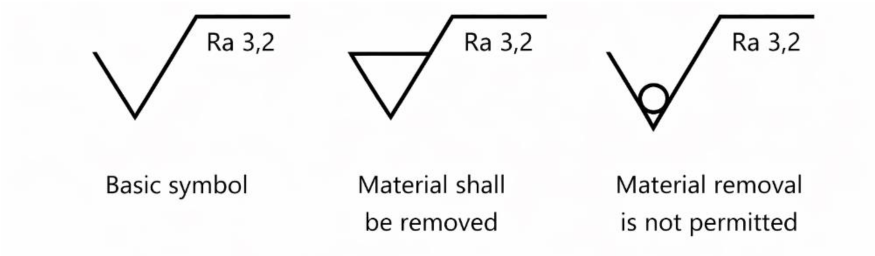

Figure 13. Standardized surface texture symbols used in technical drawings to indicate surface roughness requirements and material removal conditions.

The symbol can include additional information such as machining method, surface lay, or other surface texture parameters. Only include additional information when required.

Place the symbol directly on the relevant surface or connect it using a leader line. A symbol that applies to a specific surface shall be shown once, preferably in the view where the corresponding dimension is indicated.

If the same roughness requirement applies to all surfaces, specify the general surface roughness in the title block filed surfaces using an Ra value. Use local symbols only for surfaces that require a different value.

4.7.3 Selecting Ra

4.7.3.1 General rules for specifying surface roughness

- Do not specify surface roughness unless it is required for function. In many cases, standard manufacturing processes provide an acceptable surface finish without additional specification.
- Do not specify a lower surface roughness than necessary. Unnecessarily low roughness increases manufacturing cost and machining time.
- A general surface roughness may be specified in the title block field surfaces. If no requirement is needed, the field may be left blank
- Do not specify only “Ra” without a value, as this does not define a requirement.
- Apply surface roughness symbols on the drawing only where a different requirement is needed.

4.7.3.2 Guidelines for selecting Ra

Commonly used Ra-values are, 25, 12.5, 6.3, 3.2, 1.6, 0.8, 0.4, and 0.2 µm.

The selection of Ra is based on the specific application and function of the surface. In practice, the following checks can be used as support when choosing a suitable value:

1. Check the function of the surface

Surface roughness shall be selected based on the functional requirements of the surface.

- Contact, sealing, or precision fits → low Ra
- General surfaces → medium Ra
- Non-criterial surfaces → high Ra

2. Relate to tolerances

Surfaces with tighter tolerances generally requires smoother finishes. ISO tolerance classes can be used for comparison:

• IT5–IT7 → typically Ra ≈ 0.2–1.6 µm

• IT7–IT9 → typically Ra ≈ 1.6–3.2 µm

• IT10 and above → typically Ra ≥ 6.3 µm

This relationship varies depending on the application and is only intended as a general check.

3. Compare with manufacturing processes

It can also be useful to compare the selected Ra with typical values for different manufacturing processes. Use Table 7 as a reference. If the chosen value is significantly lower than what a process usually produces, it may be necessary to either select a different manufacturing method or reconsider whether the specified Ra value is required.

Table 7: Surface roughness values for typical manufacturing processes.

Surface description	*Typical manufacturing processes*	*Typical Ra (µm)*
Very rough	Saw cutting, rough forging	25
Roug	Rouch machining, drilling	12.5
Clearly visible tool marks	Standard milling, turning	6.3
Visible tool marks	General machining	3.2
Smooth, slight marks	Precisions, reaming	1.6
Very smooth, no visible marks	Grinding, honing	0.8
Near-mirror finish	Precision grinding, lapping	0.4
Mirror-like finish	Polishing, superfinishing	0.2

5 Drawing content

5.1 Required information in drawings

A drawing shall contain the information required for its intended use. This includes definition of product geometry, dimensions, tolerances, and technical specifications, as well as necessary metadata and identifiers to ensure traceability. What constitutes required information depends on the purpose of the drawing, for example whether it is used for manufacturing, purchasing, or customer communication. Differences in required level of detail between production and customer drawings are described in Section 2.4.2.

The design engineer is responsible for ensuring that the drawing includes all necessary information for its intended use and that it can be correctly interpreted by relevant stakeholders, through alignment with relevant functions when required. Review of similar existing products may be helpful when determining what content should be included in the drawing.

Minimum requirements for drawing content are defined as part of the review criteria in Section 7.5. These are divided into general criteria and additional criteria for production and purchasing drawings. The criteria describe key aspects that shall be verified during review but do not represent a complete list of all required information.

A complete definition of required drawing content cannot be fully specified in a predefined set of requirements, as it depends on the complexity and intended use of the product. By following applicable standards and company practices, together with considering the intended use, the drawing shall include all necessary information.

An additional tool to ensure all required content is included is the document *Checklista för konstruktionsgranskning.* It may be used in applicable development processes as a self-review tool and during design reviews, supporting verification of drawings by highlighting key aspects that should be included prior to approval.

Regardless of the tools and guidelines applied, the required content of a drawing shall ultimately be determined based on its intended use and applicable requirements.

5.2 Completeness and clarity of drawings

Completeness means that no required information is missing. Clarity means that the information is unambiguous and can be interpreted consistently. Clarity and completeness are achieved by applying the requirements and principles defined in this handbook such as defined rules for dimensioning, tolerancing and specifications.

Drawings shall be complete and clear to ensure that they can be correctly interpreted and used for manufacturing, purchasing, and verification. Incomplete or unclear drawings increase the risk of errors, rework, and miscommunication, and may lead to incorrect manufacturing or delays.

A drawing shall contain all information required for its intended use. What constitutes required information depends on the intended use of the drawing. Missing or ambiguous information may result in assumptions during manufacturing or purchasing, increasing the risk of incorrect interpretation.

Information shall therefore be defined in a clear and consistent manner, and all critical requirements shall be explicitly stated.

In relation to the customer, completeness means that both customer and company requirements are documented in the drawing. The drawing shall represent a complete and agreed product definition. To ensure this, all drawings provided by the customer shall be recreated within the company and assigned a company drawing number. The resulting drawing shall be submitted to the customer for review and approval. If deviations from customer requirements are necessary, these shall be clearly defined and accepted by the customer prior to release.

For manufacturing, completeness means that the drawing and related documents provide the information required for production. For on-site production, a complete production basis consists of the drawing, data card, and bill of materials (BOM), and, where applicable, the operation list. These documents shall be consistent and used together.

5.2.1.1 Duplication of information

Duplication of information within a drawing and across related documents shall be avoided where possible. This applies both to repetition within the drawing and to information shared between the drawing and other documents, such as the data card, BOM, or operation list. This does not apply to metadata and basic information managed in PLM or ERP systems, where the same information is intentionally maintained across systems.

