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Identification Of Hospital Objects To Design The Transformability Of Hospital Systems - A Factory Planning Approach For Hospitals

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Abstract

Hospitals are facing the challenges of a turbulent environment. External influences such as cost pressures and changing disease patterns limit their actual performance and frequently pose challenges to their regular operations. Manufacturing companies face similar challenges. To counter external influences and adapt quickly and cost-effectively to changes in the environment, factory planning utilises transformability as a key strategy. Transformability describes the ability of a system to actively implement structural changes with little effort and thus adapt to changing requirements. However, the design of transformability cannot be carried out for the entire system, but is realised on the basis of individual system objects, in this case factory objects. In order for hospitals to be able to position themselves in a transformable way, hospital objects are needed in analogy to factory objects. The aim of this paper is to identify those hospital objects in which a change process is possible or which can influence such a process. In order to identify these hospital objects, a search space is first created using defined system levels and design fields, on the basis of which the hospital objects can then be identified and systematised. This work thus provides a basis for operationalizing transformability in hospitals and contributes to securing the future of the healthcare system.

Keywords

change capability; transformability; hospital planning; hospital objects

1. Introduction

Hospitals are at the mercy of change drivers such as demographic change, the shift in the distribution of disease patterns or consolidation in the hospital market [1,2]. To make matters worse, some drivers of change, such as the recent COVID-19 pandemic, have little predictability [3]. The environment of hospital systems can therefore also be described as turbulent [4]. In order to remain operational and competitive, hospital systems must be able to adapt to these change drivers. However, examples from practice demonstrate that hospitals are unable to meet this requirement due to their transformation inertia.

1.1 Transformability and transformation objects

The concept of transformability has its roots in factory planning, whereby transformability must be distinguished from flexibility. The flexibility of a factory describes its ability to react to preconceived changes within a defined area. Transformability, on the other hand, goes beyond this ability in that structural changes can be implemented in the factory beyond the initially defined area. The preconceived solution space must be activated in the desired form and, in contrast to flexibility, is not immediately available for

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use. In order to implement a transformation process, systems must have certain properties that can be described as transformation enablers [5]. Investing in transformability thus offers hospitals, like factories, the potential to extend their life cycle [6] and thus ensures the future viability of the system [7]. For this reason, transformability is considered a success factor for maintaining and expanding competitiveness [8].

The transformability of a system is achieved through the design of transformation objects [5,9,10]. Transformation objects, also known as factory objects in relation to the factory system, are physical and non-physical components into which a factory can be categorised as a highly complex system. Examples are the factory layout, the technical equipment of the factory or the underlying logistics concept [11]. Transformation objects can be designed by people and have neither their own will nor their own needs [12].

1.2 Motivation and structure

In order to realise sustainable hospital systems that can absorb the change drivers from their turbulent environment, hospital systems must be designed to be transformable in a similar way to factories [13]. However, there is no established planning procedure for this in hospital planning [14]. In order to create the necessary basis for this, it is therefore necessary to identify transformation objects in the hospital system with which its transformability can be designed. This paper identifies and systematises the so-called hospital objects and thus lays the foundation for the targeted design of transformable hospital systems.

To this end, Section 2 of this paper sets out and describes a search space consisting of hospital system levels and relevant design fields. For a better understanding, the systems theory on which the approach is based is also discussed here. With this basis, the first-order hospital objects can be identified, described and localised in the search space in Section 3. A detailed description of the second-order hospital objects is provided in the appendix. Finally, a summary and discussion follows in Section 4.

2. The search space

In order to identify and systematise the transformation objects in the hospital system, a search space is established. The search space is shown in Figure 1 and results from the system levels of the hospital and its design fields [11]. In the following, the system levels and the design fields are derived for a better understanding and differentiated from each other in terms of definition for the identification of the hospital objects based on this.

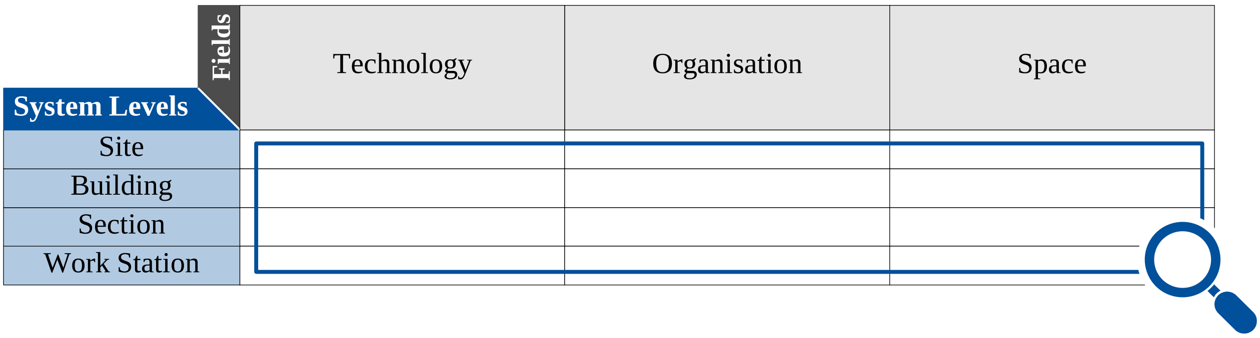

Figure 1: Search space for the identification of hospital objects

2.1 System levels

Due to the diversity of patient treatments and specialised medical facilities, hospitals are complex systems [16] whose description as an overall system does not make sense. With the help of systems theory, however, they can be broken down into less complex system levels, which makes it possible to describe them [17,18]. A system is a number of elements that interact with each other [19], which can also be described as relationships [20,21]. The hierarchical system concept, shown in Figure 2 (left), breaks down each system into logical subsystems of a lower order in which each higher level includes the levels below it. It is therefore suitable for reducing the complexity of the overall system [17]. By forming subsystems at different levels, the level of detail increases as the system level decreases [18,21].

Following the example of factory planning [22], the hospital is divided into the five system levels shown in Figure 2 (right) using hierarchical system theory. The subdivision of the planning levels is not standardised in hospital planning [5,23,24], so that these were only used as a guide and own definitions were determined.