Duplication increases the risk of inconsistencies and creates additional effort when updates are made, as changes must be applied in multiple locations. This may lead to incorrect or outdated information being used. In case of discrepancies between documents, the drawing is the governing document.

Drawings should primarily contain the information required for manufacturing. Information that is managed and maintained in other systems should not be unnecessarily repeated in the drawing. The aim is to limit the amount of text and avoid duplication of information, even though this may not always be fully achievable in practice.

The following are examples of duplication that may occur in practice. In some cases, such duplication is used or required, but it shall be applied with care and with consideration of the associated risks:

- Manufacturing-related information , e.g. sealing, annealing, temperature included both in the drawing and in the data card or the operation list.
- Information repeated within the drawing, for example when the article name and description fields in the title block contain the same or overlapping information
- Dimensions or notes repeated in multiple views or sections of the same drawing.
- General notes that repeat information already defined through symbols, standards, or tolerances.

In some cases, such duplication is necessary or beneficial, for example to improve usability or accessibility. If duplication cannot be avoided, the information shall be kept consistent in all locations.

5.3 Title block content

The title block is a standardized section on the drawing sheet, located in the lower right corner, used to record essential information related to the drawing. It contains key metadata and its purpose is to enable identification, organization and management of drawings throughout their lifecycle, ensuring that relevant information about ownership, components, and revisions are clearly communicated. Title blocks for technical drawings are described in ISO 7200, and the title block used in this handbook follows similar principles adapted to company-specific requirements.

The title block consists of a set of predefined fields, each with a specific purpose, as defined in Table 8.The table specifies the required fields, their descriptions, and instructions for how the information shall be entered, as well as the source or system responsible for the information. These fields shall be completed in accordance with the requirements defined in this handbook and shall reflect accurate and up-to-date information, to ensure traceability of the drawing.

Information in the title block may either be generated automatically through the integration between PTC Creo and PTC Windchill, included through the drawing template, or entered manually by the user. Parameters controlled through Windchill, such as revision, state, approver, and approval date, are automatically populated and locked from editing in Creo. Other fields require manual input by the user through editing them in the *Parameters* tool found in the *Tools* tab in Creo. Certain fields included automatically through the template, such as tolerances or surface roughness symbols, may also require updating or removal depending on the specific drawing requirements. Windchill-controlled information shall not be modified manually and shall be verified for correctness before release.

Table 8: Fields of the title block and their purpose and source

Field name	***Description***	***Required***	***Source/entry method***
Drawing number	Name given when creating the model file. See Section 8.1.4.2 for naming rules.	Yes	File creation
State	Indicates the current lifecycle state (e.g. draft, under review, released). Verify that the correct state is set before release. Automatically managed through Windchill.	Yes	Windchill
Revision (rev.)	Indicates the current revision level of the drawing. Updated through the revision process. Automatically managed through Windchill.	Yes	Windchill
Sheet	Indicates current sheet number and the total number of sheets (e.g. 1(2)). Automatically generated by template.	Yes	Template
Description	Enter a descriptive name of the part or assembly in parameters in Creo.Max 25 characters recommended	Yes	Manual input, Creo (Parameters)
Class	Enter the applicable class in Creo according to the established classification rules.	Yes	Manual input, Creo (Parameters)
Manufacturing standard	Enter applicable manufacturing standard and test code according to TI, in Creo	Production drawings only	Manual input, Creo (Parameters)
Customer reference	Enter customer's own reference number in Creo.	No	Manual input, Creo (Parameters)
Drawn	Initials of the person who created the drawing. Automatically retrieved through Windchill.	Yes	Windchill
Reviewer	Initials of the person who reviewed the drawing. Automatically retrieved through Windchill.	Yes	Windchill
Approver	Initials of the person who approved the drawing. Automatically retrieved through Windchill.	Yes	Windchill
Approved date	Date of approval. Automatically retrieved through Windchill. Automatically generated by template.	Yes	Windchill
Scale	Scale used in the drawing views	Yes	Automatic(CAD/template)
Projection method	The symbol for first-angle projection is automatically included in the template, see Section 4.3.1.	Yes	Template
Tolerance	ISO 2768 general tolerances are included by default in the template. Change if not applicable, see section 4.5 for guidance.	Yes	Template, manual input
Surfaces	Surface roughness symbol (Ra) is included in the template. Enter applicable value or remove if not required, see Section 4.7.	No	Manual input
Note	Enter additional information in Creo not covered elsewhere. Keep concise.	No	Manual input, Creo (Parameters)
Company logo	Automatically included in template.	Yes	Template

All title block fields shall be completed unless otherwise specified. The user is responsible for ensuring that all manually entered fields are completed correctly and based on applicable product data, standards, and project documentation.

An example of a filled out title block is shown in Figure 14.

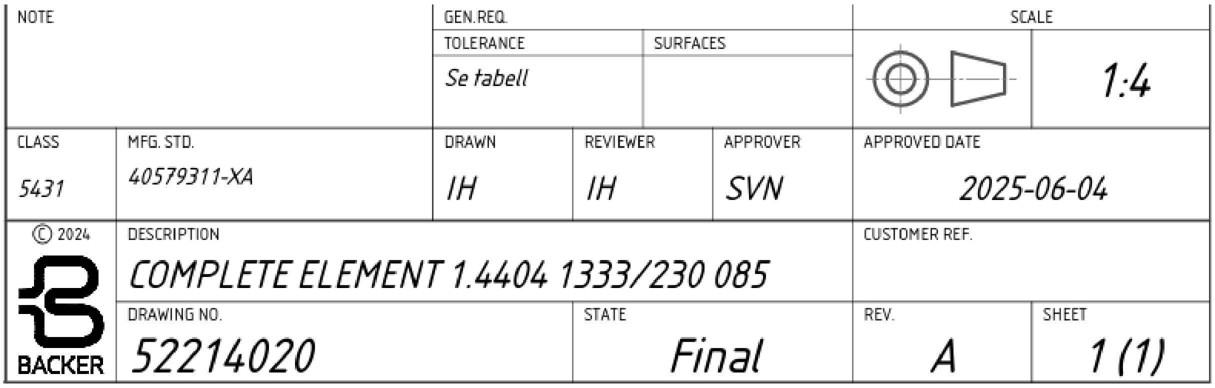

Figure 14: Example of title block.

5.4 Parts list

The parts list defines the components included in an assembly drawing. It provides the information required to identify each item and link it to its graphical representation. The basics content and requirements for parts lists are defined in ISO 7573.

The term *parts list* is sometimes used interchangeably with Bill of Materials (BOM). In this handbook, the term *parts list* is used for the drawing-based representation shown on assembly drawings. Further description of BOM structures and their relationship to parts lists is provided in Section 5.4.1.1.

The an example of the part list in the standard template can be seen in Figure 15, with the corresponding placement of ballons in the drawing field in Figure 16.

4	2	ÄNDBUSSN STEATIT 140/1X6	40437902	SteatiteC221	Neutral / (White)
3	2	Nut	60064301	Steel_Zn_pl	M6
2	2	Nipple	40549602	Steel_Zn_pl	
1	1	EL 1.4404 4400/400 140 L6246	5052104915	EN_1.4404	FL=6246±80
No.	QTY.	DESCRIPTION	PART NO.	MATERIAL	MFG. NOTE

Figure 15: Example of parts list.

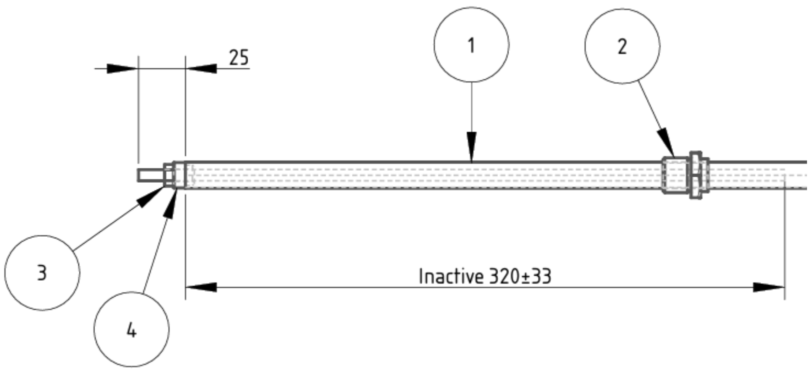

Figure 16: Corresponding placement of ballons for parts list in Figure 15.

When creating a drawing from an assembly in the CAD system, the parts list is automatically generated from the assembly structure. The information is linked to the 3D model and associated metadata. The generated parts list shall be verified to ensure that all components, quantities, and identifiers are correct.

The part list includes the following fields:

- **Item number:** Identifies each component in the assembly. The number links the parts list to the graphical representation in the drawing, shown using numbered ballons placed adjacent to corresponding component, as shown in Figure 16. Identical component share the same item number.

  Each item shall be identified with a balloon in the drawing. Place balloons close to the component they refer to, without overlapping geometry, dimensions, or other annotations. Use leader lines where necessary to clearly associate the balloon with the correct component. Missing or incorrectly placed balloons are a common error and reduce the readability of the drawing.

  Balloons can be generated automatically in the CAD system based on the parts list. However, the automatically generated balloons shall still be positioned and adjusted manually to ensure that all items are clearly associated with the corresponding components and that the drawing remains easy to read. In some cases, it may be more efficient to create the balloons manually.

- **Quantity:** Specifies the number of each part or material required in the assembly. Include a unit only when the quantity is not given in pieces (e.g. length or mass).
- **Description:** Provides the name or description of the component.
- **Part number:** Defines the unique identifier of the component within the organization, i.e. article number.
- **Material:** Specifies the material of the component when required.
- **Manufacturing note:** Provides additional information required for manufacturing, such as special instructions or requirements. Include only when necessary. This may include thread specifications (e.g. M14×1.5, defining thread size and pitch), color or surface finish (e.g. White), or dimensions with tolerances (e.g. L = 1673 ± 20, defining length and allowable variation). Include only information necessary for manufacturing or procurement. Manufacturing notes are not generated automatically and shall be entered manually in the *Parameters* tool for each relevant component in the assembly.

5.4.1.1 Bill of Materials

The term parts list is often used interchangeably with Bill of Materials (BOM), but the terms here refer to different concepts. A parts list describes the components included in a single assembly drawing and represents the assembly information displayed directly on the drawing.

A BOM, on the other hand, represents the product structure containing assemblies, subassemblies, components, and quantities. In the PLM and ERP system, BOM structures are connected to related parts, CAD models, and multilevel assembly structures. Unlike the drawing parts list, a BOM is not limited to a single drawing representation, but is instead used for product structure management, traceability, purchasing, and production-related activities.

5.5 Related documentation

5.5.1 Data card

The data card contains calculated data for the heating element that is not fully represented in the drawing. It is used in internal production and provides information needed to support manufacturing. It also supports the design engineer in verifying that the heating element fulfils specified requirements and remains within defined limits. Customer product requirements shall not exceed the limit values defined in Technical Information (TI).

The data card is created by the design engineer in the software Elber based on a set of input parameters, such as power, voltage, and length, used to dimension the straight element. Based on these inputs, the system calculates additional parameters, which are included in the data card.

The data card contains information related to both the spirals and the outer tube. This includes, for example:

- Spiral data (e.g. power, thread length, thread dimensions, resistance per meter (Ω/m), inactive length).
- Tube data (e.g. voltage, diameter, material, cut length, final length, temperature, MgO filling, marking position, marking text, sealing plugs).

The data card accompanies the drawing and the operation list and follows the component throughout the manufacturing process. The data card and the drawing are used as complementary documents. The drawing defines geometry, dimensions, and general specifications, while the data card provides additional technical information required for manufacturing and verification.

Including information from the data card in the drawing is allowed, but should be applied with care, as it increases the risk of inconsistencies. When this is done, the information shall be kept consistent across the data card, drawing, and other related documents.

5.5.2 Operation list

The operation list is used in production to define the sequence of manufacturing steps required to produce a component. It is created, by the Production Technique department, based on the drawing before production begins. The completeness of the drawing is therefore important, as it forms the basis for creating the operation list and determining how the product is to be manufactured. The operation list is accompanied by the drawing and follow the product throughout the manufacturing process.

The operation list and the drawings are used as complementary documents. The operation list describes the order of the manufacturing steps and the necessary instructions for their execution, while the drawing specifies the geometry, dimensions, and other technical details required to carry out these operations. In case of ambiguity, the drawing is considered as the governing document.

Manufacturing steps defined in the operation list, such as stamping, bending, assembly, or brazing, shall be supported by corresponding information in the drawing, for example locations, dimensions, or bend tables.

5.6 Language policy

The language used in technical drawings shall be determined by their intended use. For drawings used in production, Swedish shall be used for all free text and instructions to ensure that production operators can clearly understand the information. Title block headlines and article names may still be written in English.

For drawings used in purchasing, English should be used throughout the drawing, particularly when working with international suppliers, to facilitate clear communication. The use of multiple languages within the same drawing is discouraged but not forbidden, as it may reduce clarity and make the drawing more difficult to interpret.

Existing drawings may be in either Swedish or English due to previous practices. When such drawings are revised or reused, the language shall be updated as necessary to meet the intended use of the drawing.