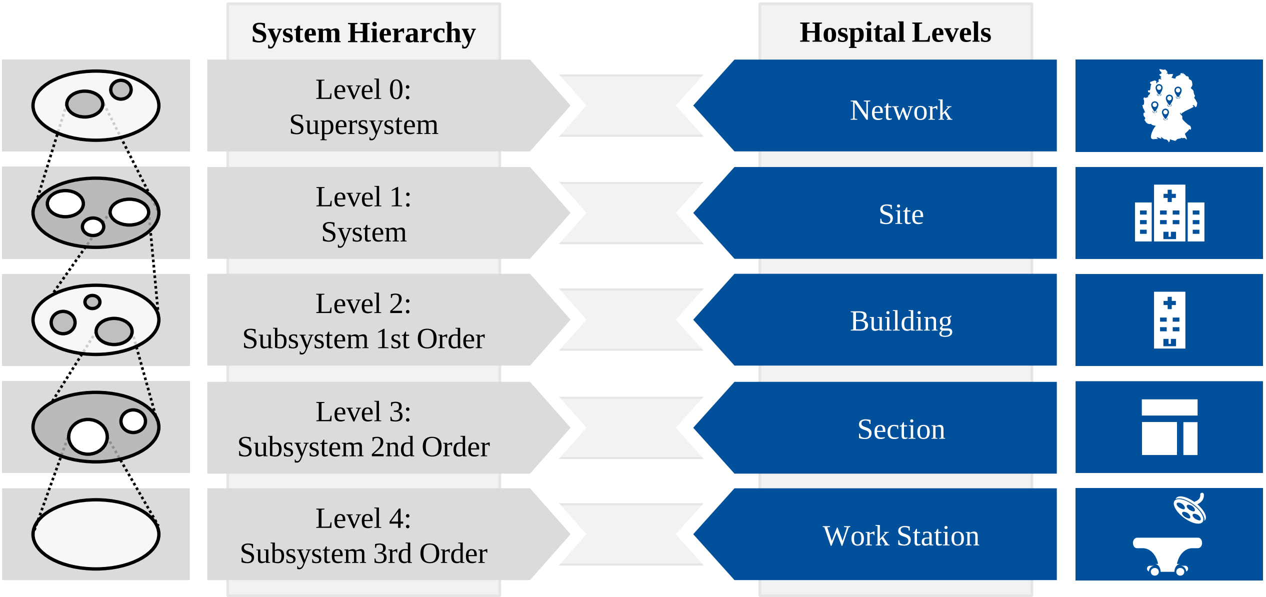

Figure 2: Illustration of the hierarchical system concept and hospital levels

Level 0 is the **network** as the highest hospital level. This is a cross-location organisation of hospitals [25] that includes other hospitals and the global environment. This includes, for example, the healthcare market, society, politics and competitors [26]. The network system level is not included in the search space, as it cannot be influenced by hospital planning. Level 1 is the **site**, which is at a fixed location and may have several buildings. It refers to the combination of all buildings and outdoor facilities of the healthcare facility as a whole [27,28] and also includes internal path networks and other developments. While the site represents the healthcare facility as a whole, level 2 focuses on the **buildings**. Buildings are structurally constructed and architecturally and spatially self-contained areas [24]. Depending on the structural design, this level contains either an individual building that can be clearly demarcated within the hospital site or, as is usually the case, a coherent complex of buildings [29]. However, if there are clear demarcation criteria, it is also possible to subdivide connected building complexes, e.g. in the case of building parts from different years of construction that are connected by structural elements. Level 3 is the **section**, which is defined as an individual sub-unit of the hospital that specialises in a defined specialist or functional area of medical service provision [30]. This understanding is supplemented by areas that are not directly involved in the provision of medical services and can be summarised by similar functions. Examples of such areas include wards, radiology departments as well as heating centres and kitchens [28]. Level 4 comprises the **work station**, in which specific work activities take place. As the smallest unit, a work station contains the basic elements of equipment and the necessary space [11]. Other sources also include people among the basic elements of the lowest level [26,31,32], although this does not necessarily have to be the case in the course of digital transformation [33]. Accordingly, at the lowest level, the work station of the hospital contains the basic elements that are necessary for the underlying process, regardless of the presence of a person.

2.2 Design fields in the hospital

In order to further reduce the complexity of the hospital and thus make its system describable, it is also useful to establish design fields [15]. WIENDAHL ET AL. and other list the design fields of technology, organisation, personnel, location and building [26,31,34,35]. Other design fields listed in the literature include management [26], logistics [15,35,36] as well as facilities and equipment [37,38].

In the following, the design fields and their definitions are taken from HEGER in conjunction with HERNÁNDEZ. The design field of **Technology** covers technical building equipment and information technology (IT) on the one hand and all technical resources for primary and secondary services on the other. This also includes, for example, facilities and equipment, which therefore do not constitute a separate design field. According to HEGER's definition, the design field of **Organisation** also includes aspects such as logistics and quality assurance in addition to the structural and process organisation [11]. According to HERNÁNDEZ's description of organisational transformability, logistical processes and principles can be assigned to the organisational design field, as changes and adaptations influence organisational structures and processes [26]. They are therefore not considered as an independent design field below. HEGER subsumes the design fields of location and building under the design field of **Space**. Space considers the site from an architectural perspective, the structural facilities and their arrangement as well as the layout and workstation design.

People also form a design field, although they are not an object but a subject. They have their own will, needs, mind and intelligence [12]. However, individual human characteristics such as knowledge, skills or behaviour can be shaped and can therefore be defined as transformation objects [11,39]. People can be influenced by goals and strategies from the additional design field of leadership [11,15]. However, the design fields of people and leadership are not part of the search space. This is due to the fact that although people play a fundamental role in the socio-technical system of hospitals as key service providers and are responsible for the success of the transformation processes [15], they can only be shaped through, for example, training or further education after the planning phase has been completed. The definition of objectives and strategies, which are part of the leadership design field, exceed the scope of action of planning. Objectives and strategies are primarily defined at the organisational level [11]. In addition, the objectives for hospital planning are often predetermined, so that the definition of objectives and strategies can be regarded as defined [13].

3. Identification of hospital objects

Hospital objects are to be identified as those objects for which a change process is possible or which support the transformation through existing characteristics [26]. Only transformation objects that can be clearly assigned to the axes of the search space in Figure 1 are relevant hospital objects. This not only allows different levels of detail to be considered, but also ensures that all transformation objects of the entire hospital system are taken into account. The search starts at the top level of the search space for each design field and moves downwards from the site level to the work station level. If the assignment of a transformation object to a design field from Section 2 proves to be ambiguous, its primary function must be taken into account as the decisive characteristic.

The hospital objects identified using this procedure are shown in Figure 3. The hospital objects were identified on the basis of the existing factory objects, which were adapted and extended to the hospital system under consideration using specialist literature, e.g. from hospital or construction management, and two expert interviews. One expert for the interviews is a qualified architect with several years of professional experience. Through her current employment at the Institute of Technology and Management in Construction, she has also acquired expertise in the field of technical building services, enabling her to reliably validate the design fields of technology and space. The other expert for the interviews has already gained experience as the managing director of a manufacturing company and has now been the division manager of a hospital for several years. In this role, she is responsible for commercial, technical and infrastructural tasks. In addition to the objects in the Technology and Space design fields, she was also able to validate those in the Organisation design field.