6 Use of drawings

6.1 Use in production

6.1.1.1 Workflow for use in production

Drawings are a central part of the production process, as they define the product geometry and technical requirements and serve as the authoritative source for what the product shall be, including dimensions and tolerances.

In the onsite production drawings are used in printed form and accompany the product together with the operation list. Both documents follow the product throughout the manufacturing process, and the operation list is signed after the completion of each operation. See Section 5.5.2 for more detailed information about the operation list.

The drawing and the operation list are used as complementary documents. The operation list defines the sequence of manufacturing steps, while the drawing provides the technical information required to perform these steps. The drawing is the governing document.

Since drawings are used in printed form, they shall be designed to ensure readability, including appropriate use of scale as described in Section 4.3.4. As drawings only provide a two-dimensional representation of the product, they may make it more difficult to interpret complex geometries and visualize the complete product. The designer shall therefore ensure that the drawing can be clearly understood without prior knowledge of the design and include a sufficient number of views and information to fully describe the product, see Section 4.3.3.1 for guidance on view selection.

6.1.1.2 Manufacturing and verification

Dimensions and technical details defined in the drawing shall support both manufacturing and inspection. Drawings shall therefore be clear, complete, unambiguous and include sufficient information to support manufacturing and verification. Unclear drawings may lead to questions from production personnel, resulting in delays and inefficiencies.

Dimensions important for manufacturing and inspections shall be clearly defined. Examples of such information include:

- Distances to center of holes and between features
- Overall geometry and main dimensions
- Diameters, radii and lengths
- Bend positions, angles, radii (may be combined with a bend chart)
- Interface and assembly-related dimensions
- Alignment and positioning of features
- Locations for welding, brazing, or other joining operations

It is beneficial to include functional dimensions, i.e., dimensions that are critical for the fit, function, or assembly of the product, as these simplify measurement and reduce the need for operators to perform calculations.

After manufacturing, a final inspection is performed to verify that the product meets the specified requirements. During this inspection, the produced component is measured, and its dimensions are compared directly to those defined in the drawing. It is therefore helpful to include auxiliary dimensions, i.e. non-toleranced dimensions provided for reference, as these may simplify the measurement process.

6.2 Use in purchasing

Drawings are used by the purchasing department to communicate product requirements to external suppliers.

In supplier communication, CAD models are often used to convey the overall design and geometry of the product, while drawings are used to define tolerances and additional technical requirements. Together, these provide the necessary information for suppliers to manufacture components according to specification.

All requirements necessary for the supplier to manufacture the product shall be defined in the drawing. The drawing serves as an authoritative source for the technical product definition and forms part of the agreed specification between the company and the supplier. It shall be complete and independent of other communication. Information communicated through emails or other informal channels shall therefore be incorporated into the drawing to ensure consistency and traceability.

When drawings are received from customers, they shall be reviewed against the Backer standard tolerance table to ensure that the requirements can be fulfilled in the company's production. Further information is provided in Section 4.5.5.

7 Drawing review and approval

7.1 Purpose and benefits of drawing review

Drawing review ensures that drawings contain the information required for manufacturing, purchasing and correct product function before release.

The purpose of the review is to:

- Verify that the drawing is complete and clear for its indented use.
- Ensure that the design is feasible to manufacture.
- Support correct application of company standards.
- Reduce the risk of errors, rework, and miscommunication in production and purchasing.
- Support efficient communication between design, production, and suppliers.
- Improve drawing quality, consistency, and standardization by identifying recurring issues and providing feedback to designers.

7.2 Review and approval in PLM

All drawings shall follow the approval workflow in the PLM system (Windchill). The workflow controls the lifecycle state of the drawing and ensures that drawings are reviewed, approved, and released in a controlled and traceable manner.

The lifecycle states in the PLM system includes:

- **Draft –** Drawing under development.
- **Under review –** Drawing submitted for review and approval.
- **Published –** Drawing approved for limited use, for example prototype manufacturing, testing, or samples.
- **Approved –** Drawing approved within the workflow.
- **Final –** Drawing formally released for purchasing and production.
- **Obsolete –** Drawing previously released but no longer valid for use.
- **Canceled -** Drawing or revision withdrawn before release or completion.

The workflow is performed as follows:

- The drawing is created and checked into the PLM system and is then in state **Draft**.
- When the drawing has been completed, it shall be submitted for review and approval and then enters state **Under Review**.
- When submitting the drawing for approval in Windchill, the designer shall select one of the designated reviewers responsible for reviewing design documentation.
- After review, the drawing is either approved or rejected.
- If a drawing is rejected:
    - It shall be returned to the designer with comments, and transitions back to state **Draft**.
    - The designer shall correct the issues.
    - The drawing shall then be resubmitted for review and enters state **Under Review**.

- Approved drawings transition to state **Final**, and are considered released for use in production and purchasing.
- Drawings intended for prototype manufacturing, testing, or customer samples may instead be submitted for publishing rather than final release. The drawing is submitted through the same approval workflow in Windchill, but transitions to state **Published**. Published drawings are approved for limited use, but are not formally released for serial production. In these cases, the drawing creator may perform the approval activities themselves.
- If modifications are required to a drawing already in state **Final** or **Published**, a new revision shall be created. The new revision enters state **Draft** and shall follow the review and approval workflow before it can be released or published again.
- Released drawings that are replaced or no longer valid transition to state **Obsolete**.
- Drawings or revisions withdrawn before release transition to state **Canceled**.

Review and approval are distinct steps. Review is performed to identify errors, missing information, and improvement opportunities, while approval provides formal confirmation that the drawing is complete and ready for release. In many cases, both steps are performed by the same person.

Only drawings in state **Final** shall be used for production or purchasing.

Figure 17 illustrates the review and approval workflow in Windchill.

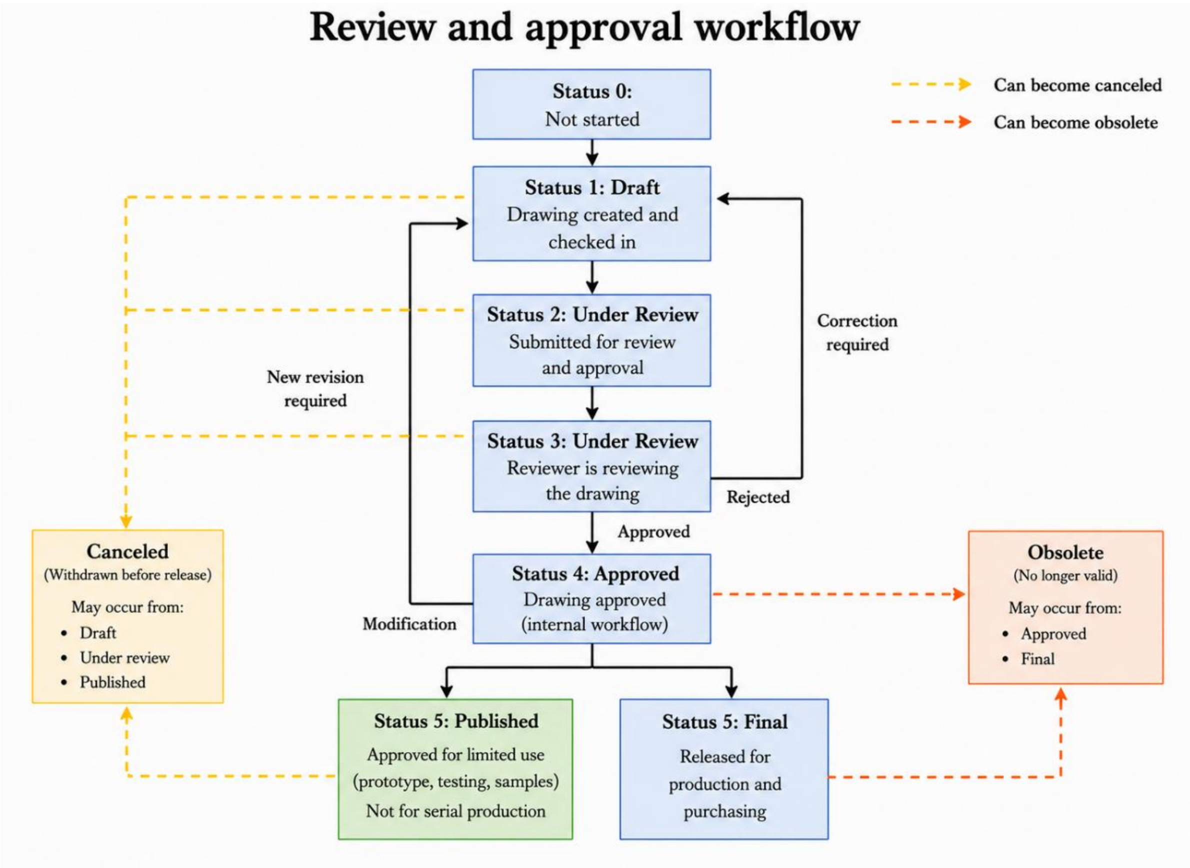

Figure 17: Review and approval workflow in Windchill.

7.2.1.1 Review and approval in Windchill

To submit drawings for review and approval in Windchill, a change notice is created from the relevant object, typically the assembly. The change notice is created by selecting the object in Windchill and choosing **Actions** → **New** → **New Change Notice**. The change notice is created from the assembly or CAD Part to be released. When submitting the request, associated drawings, CAD models, assemblies, and related files shall be included in the request.

Under the implementation plan, the change notice contains related change tasks connected to the review and approval workflow.

The workflow involves both the drawing creator and an assigned approver/reviewer. The drawing creator is responsible for opening, reviewing, and reworking the change notice task, while an assigned colleague acts as approver and performs the approval activities.

7.3 Review of drawings for production

All production drawings for onsite production shall be reviewed before release. The purpose of the review is to ensure that the drawing contains sufficient information for manufacturing and can be used without additional clarification.

Production drawings are reviewed and approved by a designated reviewer from the production department (see Section 3 for current responsibility).

The review and approval process is performed through the PLM system (Windchill), where the drawing is assigned to the reviewer and approved or rejected based on the review outcome. If errors or missing information are identified, the drawing is returned to the designer with comments for correction. The designer shall update the drawing and resubmit it for review. Both new drawings and revised drawings shall go through the review process.

Before submission for approval, the designer is responsible for ensuring that the drawing is complete. The aspects described in Section 7.5 shall be used by the designer to support self-review and provide an indication of what is typically evaluated during the formal review.

The review formal shall verify that the drawing is complete, clearly defined, and feasible to manufacture, and that it complies with applicable standards and company-specific production requirements. The review is based on established practices and experience from on-site production. The aspects described in Section 7.5 define a minimum level to be achieved but do not constitute formally defined review criteria, as no such criteria are currently established.

7.4 Review of drawings for purchasing

Purchasing drawings shall be reviewed before release to ensure that the supplier has sufficient information to manufacture the component.

The designer is responsible for ensuring that the drawing is complete and suitable for purchasing before it is submitted for approval. This includes reviewing the drawing and, when necessary, discussing it with colleagues or the purchasing department to verify that the information provided is sufficient.

All purchasing drawings shall follow the formal approval workflow in the PLM system (Windchill). Purchasing drawings should be approved by a colleague, preferably a senior designer depending on the complexity of the component, and in consultation with the purchasing department where appropriate.

The person performing the review is responsible for verifying that the drawing meets the required criteria before approval. Approval in the system indicates that the drawing has been reviewed and is considered complete, unambiguous, and suitable for use by the supplier, and shall only be given after such a review has been performed. The aspects described in Section 7.5 may be used as guidance during review and approval and define the minimum requirements that shall be verified. These do not constitute formally defined review criteria.

The review shall ensure that the drawing is complete, clearly defined, and contains all information required for the supplier to manufacture the component, including dimensions, tolerances, materials, and other relevant specifications, and that it can be used independently without relying on external communication.

All information required for manufacturing shall be included in the drawing to ensure traceability. Critical specifications shall not be communicated only through external communication (e.g. email), as this may lead to incomplete documentation and difficulties when reusing the drawing or changing suppliers.

7.5 Review criteria

7.5.1 General criteria

Review criteria define the aspects that shall be verified during drawing review.

At present, detailed and fully standardized review criteria are not formally defined. The criteria below describe the minimum requirements that shall be verified during review.

The drawing shall be reviewed to ensure that:

- The drawing is complete and contains all information required for its intended use.
- The drawing is fully dimensioned, and all critical dimensions are included.
- Tolerances are defined in accordance with applicable specification or agreed requirements.
- All dimensions are toleranced, either by individually specified tolerances or by applying general tolerances where appropriate.
- Dimensions, tolerances, and specifications are complete and unambiguous.
- All included parts or materials are listed in the parts list.
- Balloons are correctly placed and correspond to the parts list.
- The title block is correctly completed.
- All required notes and specifications are included.
- Surface roughness is specified where required.
- Geometrical tolerances are applied where necessary.
- The drawing is clear, readable, and easy to interpret.
- The drawing follows applicable ISO standards.
- The drawing follows company-specific standards defined in this handbook.

7.5.2 Differences for production vs purchasing

7.5.2.1 Production drawings

In addition to the general criteria, production drawings shall be reviewed to ensure that:

- The design is feasible to manufacture using available on-site production methods.
- The drawing is clear and understandable for production personnel.
- Backer standard tolerance table is included and applied to all dimensions without individual tolerances.
- Individual tolerances are specified for critical dimensions where tighter control is required.
- Textual elements are in Swedish.
- Required manufacturing notes are included.
- The manufacturing standard is defined in the title block.