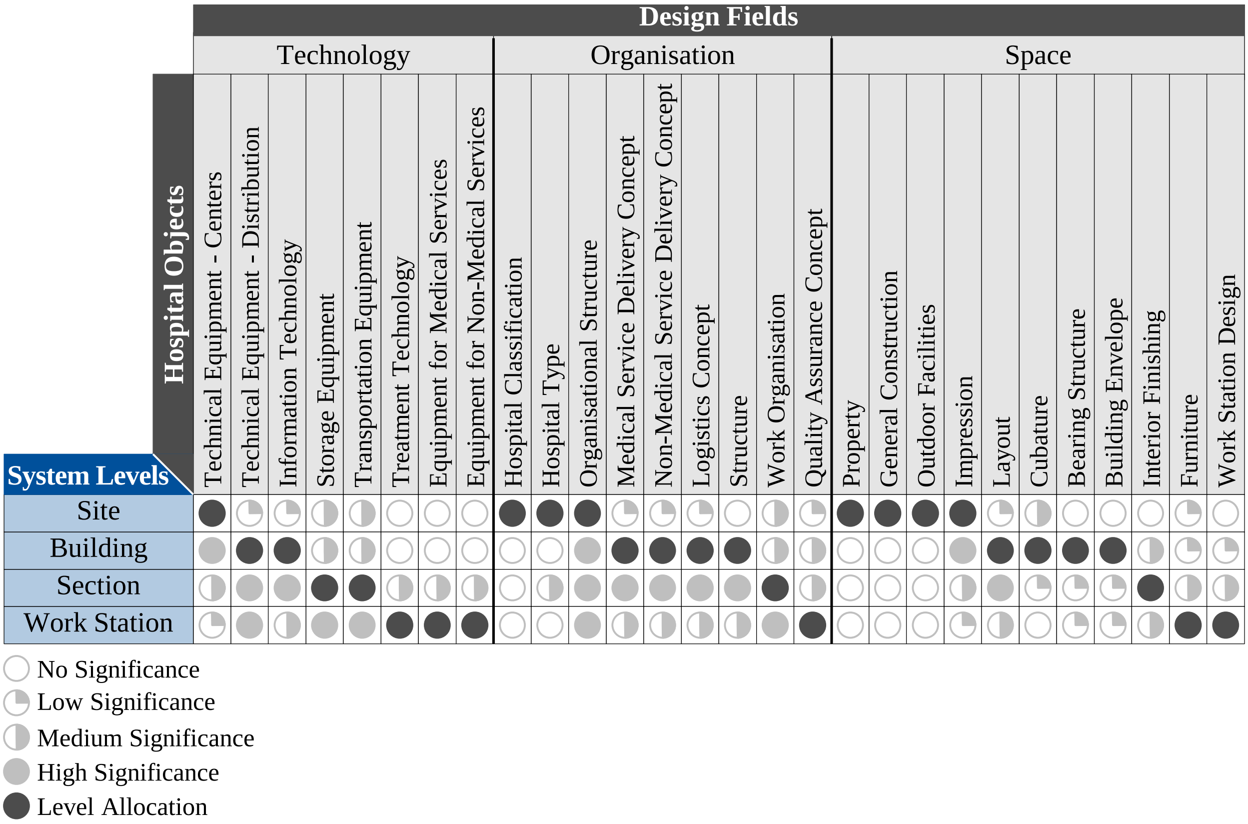

Figure 3: Identification of hospital objects 1st order

The first-order hospital objects shown in Figure 3 are themselves very complex systems. In order to be able to design them in terms of transformability, the first-order hospital objects are also subdivided into second-order hospital objects in accordance with systems theory. The results and the description of the individual second-order hospital objects can be found in the appendix. In the following, only the first-order hospital objects are described in the individual design fields.

3.1 Design field technology

The described dynamics in the hospital system environment require constant adjustments to the technology from the first day of commissioning [40]. Changes in medical technology and care processes result in requirements for building technology [41]. This includes, for example, ensuring that new or further developed diagnostic and treatment procedures, including their equipment upgrades, can be implemented without disruption to ongoing operations. The technical infrastructure is a decisive quality criterion for good hospital planning [42].

At the **site** system level, "Technical Facilities - Centres" are classified as a first-order hospital object. This includes all facilities inside and outside the buildings on the hospital site with the exception of equipment and information technology. "Technical Facilities - Centres" have a significant influence on transformation, as not only the buildings but also the technical systems installed in them have to keep up pace with the transformation of the environment [40].

At the **building** system level, "Technical Facilities - Distribution" and "Information Technology" are classified as first-order hospital objects. The hospital object "Technical Facilities - Distribution" ensures the supply and disposal of media to the buildings and processes through main routes, networks and connections. These media can be liquids, gases or gas mixtures, electricity and information [43]. Due to the increasing number of electronic devices as a result of medical-technical progress, an increasing number of connections for different media is also necessary so that the devices can be used everywhere according to their requirements [44]. The distribution of technical facilities thus influences the transformation process [13] and is to be considered as a hospital object of first-order. The hospital object "Information Technology" deals with the entire IT infrastructure, which includes all facilities for the electronic or messaging transmission, storage, processing and provision of voice, text, still and moving images and data. Information technology in hospitals is not only relevant for applications such as personnel administration, accounting, materials management and controlling, but is also strategically crucial for the efficient management, implementation, documentation and quality assurance of medical treatment [45]. As a result of the digital transformation, both hardware and software components are subject to constant transformation processes. For example, NICKL-WELLER AND NICKL anticipate a networked healthcare landscape in which patients' data is stored in the cloud [33]. Information technology should therefore be listed as a first-order hospital object.

At the system level of **section**, "Storage Equipment" and " Transportation Equipment" are classified as first-order hospital objects. These are facilities that are used for the storage or internal transport of patients and materials. Internal transport is limited to the hospital premises. Due to (medical) technical progress, both storage and transport equipment are subject to change [46,47] and are therefore each to be considered as hospital objects.

At the **work station** system level, "Treatment Technology", "Equipment for Medical Services" and "Equipment for Non-Medical Services" are categorised as first-order hospital objects. These have parallels to HEGER's factory objects Production Technology, Production Resources and Other Resources [11]. Treatment technology comprises the knowledge for the treatment-orientated application of scientific, engineering and medical knowledge. This knowledge is subject to constant progress, which treatment technology must always take into account. This progress also influences equipment for medical and non-medical services [48], resulting in the three hospital objects at this level.