- Leak-tightness requirements are specified where applicable and stated in connection with the manufacturing standard.
- A bend chart is included where necessary.

7.5.2.2 Purchasing drawings

In addition to the general criteria, purchasing drawings shall be reviewed to ensure that:

- The drawing contains all information required for the supplier to manufacture the component.
- The drawing can be used without relying on external communication.
- Tolerances are defined in accordance with agreed specifications established with the customer.
- General tolerances are applied where individual tolerances are not specified.

7.6 Common mistakes identified during drawing review

Examples of common issues identified during drawing review include:

- Use of bending radii below the minimum values specified in TI, which may lead to failure during manufacturing (e.g. pipes breaking during bending).
- Missing or incomplete notes specifying required tests in the manufacturing standard field.
- Missing balloon references linking components in the drawing to the parts list.
- Unclear or ambiguous dimensioning, where it is difficult to determine which feature a dimension refers to.

These issues shall be corrected before the drawing is approved.

8 Systems supporting drawing management

8.1 PLM System

8.1.1 Purpose of the system

The PLM system (Windchill) is used to manage drawings and related product data throughout their lifecycle. It provides a controlled environment for storing, reviewing, approving, and updating drawings. Drawings move through defined lifecycle states, which control their status and how they may be used.

The system ensures that only the correct and approved versions of drawings are available for use, while maintaining traceability of revisions, approvals, lifecycle states, modification history, and related objects within Windchill. Drawings are linked to related product data such as Parts, assemblies and BOM structures, enabling traceability between individual components and the overall product structure.

The PLM system is used to maintain controlled documents. For drawings, this means that:

- The latest approved version stored in the PLM system is the valid reference.
- Changes shall go through review, approval, and revision handling.
- Drawings and related product data are protected from unauthorized modifications.

This section provides an overview of selected Windchill functions and tools relevant for drawing and product data management. More detailed instructions regarding the use and functionality of Windchill are referred to PTC online documentation and support material.

8.1.2 Object types and relationships

The PLM system stores several different object types used to represent product information. The main object types are:

- CAD Parts (.PRT)
- CAD Assemblies (.ASM)
- Drawings (.DRW)
- Parts

These object types are connected through relationships established within Windchill.

A distinction is made in Windchill between CAD documents and Part objects. CAD documents represent the actual CAD files created in Creo and contain the geometric and engineering definition of the product, such as models, assemblies, and drawings. Part objects are instead used to manage product-related information such as revisions, lifecycle states, BOM structures, and traceability. Each CAD Part and assembly is linked to a corresponding Part object in Windchill, while drawings are linked through references to related models or assemblies.

By selecting the information view for an object, users can access object-specific information such as metadata, lifecycle information, history, related objects, and structure views. Depending on the object type, different relationship categories and structure views are available under the *Related Objects* and *Structure* tabs.

The *Related Objects* view includes:

- **Where Used**, which shows in which higher-level assemblies an object is used.
- **References**, which shows objects referenced by the current object.
- **Referenced By**, which shows objects that reference the current object.

Together, these relationships create a connected product structure that allows users to navigate between related CAD documents, assemblies, BOM structures, and drawings within the system. Depending on the object type, different related information and relationship views are available, as summarized in Table 9.

Table 9:Relationships and accessible related information between object types Windchill.

Object type	***Related information visible in Windchill***
Part	Corresponding CAD document such as drawing and assembly or CAD Part. If the Part is related to an assembly, one can view all Parts included in the assembly and their quantities, as a BOM.
CAD Part (.PRT)	Corresponding Part object. The “Where Used” view shows in which assemblies the component is included, and these assemblies can in turn be traced further upward through multilevel assembly structures. It is also possible to see which drawings reference the CAD part, including both its own drawing and higher-level assembly drawings.
Assembly (.ASM)	Corresponding Part object. The assembly structure can be viewed together with all included CAD Parts and subassemblies. It is possible to navigate further into the structure to view the CAD Parts included within subassemblies. In addition, assemblies where the current assembly is used as a subassembly can be viewed under “Where Used”.
Drawing (.DRW)	Referenced CAD Parts or assemblies shown in the drawing and their corresponding Part objects.

8.1.3 Data transfer from CAD

8.1.3.1 Integration between Creo and Windchill

The connection between Creo and Windchill is used continuously during design work. The connection enables information created in Creo to be transferred and managed within the PLM system, and vice versa. Models and drawings created in Creo are transferred to PTC Windchill through check-in operations. During check-in, the CAD files are stored in the PLM system together with associated metadata, parameters, revision information, and lifecycle data.

All models and drawings created in Creo are stored and managed in Windchill through the integration between the systems. However, older legacy 2D drawings created in other systems are not stored within the PLM system. Handling of legacy drawings is described in Section 9.4.2.

Before a CAD document can be modified, it is checked out from Windchill. Check-out reserves the object for editing and prevents conflicting modifications by other users. After modifications have been completed in Creo, the updated object is checked back into Windchill, where the updated file and associated information are stored and version information is updated.

8.1.3.2 Parameters and drawing Information

Information created or modified in Creo can be stored in Windchill, while information managed in Windchill can automatically populate parameters, metadata, and drawing information in Creo. Parameters in Creo may be controlled through Windchill, generated from model relations, or defined by the user.

Some parameters are automatically generated or controlled through Windchill and are therefore locked from editing in Creo. Drawing information and title block data are therefore partly controlled through Windchill, partly through the drawing template, and partly entered manually by the user. Further description of title block fields and parameter handling is provided in Section 5.3.

8.1.4 Information stored

The PLM system stores drawings and related product information. Stored information includes:

- CAD models and assemblies.
- Drawings and associated documents
- Part objects
- Metadata and product attributes
- Revisions and lifecycle states
- Approval information
- BOM structures and related product relationships
- Change history and revision information

8.1.4.1 Libraries and data organization

Product data in Windchill is organized into different libraries depending on object type and business area. The libraries include standard components, Backer-specific components, tools, and project- or business area-related data. Objects shall be stored in the correct library according to the applicable project, component type, or business area, to maintain structured organization and traceability of product information.

8.1.4.2 Object identification

Each object in PTC Windchill is identified by both a **number** and a **name**. The **number**, i.e. the file name defined when the object is created, shall correspond to the article number and is used as the primary identifier within the system. Further guidance for creation of new article numbers is provided in document *Konstruktionshandbok*. In Windchill, the article number consists of 8 digits, while the corresponding article number in the ERP system consists of 10 digits. The two omitted digits form a prefix in the ERP system used to define the article type.

The **name** provides a descriptive representation of the object and shall follow established naming conventions. The name shall be sufficiently descriptive to distinguish the object from similar components and support identification within the system, although searching is primarily performed using the object number. Consistent application of naming conventions is important to maintain organized product information within the PLM system.

8.1.4.3 Metadata and attributes

Each object also contains metadata and product-related attributes used for identification, traceability, and lifecycle management. Metadata stored in the system may include:

- Object number and name
- Revision and version
- Lifecycle state
- Creator and modification history
- Approver and approval date
- Check-in status
- Storage location within the system

Objects may additionally contain product-related attributes such as:

- Article number
- Description
- Material information

- Classification
- Manufacturing information

8.1.4.4 Lifecycle and revision information

The lifecycle states used in the company include Draft, Under Review, Published, Approved, Final, Obsolete, and Canceled. These states are used to control the status and usage of drawings and related objects. Further description of lifecycle state transitions and the review and approval workflow is provided in Section 7.2.

Previous versions and revisions remain stored in the system and can be accessed through the object history. The history view shows information such as revisions, lifecycle state transitions, check-ins, version updates, dates, and associated users. Older versions of objects can still be opened and reviewed, although they are marked as not being the latest revision.

8.1.4.5 Change Information

The Change Information view in Windchill is used to display release, review, and approval activities associated with publishing or revising objects in the PLM system. When requesting release or publication of drawings and other product data, a change notice is created in Windchill as part of the approval workflow. Through the Change Information view, users can access associated change notices, related tasks, affected objects, and approval information connected to the release workflow. Further description of the review and approval workflow is provided in Section 7.2.

Formal change management of released products is not handled through Windchill, but through the company change management process in the AM system, see Section 9.2.1.

8.2 ERP System

8.2.1 Purpose of the system

The ERP system (Epicor) is used to manage released product and operational information within the company. While the PLM system is used to manage engineering documentation and product development data, the ERP system supports processes such as purchasing, production planning, inventory management, manufacturing, and financial reporting.

The purpose of the ERP system is to provide a centralized platform for managing and sharing product and business-related information between different departments within the organization. Within the context of drawing and product data management, the ERP system is used to make approved engineering information, such as released drawings, article information, and BOM data, available to functions outside engineering. The ERP system therefore functions as the primary operational system used after engineering data has been approved and released.

Further instructions regarding ERP-specific workflows and administration are described in separate internal company documentation.

8.2.2 Data transfer from PLM

Since no automatic integration currently exists between the CAD, PLM, and ERP systems, released drawing information and related product data must be transferred manually from the PLM system to the ERP system.

Once a drawing has been released in the PLM system, the released drawing information shall be transferred to the ERP system. A corresponding article shall either be created in Epicor or connected to an existing article, depending on whether the product already exists in the system. The released CAD drawing shall first be saved as a PDF from the PLM system and thereafter attached to the corresponding article in Epicor.

After the drawing has been added to the ERP system, additional article-related information shall also be entered into the article. Some of this information already exists within the drawing or PLM system but has to be transferred manually into Epicor. Examples of such information is described in Section 8.2.3.

BOM information shall likewise be entered into the ERP system manually. A common approach is to copy the BOM from a similar existing article and modify it to correspond to the new product structure.

When information is entered manually into the ERP system, care shall be taken to ensure that the entered information is correct and consistent, to avoid errors and inconsistencies in downstream operational processes.

8.2.3 Drawing related data

The ERP system stores product and drawing-related information required for purchasing, production, inventory management, and related company processes. Examples of information managed within Epicor include:

- **Released PDF drawings -** Used by purchasing, production, and other operational functions to access approved drawing documentation.
- **Article numbers -** Unique identifiers used to identify and manage products within the ERP system. Article numbers in Epicor consist of 10 digits, while corresponding object numbers in the PLM system consist of 8 digits, as described in Section 8.1.4.2.
- **Article descriptions -** Descriptive names used to identify the product.
- **Item type - S**pecifies whether the item is manufactured internally or purchased from a supplier.
- **Business unit -** Defines operational area associated with the article, such as OEM, Automotive, Industry.
- **Item class** - Used to categorize articles according to internal classification structures.
- **Reference categories -** Used for grouping and statistical purposes, for example product categories such as heat pumps.
- **Material-related information** - Information related to material definitions or material specifications connected to the article.
- **Bill of materials (BOM) -** Defines the product structure and lists components and quantities required for manufacturing or assembly.

9 Change management

9.1 Purpose of change management

The purpose of the change management system is to ensure that all modifications to products and product-related information are controlled, traceable and approved before implementation.

Changes to a product can affect multiple areas, including design, manufacturing, purchasing, quality, and customer requirements. When properly managed, changes help ensure correct production, controlled costs and improved product quality.

Change management ensures that:

- **Changes are controlled:** Proposed changes are reviewed in advance with regard to impact, risk, and feasibility before implementation.
- **Traceability is maintained:** Each change is documented, enabling a complete history of what was changed, why it was changed, and who approved it.
- **Cross-functional alignment:** Relevant functions are involved in the process so that changes are reviewed, communicated, and approved by all affected stakeholders.

As drawings are a central part of the product definition, any change affecting the product shall also be reflected in the associated drawings.

9.2 Change management process

For a complete description of the company's engineering change process, refer to the document *Engineering Change Process*.

Product changes shall follow the established engineering change process to ensure controlled implementation and traceability.

The general process follows these steps:

1. A need for a change is identified.
2. A business case and a risk analysis is created for the change.
3. An engineering change request (ECR) is created and documented in the change management system.
4. The proposed changed is evaluated by relevant stakeholders.
5. The change is approved or rejected.
6. Approved changes are implemented.
7. Updated product information is released and communicated.

As part of this process, all affected product documentation, including drawings, shall be updated to reflect the approved change. This may include, for example, CAD models, bills of materials, parts lists, manufacturing documentation, and requirement specifications.

Product changes involve multiple functions, which evaluate the impact of the change within their respective areas. A change is implemented only after it has been reviewed and approved by the relevant stakeholders.

Product changes are handled differently depending on the lifecycle stage and the degree of maturity of the product.

During development, changes are managed more flexibly as part of the ongoing design process. Drawings may be updated iteratively, and revisions are primarily used to track design progress. However, the extent to which modifications may be performed directly depends on the maturity and status of the related product data.

Once a product has been released, all modifications to released product data and associated documentation shall be managed through the formal engineering change management process in the AM system. In this phase, all changes must be registered, evaluated, and approved before implementation, and all affected documentation, including drawings, shall be updated accordingly.

9.2.1 Change management system

Engineering change request are registered in the change management system (AM-system), where a change request is created to describe the proposed modification, including reason, feasibility, and expected impact.