3.2 Design field organisation

There are also demands on the organisation, particularly with regard to the high levels of competition and cost pressure. The following section identifies hospital objects in the design field of organisation that are themselves capable of change or that influence the ability to change.

At the **site** system level, "Hospital Classification", "Hospital Type" and "Organisational Structure" are classified as first-order hospital objects. The hospital classification includes the sponsorship, the legal form and the care level. The hospital type describes the type of cooperation with other hospitals [13] and can take the forms of association, purchasing group, cooperation and merger [49-52]. Due to the dynamic developments in the hospital market, hospitals sometimes adjust their hospital classification or hospital type in order to remain competitive. According to SCHLÜCHTERMANN, the increasingly dynamic environment also leads to a faster need for change in the structural setup of the organisation [53]. Consequently, in addition to the hospital classification and type, the organisational structure is capable of change and must be identified as a hospital object.

At the **building** system level, "Medical Service Delivery Concept", "Non-Medical Service Delivery Concept", "Logistics Concept" and "Structure" are categorised as first-order hospital objects. The medical service delivery concept and the non-medical service delivery concept are based on the factory object production concept. Both describe the fundamental relationships in treatment and therapy. Due to endeavours to meet the competitive and cost pressure of hospitals, the medical and non-medical service delivery concept is adapted as required and must therefore be capable of change. The same applies to the logistics concept, the processes of which are constantly being improved in order, for example, to save on logistics costs caused by transport activities [54]. The structure of hospitals is determined, among other things, by DIN 13080, which divides hospitals into functional areas and functional units [55]. This has been adapted several times since its first version in 1997. Structural changes must also be made as a result of changes in the hospital itself, e.g. the medical departments [56].

At the system level **section**, "Work Organisation" is to be classified as a hospital object of the first order. The ability of work organisation to change is fundamental, particularly in view of the increasing demands placed on working conditions in hospitals from employees and society. For example, better working hours and better pay are required. But other developments also require adjustments to work organisation. One example of this is the outbreak of the coronavirus pandemic, which led to an increase in shift work in fixed groups in order to slow down the spread of the virus by reducing contact [57].

At the **work station** system level, "Quality Assurance Concept" is categorised as a first-order hospital object. Quality management encompasses both the concept of quality assurance and approaches to quality improvement [58]. Quality is influenced by the dynamics of the hospital environment. Cost pressure and the resulting scarcity of resources can have a positive or negative impact on the quality characteristics of both medical and non-medical services, meaning that quality management must be adapted if necessary.

3.3 Design field space

Due to their rigid and outdated building structures, hospitals are often resistant to transformation. However, external influences such as new developments in medical technology require continuous adaptation of spatial structures [16]. In order to meet the dynamic developments in the hospital environment, the use of neutral and transformable building structures is necessary [59]. PAWLIK characterises hospital architecture as a "never-ending innovation process" that is constantly evolving due to external influences [60].

At the **site** system level, "Property", "General Construction", "Outdoor Facilities" and " Impression" are categorised as first-order hospital objects. The increased demand resulting from demographic change, changing values in society and medical-technical progress places demands on the built environment [61]. To achieve this, the property must be transformable, for example, by being expandable to meet increasing demand [42,62]. In order to counteract uncertainties resulting from rapid developments in medicine, use-neutral and transformable general developments are necessary [59], for example by using a grid as a uniform dimensional coordinate system [30]. Similar to the property itself, the outdoor facilities on it must also be transformable, for example, to meet increased demand. Hospitals should not only focus on functionality, but also take into account the aesthetic, psychological and spiritual comfort of patients and staff [44]. In order for the hospital grounds to create a sense of well-being for patients and staff during medical care, regardless of their current status, it is necessary to adapt the appearance to changing requirements [63].

At the **building** system level, "Layout", "Cubature", "Bearing Structure" and "Building Envelope" are categorised as first-order hospital objects. Due to medical and technical changes, the hospital layout must be capable of change [64]. PAWLIK summarizes the history of hospital construction by stating that no form of construction and organisation has ever been considered optimal for its time and that external influences are constantly forcing us to rethink and initiate new cubature [60], meaning that these must be capable of change. Structural changes to the building are closely linked to the bearing structure. Due to its load-bearing function, the bearing structure's capability for change is limited [65] and proves to be rather rigid due to the concreting [16]. This makes the influence of the bearing structure as a feature that affects the transformability of the building all the greater. This means that although the structure itself has limited transformability, it influences the transformability of other objects [66]. Just like the bearing structure, the building envelope also contributes to the changeability of the building [16], for example, in the case of a building extension.

Accordingly, the building envelope represents a hospital object that influences transformability and can itself be changed at the same time [67].

At the system level **section**, "Interior Finishing" is categorised as a first-order hospital object. In order to enable the scalability of individual substructures, the expansion of the clinics must be transformable. This results, for example, from the change in the floor space ratios of care, examination and treatment areas, in which the percentage of floor space for diagnostic and therapeutic facilities increases [13].

At the **work station** system level, "Furniture" and "Workstation Design" are categorised as a first-order hospital object. Changes in treatment or therapy measures as well as new statutory operational or functional requirements mean that the workplace in hospitals must be capable of change [68,69].

4. Summary and discussion

Based on factory planning, 167 hospital objects were identified through expert interviews and a literature search using a predefined search space. Of these, 28 belong to the first-order hospital objects, which are further subdivided into 138 second-order hospital objects. Hospital objects are those that influence a transformation process or for which a change is possible. Hospital objects can be used to describe the hospital system in varying degrees of detail depending on to the requirements. The hospital objects also form the basis for making the transformation capability of hospital systems assessable and plannable. This will require further research to determine the transformation enablers in the hospital and to develop and assess transformation potential characteristics for the hospital objects.

Different countries place different demands on hospitals. These results, for example, from country specific political and legal environment, and healthcare systems. Hence, the transferability of the identified hospital objects to hospital systems could be different in other countries, as this research work focused primarily on the German system. In addition, the focus was on identifying hospital objects that enable the primary and secondary processes of the hospital. Administrative activities were not taken into account, although they may be of interest for further research activities. The concept should therefore be expanded accordingly.

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Appendix

A. Hospital objects

In this part of the appendix, the first and second order hospital objects – sorted according to hospital fields and levels – are listed and described. The elaborations are based primarily on the work of HEGER [11]. Other sources are listed individually.

A 1. Design field technology (T)

Level site (1)

First order factory object	T.1.1	Technical Equipment – Centres
Second order factory object	T.1.1.1	Sewage, water and gas systems
	T.1.1.2	Heat supply systems
	T.1.1.3	Ventilation Systems
	T.1.1.4	Power and safety current systems
	T.1.1.5	Telecommunications and information technology systems
	T.1.1.6	Transport systems
	T.1.1.7	Utilisation-specific systems
	T.1.1.8	Building automation
	T.1.1.9	Technical installations in outdoor facilities
Description:		
The hospital object “Technical facilities – centre” includes all facilities inside and outside the buildings on the hospital premises with the exception of equipment and information technology. Examples are sewage, water and gas systems, which include sewage collection, gas storage, fire extinguishing systems and sanitary cells. Heat supply systems fulfil a heating function with the help of heat generation systems, heat distribution networks and room heating surfaces [70]. Ventilation systems describe ventilation, partial ventilation, air conditioning, refrigeration and process technology systems. These include, for example, ventilation systems and cooling centres [43]. Ventilation technology contributes to the prevention of germs in hospitals by filtering, diluting and displacing the air [43]. Power systems include transformers, internal power supply and lightning protection systems. If the general power supply fails, life-sustaining measures must be taken by safety current systems such as diesel generators with three-phase motors or battery systems [43]. Telecommunications and information technology systems include telecommunications, satellite reception, antenna, fire alarm and electro-acoustic systems as well as search and signalling systems in the form of nurse call systems in hospitals [43]. Transport systems such as lifts, goods transport and pneumatic tube systems exist in hospitals [16,46]. Kitchen, laundry, cleaning, waste disposal and laboratory technology systems are referred to as utilisation-specific systems. Building automation includes control cabinets, automation and control stations. At the hospital site level, there are also technical systems in outdoor facilities such as sewage treatment plants, water extraction systems, hydrant systems and collecting pits [71].		

Level building (2)

First order factory object	T.2.1	Technical Equipment – Distribution
Second order factory object	T.2.1.1	Main routes
	T.2.1.2	Networks
	T.2.1.3	Connections
Description:		
The hospital object “Technical Equipment – Distribution” ensures the supply and disposal of media to the buildings and processes through main routes, networks and connections. These media are liquids (e.g. water, fuels), gases and gas mixtures (e.g. oxygen, nitrogen or compressed air), electricity and information (e.g. data, voice, text and images) [43].		

First order factory object	T.2.2	Information Technology
Second order factory object	T.2.2.1	Hardware
	T.2.2.2	Software

Description:
“Information Technology” comprises all equipment for the electronic or telecommunications transmission, storage, processing and provision of voice, text, still and moving images and data. Hardware refers to all material components of a computer system. This includes, for example, the components contained inside the housing, such as the system board, central processing unit and all types of plug-in cards, as well as all peripheral devices connected to the system, such as printers or monitors. In contrast, software includes all data or programmes stored on the computer systems.

Level section (3)

First order factory object	T.3.1	Storage Equipment
Second order factory object	T.3.1.1	Frame
	T.3.1.2	Storage device
	T.3.1.3	Drive
	T.3.1.4	Kinematic system
	T.3.1.5	Systems for control, regulation, measurement and diagnostics
	T.3.1.6	Storage aid
	T.3.1.7	Peripheral systems
	T.3.1.8	Other aids
Description:		
“Storage Equipment” means equipment used, for example, to store patients, tools or instruments and materials. The storage equipment has several components. These include the frame as the body of the storage equipment. The equipment also has a storage device and drives in the form of power and positioning drives. There are also kinematic systems and corresponding systems for control, regulation and measurement, which enable the objects to be stored, moved and positioned. Storage aids are related to the direct storage process and include pallets, crates or boxes. Peripheral systems include additional systems that support, for example, work safety or media supply. Aids that are not directly related to the storage process, such as ladders or steps, are summarised under other aids.		

First order factory object	T.3.2	Transportation Equipment
Second order factory object	T.3.2.1	Frame
	T.3.2.2	Transport device
	T.3.2.3	Drive
	T.3.2.4	Kinematic systems
	T.3.2.5	Systems for control, regulation and measurement
	T.3.2.6	Transportation aid
	T.3.2.7	Peripheral systems
	T.3.2.8	Other aids
Description:		
"Transport Equipment" is equipment used to transport patients, tools or instruments and materials, for example. The transport equipment has several components. These include the frame as the body of the transport equipment. The transport equipment also has a transport device and drives in the form of power and positioning drives. There are also kinematic systems and corresponding systems for control, regulation and measurement, which enable the objects to be transported to be moved and positioned. Transport aids are related to the direct transport process, such as the loading area. Peripheral systems include additional systems that support, for example, work safety or media supply. Aids that are not directly related to the transport process, such as wheel chocks, are summarised under other aids.		

Level work station (4)

First order factory object	T.4.1	Treatment Technology
Second order factory object		none
Description:		
"Treatment Technology" comprises specific, individual and collective knowledge in explicit and implicit form for the medical and therapeutic utilisation of scientific findings. This includes the expertise that can be used to solve a problem, the activities associated with solving the problem and the material characteristics of the problem solution.		

First order factory object	T.4.2	Equipment for Medical Services
Second order factory object	T.4.2.1	Foundation
	T.4.2.2	Frame
	T.4.2.3	Drive
	T.4.2.4	Kinematic systems
	T.4.2.5	Systems for control, regulation, measurement and diagnosis
	T.4.2.6	Peripheral systems
	T.4.2.7	Instruments
	T.4.2.8	Other aids
Description:		
"Equipment for Medical Services" describes facilities that contribute to direct medical or therapeutic treatment. The foundation includes all parts that transfer the loads of the equipment into the ground, such as fundaments, piles, subfloors or slabs, as well as other requirements such as radiation protection, which are necessary for large medical equipment. Equipment for medical services also has the following components: frame, drives, kinematic systems and systems for control, regulation, measurement and diagnosis. The body of the device is, for example, the device bed, the stands or the housing. Drives include both power drives and positioning drives. Kinematic systems enable the movement of patients or instruments. There are also systems for control, regulation, measurement and diagnostics. Additional systems that are used for occupational safety or media supply, for example, are referred to as peripheral systems. Furthermore, surgical and diagnostic instruments are used for medical readings, such as drills, mirrors or scalpels. There are also other aids, such as surgical templates or nuclides for use as contrast agents.		

First order factory object	T.4.3	Equipment for Non-Medical Services
Second order factory object	T.4.3.1	Frame
	T.4.3.2	Specific devices
	T.4.3.3	Drive
	T.4.3.4	Kinematic systems
	T.4.3.5	Systems for control, regulation, measurement and diagnosis
	T.4.3.6	Peripheral systems and aids
	T.4.3.7	Tools
Description:		
"Equipment for Non-Medical Services" is understood to mean equipment for quality assurance and for handling, picking, sorting, staging and packaging. They can have the following components: The body of the device (frame), devices, e.g. for handling or picking (specific devices), power and positioning drives (drives), moving parts that are required for moving and positioning patients or instruments, for example (kinematic system) and systems for control, regulation, measurement and diagnosis. Additional systems,		

e.g. for work safety or media supply, are summarised under the term peripheral systems. These also include aids such as restraint belts.