Each change request is assigned a unique reference number in the system. Once the change has been reviewed and approved, this reference number is used to link the implemented change to affected documentation.

When a drawing is updated as part of an approved change, the reference number shall be included in the revision filed together with the a brief description of the modification, as shown in Section 4.2.1.2. This ensures that the drawing change can be traced back to the corresponding change request, where more detailed information is available.

When a drawing is revised, it shall be submitted for approval and go through the formal release process again in the PLM system.

9.2.2 Handling of minor corrections

For drawings used only internally, minor changes such as spelling or formatting corrections may in some cases be implemented without creating a new revision by temporarily unlocking the revision to perform the correction so that the updated version becomes available to all users.

However, this is discouraged for externally distributed drawings, as it may lead to inconsistencies between internally and externally distributed versions of the drawing. Formally, any change to a released drawing requires a new revision to be issued and redistributed to affected stakeholders. To avoid unnecessary updates, minor corrections shall therefore be postponed and included in the next revision.

9.3 Revision management

9.3.1 Revision numbering

Revision numbering defines how different versions of a drawing are identified.

During development, when drawings have status *Draft* or *Published* in the PLM system, versions are indicated using letter-number combinations (e.g., A1, A2, B1, B2), reflecting ongoing design iterations. Multiple versions may exist simultaneously in the PLM system and may represent different design alternatives under evaluation, which do not necessarily need to resemble each other. Once published, versions can, for example, be used to manufacture samples or prototypes for testing in order to determine the most suitable design solution.

Once a suitable version has been selected and approved, it is released to status *Final* and may then be used for serial production, manufacturing, and purchasing activities. Released revisions are indicated using letters (e.g., A, B, C), representing approved versions of the product definition.

A transition from one revision to another, ex. A to B, indicates that the released product definition has been modified. Such changes shall be managed through the formal engineering change management process in the AM system (see Chapter 9).

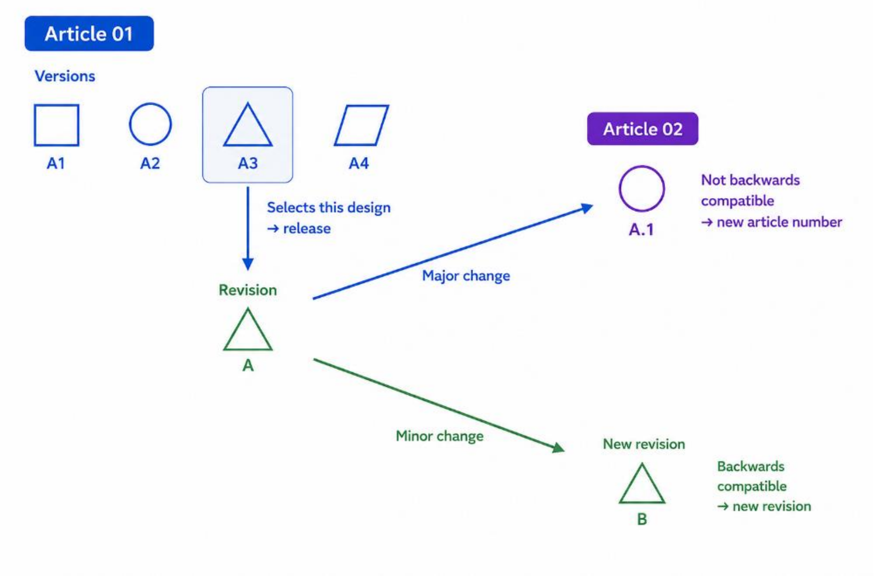

Figure 18: Example of revision management through versions, revisions and article numbers.

The relationship between versions, revisions, and article numbers is illustrated in Figure 18. In the example shown, versions A1, A2, A3, and A4 represent different design alternatives under evaluation, where version A3 is selected and approved as released revision A. Subsequent modifications to the released product definition may either result in a new revision of the existing article number, i.e. B, or, in the case of major changes, creation of a new article number. Further information regarding the use of revisions and handling of changes requiring a new article number is provided in Section 9.3.2.

9.3.2 Use of revisions

Revisions are used to track changes to the existing product definition and to maintain traceability. Depending on the scope of the change, it may instead be necessary to create a new article number rather than a new revision. The rules for this are defined in the document *Engineering Change Process*.

When a change is managed as a revision, traceability is maintained within the same article number. All revisions are directly linked within the PLM system (e.g., PTC Windchill), which simplifies tracking since the product identity remains unchanged while its evolution is documented through revision updates.

When a change instead requires a new article number, traceability must be maintained by linking the new article to the previous one in the PLM system. This allows the product history to be followed even when the product identity changes.

From a drawing perspective this means that:

- Changes managed as revisions shall result in an updated drawing revision.
- Changes requiring a new article number require a new drawing linked to the new article.

9.4 Updating existing drawings

9.4.1 General procedure for updating drawings

When a change is managed through a revision, the drawing shall be updated in a new revision in the PLM system based on the approved product definition.

If a CAD model exists, the change shall be implemented in the model and not directly in the drawing. The drawing shall then be updated through the model to ensure consistency between the model and the drawing. If no CAD model exists, see Section 9.4.2.

The following general steps shall be followed:

1. Review the current revision and identify the required changes based on the approved product change.
2. Create a new revision in the PLM system.
3. Update the drawing in the new revision.
4. Document the changes in the revision field by:
    i. Adding a brief revision description
    ii. Including the reference number from the AM-system
    iii. Adding revision indicators on the drawing, where applicable.
5. Submit the updated drawing for approval and release

The extent to which drawings should be updated or adapted to current standards depends on the scope, complexity, and expected future use of the project. For products expected to be reused repeatedly or maintained over time, more extensive updates may be justified, while for smaller or one-of-a-kind projects, more limited modifications may be a more time-efficient alternative.

9.4.2 Legacy drawings

Only drawings created in Creo from 3D models are stored in Windchill. However, a number of older legacy drawings exist only as 2D PDF drawings without associated 3D models. These drawings are stored in **Gemensam (G:)\Specifikations**, where the correct drawing can be located based on the item class. Legacy drawings may be relevant, for example, when a customer requests a product based on an older drawing.

When updating a legacy drawing, two approaches may be used depending on the scope of the change, available time, and future need for the drawing.

- **Create a new 3D model and associated drawing in Creo.**
  This approach creates a fully managed drawing package stored in Windchill and supports future revisions and reuse. This approach is generally preferred for products intended for repeated or serial production, where the drawings are expected to be reused and maintained over time.
- **Modify the existing 2D drawing in BricsCAD.**
  This approach allows required changes to be made manually directly in the drawing without creating a 3D model, which reduce the time required for simpler updates. This approach may be suitable for one-of-a-kind products or smaller projects where the drawing is not expected to be reused extensively in the future.