A 2. Design field organisation (O)

Level site (1)

First order factory object	O.1.1	Hospital Classification
Second order factory object	O.1.1.1	Sponsorship
	O.1.1.2	Legal form
	O.1.1.3	Care level
Description:		
The "Hospital Classification" differs in its sponsorship, its legal form and its level of care [13]. The sponsorship of the hospital is private, non-profit or public [64]. The choice of legal form determines the legal regulations for the organisation of the company [17]. Both public law (e.g. institutions or foundations) and private law forms (e.g. limited liability company (GmbH), non-profit limited liability company (gGmbH) or public limited company (AG)) are possible. While public hospitals are free to choose their own legal form, private hospitals are bound to private legal forms, as they act according to commercial principles. The care levels depend on the number of beds and are divided into four levels: basic care, standard care, specialised care and central or maximum care. University hospitals generally provide maximum care [17,43].		

First order factory object	O.1.2	Hospital Type
Second order factory object	O.1.2.1	Group
	O.1.2.2	Co-operative
	O.1.2.3	Cooperation
	O.1.2.4	Merger
Description:		
The "Hospital Type" describes the co-operation with other hospitals [13]. Collaboration is expressed in the forms of groups, co-operatives, cooperation and mergers with varying degrees of intensity. The group describes a long-term, binding, cross-organisational cooperation between hospitals [51]. The purpose of the co-operative is to promote the goals of the individual members by means of joint business operations, e.g. with regard to procurement or personnel. When cooperating with another hospital, it is possible for them to share areas such as radiology or anaesthesia [49]. Through a merger, hospitals achieve synergy effects and cost savings, for example by introducing cross-location staffing in the administrative area, merging technical areas or the range of services [52].		

First order factory object	O.1.3	Organisational Structure
Second order factory object	O.1.3.1	Jobs
	O.1.3.2	Structure (-type)
	O.1.3.3	Degree of centralisation
	O.1.3.4	Degree of delegation
	O.1.3.5	Range of services
Description:		
The "Organisational Structure" deals with the targeted structuring of the task system. This involves summarising individual tasks and assigning them to jobs or departments. Jobs are characterised by the task to be fulfilled, workstation assignment, competence and responsibility. In order to divide the entire task complex into smaller parts, there are various structures (types) of organisational forms. A basic distinction		

is made between one-dimensional forms such as functional, divisional, regional or key account organisation and multidimensional forms such as matrix or tensor organisation [53]. The degree of centralisation provides information about the concentration and grouping of tasks in individual positions [18]. The degree of delegation describes the extent to which competences are transferred from higher to lower hierarchical levels [72]. The range of services provided by a hospital complex depends on the number and type of medical and non-medical services it provides and which are characterised in the specialist departments.

Level building (2)

First order factory object	O.2.1	Medical Service Delivery Concept
Second order factory object	O.2.1.1	Treatment paths
	O.2.1.2	Treatment type
	O.2.1.3	Treatment principle
	O.2.1.4	Interlinking structure
	O.2.1.5	Interlinking type
	O.2.1.6	Degree of automation
Description:		
The "Medical Service Delivery Concept" provides information about the fundamental relationships between treatment and therapy in the hospital. Treatment paths standardise the implementation of the entire inpatient treatment by transparently describing the process in terms of content and time depending on the illness [73]. The treatment type can be subdivided into individual or serial treatment, whereby in most cases it is individual treatment in which individual healthcare services are to be provided [17]. The treatment principle is based on the examples of the manufacturing principle: construction site, workshop, group and flow treatment. With a few exceptions, the workshop treatment principle is used in hospitals [74]. Possible interlinking structures are, for example, cell, line, ring, square and net. The interlinking of cells is most likely to be found in hospitals [17]. The interlinking type describes the continuity of patient transport and is continuous, clocked or unclocked. The degree of automation depends on the automated range of functions. For example, there is automation of support systems such as medical devices, transport robots or equipment for people in the hospital [75].		

First order factory object	O.2.2	Non-Medical Service Delivery Concept
Second order factory object	O.2.2.1	Work sequence
	O.2.2.2	Service provision type
	O.2.2.3	Service provision principle
	O.2.2.4	Interlinking structure
	O.2.2.5	Interlinking type
	O.2.2.6	Degree of automation
Description:		
The "Non-Medical Service Delivery Concept" provides information on the basic relationships between other services in the hospital, such as social services, bed preparation or catering. The work sequence defines the processing sequence of the individual work content for all services. The service provision type describes whether individual, series or mass production is involved. A distinction can be made between construction site, workshop, group and flow production. Possible interlinking structures are, for example, cell, line, ring, square and network [17]. The interlinking type describes the continuity of the transport and is continuous, synchronised or not synchronised. The degree of automation depends on the automated functional scope [75].		

First order factory object	O.2.3	Logistics Concept
Second order factory object	O.2.3.1	Procurement concept
	O.2.3.2	Supply concept
	O.2.3.3	Stockpiling concept
	O.2.3.4	Storage concept
	O.2.3.5	Structure concept
	O.2.3.6	Transport concept
	O.2.3.7	Provisioning concept
	O.2.3.8	Controlling concept
	O.2.3.9	Shipping and distribution concept
	O.2.3.10	Disposal and recycling concept
Description:		
Examples of logistics functions include patient transport, laundry logistics, laboratory transport, sterile supplies, food supply, postal services and medical and pharmaceutical logistics [76]. The "Logistics Concept" of the hospital thus serves to provide the right materials, in the right quality and quantity, at the right time and in the right place [77] and the patients at the right time and in the right place. The procurement concept spans a frame of reference consisting of subject (by whom purchasing is carried out, e.g. centralised or decentralised), object (what is purchased, e.g. modular procurement sets or system sourcing), source (from whom is purchased, e.g. single, dual or multiple sourcing), region (where is purchased, e.g. national or international) and principle (e.g. stockpiling or individual procurement) [78]. The supply concept defines a strategy for delivery to the place of consumption or treatment, for example "just-in-time", "just-in-sequence" or "ship-to-line" [46]. The stockpiling concept is largely determined by the customer decoupling point. On the one hand, clinics have stocks of seven to 14 days for a large number of products for treatments or other care services that cannot be planned in advance. On the other hand, there are also products such as transplant organs, specific medicinal products or food that need to be stored or buffered for planned, individual treatments or other care measures [79]. The storage concept describes storage and buffering in the hospital. Storage concepts differ in terms of organisation (e.g. centralised or decentralised), the organisation system (e.g. according to consumption location or chaotic), the goods (e.g. individual part or end product), the function (e.g. incoming, intermediate or buffer), the removal strategy (e.g. LIFO or FIFO) or the structure of the storage (serial, converging, diverging or general [77]. The transport and provisioning concept ensures access and provision at the workstation. This also includes the regulation of container logistics [76]. The controlling concept is responsible for controlling, planning and monitoring the logistics processes. The shipping and distribution concept describes the supply chain to the consumer. Shipping includes packaging and labelling. In distribution, a distinction is made between the number of distribution levels and the distribution structure (e.g. central and area warehouses for materials or holding areas and ward rooms for patients). The disposal and recycling concept regulates the disposal, possible recycling or commercialisation of waste products generated in the hospital. This includes, for example, avoiding overlaps with transport routes in the care and treatment area [80].		

First order factory object	O.2.4	Structure
Second order factory object	O.2.4.1	Structural unit
	O.2.4.2	Flow relationship
	O.2.4.3	Process design
Description:		
The "Structure" can be represented by the structural units of a hospital and their relationships [32]. A structural unit is a building block of the structure that fulfils a specific function [5] and results from the organisational structure of the hospital. The structural units thus result from the functional areas and		

functional centres, under which further sub-units and sub-units can be classified as required [56]. This structure is part of DIN 13080 and flow relationships, such as flows of people, materials and information, must be dimensioned between the individual structural units. Clinical process design is implemented by modelling clinical treatment pathways [17]. The service provision process basically consists of admission, diagnostics, therapy, care and discharge [17].

Level section (3)

First order factory object	O.3.1	Work Organisation
Second order factory object	O.3.1.1	Work type
	O.3.1.2	Work structure
	O.3.1.3	Communication
	O.3.1.4	Qualification
	O.3.1.5	Employment relationship
	O.3.1.6	Forms of employment
	O.3.1.7	Work time model
	O.3.1.8	Remuneration system
Description:		
The hospital object "Work Organisation" contributes to increasing the efficiency and motivation of employees. The work organisation distinguishes, for example, between individual work, group work or process-related teamwork [81]. The work structure includes the expansion or reduction of fields of work, both in terms of quantity and quality. Examples include job rotation, job enlargement, job enrichment and vertical and horizontal divisions of labour [82]. Communication is crucial for the exchange of information between employees [13], including with regard to company, programme, work system, quality and social aspects. Qualification means the targeted and quality-related improvement of employees' work-related and general skills [83]. Forms of employment are either direct or indirect. Examples of indirect forms of employment include temporary work or contract labour [84]. There are both fixed and flexible work time models, which can take the form of full-time, part-time or shift work models, for example [85]. The remuneration system regulates the remuneration for work performed and includes incentive systems. Methods for determining basic pay are requirement-, qualification- or market-oriented [86].		

Level work station (4)

First order factory object	O.4.1	Quality Assurance Concept
Second order factory object	O.4.1.1	Quality Assurance Concept for medical services
	O.4.1.2	Quality Assurance Concept for non-medical services
Description:		
Quality is the "nature of a unit in terms of its ability to fulfil specified and assumed requirements" [87]. The "Quality Assurance Concept" comprises all objectives and activities for maintaining the quality of medical and non-medical services. The quality assurance concept of medical services describes the way in which the service is provided and at the same time covers all activities of the individual medical care process. Examples include anamnesis, diagnostic examinations, medical and nursing treatments, repeat examinations, information, documentation and implementation of clinical treatment pathways. These can be measured by the change in the state of health of the person being treated as well as other effects resulting from medical care such as mortality, complications and readmission [58]. The quality assurance concept for non-medical services describes the way in which services are provided and at the same time covers all activities in the non-medical care process. Examples include logistics, food supply and bed preparation. These can be measured by their adherence to schedules, accuracy or cancellations.		

A 3. Design field space (S)

Level site (1)

First order factory object	R.1.1	Property
Second order factory object	R.1.1.1	Geometrical characteristics
	R.1.1.2	Soil condition
	R.1.1.3	Development of the property
	R.1.1.4	Supply and disposal of the property
	R.1.1.5	Obstacles
Description:		
The hospital object "Property" depends heavily on its geometric characteristics. These include the geometry, the plot area and the orientation of the plot in a specific compass direction [13,43]. The soil composition provides information about the soil's geotechnical properties. The development of the site defines the public and non-public connection to the transport network [13]. The supply and disposal of water, heat, gas, electricity and information to the property takes place with the help of routes and supply towers [13]. The use of the property is restricted by obstacles such as existing buildings, legal requirements such as monument and nature conservation or possible contaminated sites [63].		

First order factory object	R.1.2	General Construction
Second order factory object	R.1.2.1	Zoning and organisation grid
	R.1.2.2	Linking principle
	R.1.2.3	Buildings and open spaces
	R.1.2.4	Development
	R.1.2.5	Supply and disposal
Description:		
In the case of "General Construction", the zoning of the property provides information on the division of utilisation areas such as utilisation zones, protection zones, open spaces or extension areas [5]. An organisational grid is recommended for their allocation, for which a modular scale is defined in DIN 18000, which serves as the basis for hospital planning [43]. The linking principle offers links in the form of a star, network, axis, cross or circle. Possible links range from simple paths to intermediate buildings, bridges or tunnels. Overall, a general development plan defines the structure and layout at hospital site level. The zones in which buildings are located and where open spaces are to be found are defined. The development of the general development plan determines how, for example, visitors, patients, staff, commercial traffic, emergency vehicles or helicopters gain access to the buildings [43]. Finally, the general development includes the supply and disposal of media and information to the buildings. This can include, for example, medical products and pharmaceuticals, sterile circulating goods, beds, food, drinks, laundry, dirty laundry, dirty crockery, tissue and special waste, post, blood, laboratory samples, office and business supplies [30] or other requirements such as energy or fuel.		

First order factory object	R.1.3	Outdoor Facilities
Second order factory object	R.1.3.1	Terrain areas
	R.1.3.2	Paved surfaces
	R.1.3.3	Property protection
	R.1.3.4	Building structures
Description:		
The "Outdoor Facilities" of the hospital site include unpaved areas, the terrain areas. These are, for example, vegetation areas or near-natural water areas. In contrast, there are paved surfaces in the form of		

paths, roads, squares, courtyards or car parks, for example. Property protection protects the hospital site from its surroundings by means of structural measures such as noise and privacy barriers or gates and barriers [43]. Building structures in outdoor facilities include structures such as enclosures, protective structures, walls, ramps, canopies, hydraulic structures (e.g. fountains) and other counter structures (e.g. benches, signs, litter bins and flagpoles).

First order factory object	R.1.4	Impression
Second order factory object	R.1.4.1	Structural order
	R.1.4.2	Clarity
	R.1.4.3	Balance of functionality and attractiveness
	R.1.4.4	Distinctiveness
	R.1.4.5	Healing architecture
Description:		
The "Impression" encompasses the aesthetic design values of the hospital grounds [5]. The principle of structural order creates a pleasant harmony through the internal coherence of the elements in relation to the whole [5]. An attractive and self-explanatory guidance and orientation system creates clarity [88,89]. The design should strive for a balance between functionality and attractiveness [90]. While focussing on the essential function of the hospital, its attractiveness for patients as customers must also be taken into account [42]. To achieve an identity, the hospital should have architectural features that give it a distinctive character. Not only patients benefit from design elements in line with healing architecture during their recovery, but also employees during their work [91].		

Level building (2)

First order factory object	R.2.1	Layout
Second order factory object	R.2.1.1	Area
	R.2.1.2	Flows
Description:		
In the "Layout", the areas are arranged with the help of routing so that the flow of people, materials and information is as efficient as possible. The areas are assigned to the functional centres defined in DIN 13080 for the seven functional areas of diagnostics and therapy, nursing, general services, hospital management, supply and disposal, research and teaching and other facilities. The functional area of research and teaching can only be found in university hospitals. There are flows of people, material and information in the hospital. The flows of people include not only staff, but also patients and visitors. Material flows include, for example, medicinal products, tissue samples, medical equipment, food, sterile goods and linen. Treatment files or pneumatic tubes represent information flows. The flows are primarily more customisable in their form and length than in their intensity, as these are already defined by the process steps in the structure [92].		

First order factory object	R.2.2	Cubature
Second order factory object	R.2.2.1	Floor plan
	R.2.2.2	Sectional profile
	R.2.2.3	Linking principle
Description:		
The "Cubature" includes the floor plan, the sectional profile and the linking principle of the hospital building. During the historical development, specific building types emerged through a combination of sectional profile and floor plan. The pavilion type, the block type, the horizontal type (T-, H-, X- or Y-		

type), the vertical type (integrated or differentiated) and mixed types are important for today's hospital landscape [42]. Just like windows, doors and gates, the building floor type has a fundamental influence on the building climate. The linking principle of the hospital building is based on corridors that are open, multi-open or closed [30,33]. The most common principles are magistrals with connections through cross-shaped links in the core or branching combs [43,64].

First order factory object	R.2.3	Bearing Structure
Second order factory object	R.2.3.1	Foundation
	R.2.3.2	Supports
	R.2.3.3	Beams
	R.2.3.4	Walls
	R.2.3.5	Ceilings
Description:		
The "Bearing Structure" includes foundations, supports, beams, walls and ceilings. The foundation includes those parts of the structure that transfer the dead and live loads into the ground, e.g. individual and strip foundations, foundation piles, subfloors and floor slabs [93]. The supports and beams can be described in more detail by material, profiling and joining principle. Together with the load-bearing walls and ceilings, they define the static properties and structure of the building. The walls also play an important role in terms of fire protection by separating the fire-causing area from other areas [30].		

First order factory object	R.2.4	Building Envelope
Second order factory object	R.2.4.1	Exterior walls
	R.2.4.2	Roof
	R.2.4.3	Opening elements
Description:		
The structural "Building Envelope" of a structure consists primarily of the exterior walls and the roof. The functions of the building envelope include protection, lighting and facilitating the flow of people and materials. Opening elements such as windows, doors or gates supplement the envelope as required and, like the structural form, have an influence on the building climate [30].		

Level section (3)

First order factory object	R.3.1	Interior Finishing
Second order factory object	R.3.1.1	Floor
	R.3.1.2	Walls
	R.3.1.3	Ceilings
	R.3.1.4	Stairs
	R.3.1.5	Safety measures
Description:		
Stairs, walls, doors and ceilings define the areas, rooms and paths in the "Interior Finishing" hospital object. Functional areas are defined in accordance with DIN 13080. Examples of rooms include operating theatres, laboratories and offices [30]. Escape and rescue routes in particular play a role in the design of pathways. Stairs are designed to accommodate all vertical traffic if necessary [43]. In addition, the construction of walls includes fire protection considerations, such as covering walls in lightweight construction with fire protection panelling. Doors must also fulfil the requirements of fire protection and sound insulation. The heights of the doors depend on their function, so that a distinction must be made, for example, between standard doors, doors that can be used for beds and corridor doors [43]. In some areas,		

the suspension of ceilings makes it possible to route building services [43]. This is also possible with intermediate floors, whereby additional floors are added between individual main storeys [94]. The floor itself or the floor covering is of fundamental importance, as it must be able to withstand high loads in some cases [43]. Appropriate safety measures are required on walls, ceilings and doors to ensure the storage of flammable liquids and acids as well as various anaesthetics [43].

Level work station (4)

First order factory object	R.4.1	Furniture
Second order factory object	R.4.1.1	Tables
	R.4.1.2	Seating options
	R.4.1.3	Storage options
	R.4.1.4	Other workplace-specific furniture
Description:		
The "Furniture" includes tables, seating and storage options as well as other workplace-specific furniture. In nursing, for example, every hospital room must be furnished with a table, appropriate chairs (one chair per patient), a bedside cabinet and built-in cupboards [43]. However, other workplaces in hospitals also have other workplace-specific furniture, such as whiteboards or flip charts at office workplaces.		

First order factory object	R.4.2	Work Station Design
Second order factory object	R.4.2.1	Ergonomics
	R.4.2.2	Spatial Occupational Safety
	R.4.2.3	Lighting
	R.4.2.4	Climate
	R.4.2.5	Colour design
Description:		
The hospital object "Work Station Design" includes ergonomics, spatial occupational safety, lighting, climate and colour design. Ergonomics is intended to ensure that working conditions are adapted to the characteristics of the human body so that, for example, work equipment is designed to suit the body [83]. Due to the high safety requirements, spatial occupational safety at the workplace is crucial. This includes, for example, radiation protection, which can be achieved through lead inserts or voluminous concrete walls [43]. Lighting is characterised, for example, by the correct design of artificial lighting and light control. Hospital rooms, for example, should be naturally lit, while functional rooms that are not designated as permanent workplaces should have artificial lighting [43]. The climate depends on the room air temperature, humidity, velocity and purity [95]. The colour design not only takes into account specified colours for safety colours, for example, but also the psychological colour effect [96].		

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