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Comparative floorplan analysis to identify typologies of radiotherapy departments

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Abstract: 1) Objective/aim: This paper establishes levels of abstraction for analyzing floorplans of radiotherapy departments in German hospitals, to develop typologies and spatial criteria. 2) Background: The configuration of room clusters is a useful tool in the early stages of planning radiotherapy departments. Currently, there is a lack of planning requirements. With the implementation of evidence-based typologies, workflow and patient stay can be positively influenced. 3) Methods: For developing typologies and planning requirements, a comparative floorplan analysis of 20 radiotherapy departments in Germany was conducted. The analysis examined differences and similarities in patterns of spatial relationships. 4) Results: Given the complexity of radiotherapy departments, four levels of abstraction were defined to enable comparability of floorplans. The levels of abstraction were developed based on floorplan preparation for the Space Syntax analysis. The rooms of the analyzed floorplans were categorized by the cluster formations to identify their relation to and arrangement with one another. Five clusters were defined concerning the workflow of radiotherapy treatment: Reception, Outpatient, Imaging, Planning, and Therapy, with each cluster having dedicated rooms. With this comparative floorplan analysis, a classification of radiotherapy departments based on organizational and spatial characteristics was developed. 5) Conclusion: Five typologies of hallway structures and spatial characteristics were derived and visualized. The comparative analysis of floorplans shows a spectrum of built environments and cluster arrangements, which lead to typologies and planning requirements. Further research will be conducted by combining these typologies with workflow, individual travel paths, environmental behavior and requirements of all user groups, and expert knowledge. This multilayered research can identify design recommendations for planning radiotherapy departments.

Keywords: floorplan analysis; cluster; Space Syntax, adjacency, floorplan abstraction

1. Introduction

Cancer treatment is individually tailored to both the tumor type and patient and consists of surgery, radiotherapy, and/or systemic treatment, e.g., chemotherapy or immunotherapy. Radiotherapy is an essential part of cancer treatment and is at the forefront of

effective treatments offered to cancer patients (Abshire & Lang, 2018). With doctor consultation, imaging for radiation treatment planning, treatment planning itself, and high-energy photon and proton radiation treatment, radiotherapy is a multidisciplinary field that includes radiation oncologists, medical physicists, and radiation technologists besides the patient. The treatment can be planned on an in- or outpatient basis. Due to these factors, radiotherapy departments have complex building layouts.

The implementation of evidence-based design in health care facilities can positively influence workflow, travel paths, well-being, and quality of stay (Mahmood, 2021). Transferred to radiotherapy, an optimized architecture and built environment of radiotherapy departments are prerequisites for treatment.

Some Design and Planning Guidelines have been developed by American, British, and international institutions. They form a summarized collection of expert knowledge. As such, they include a master plan for radiotherapy departments in reference to the Master Plan and Design Conceptions from the International Atomic Energy Agency (van der Merwe, 2017) (IAEA, 2014), intending to develop a new radiotherapy department with different endeavors associated in low-income countries. Further, the Radiation Therapy Service Design Guide from the Department of Veterans Affairs (VA, 2008) is a series of design guides developed in partnership with the service and benchmarked with similar private-sector guides. They were developed as a tool to assist Contracting Officers, Medical Center Staff, and Architects and Planners with the design and construction of Radiation Therapy Medicine facilities. (VA, 2008) Guidance on the design and planning of new and adaptation of existing radiotherapy facilities was also processed in best practice collections in the Health Building Notes Series (NHS, 2013) and the Health Facility Briefing & Design (iHFG, 2017).

All these guidelines are the product of experience and penal discussions with different participants. The lack of planning requirements derived from evidence-based design, best practice analysis, connection to workflow optimization, and user group analysis becomes apparent. In addition, the field of radiotherapy has undergone rapid changes in the development and modernization of technical equipment, precision in therapy planning, and workflow. With these changes, the mentioned guidelines might not be currently applicable and need to be updated in reference to evidence-based findings and current situations in clinics.

With the high complexity of radiotherapy departments, the built environment and structure are eminent in providing the setting for optimized workflow and patient care. For developing design recommendations and planning requirements, it is necessary to develop typologies. The typologies will be derived and verified with various steps of analysis; they are a basis for architectural comparison and can be used as classification tools in planning future radiotherapy departments. The architectural typology of a department can be further analyzed in combination with the workflow, patient journeys, or spatial settings. Spatial patterns can be analyzed in floorplan settings to visualize the arrangement of individual elements, e.g., rooms or groups of rooms. The arrangement of said elements can also be analyzed by their direct or indirect adjacency and relation to each other. The general aim is to analyze current radiotherapy departments and workflow processes to develop recommendations for planning.

This descriptive study provides the first phase of analysis. By investigating how abstracting, comparing, and analyzing floorplan layouts in terms of their spatial patterns and adjacencies can help develop typologies for radiotherapy departments.

2. Theories and Methods

The comparative floorplan analysis was conducted with 20 floorplans of radiotherapy departments in Germany. These departments are hospitals of maximum care and/or university hospitals. The floorplans show a wide variety in size, structure, configuration, and position on the hospital premises. To enable comparability between the departments with the aim of deriving typologies, levels of abstraction were conducted. These levels of abstraction are defined in this study and are the basis of the floorplan analysis.

Given the complexity of radiotherapy departments, a list of rooms was composed. In consideration of the workflow of radiotherapy treatment, cluster formations were defined in the following chapter. The rooms of the analyzed floorplans were categorized by the cluster formations to identify their relation to and arrangement with each other. The analysis aimed to examine differences and similarities in patterns of the spatial relationship between clusters. To focus on the location and relation of the clusters, the floorplans were prepared in several layers of abstraction. The levels of abstraction were developed based on floorplan preparation for the Space Syntax analysis (Hillier & Hanson, 1984).

With the different levels of abstraction, two analyses were conducted in the attempt to categorize and compare the floorplans and develop typologies.

First, a descriptive analysis was conducted based on level 1 of abstraction by analyzing hallway configuration and spatial organization of the clusters in relation. From this analysis, five typologies of hallway configuration were developed. To verify these typologies, the 20 floorplans were categorized by the typologies. A reflection of the typologies was conducted after the categorization process.

In the next chapter, the different levels of abstraction are defined and demonstrated in the example of the radiotherapy department at the University Hospital Carl Gustav Carus at Technische Universität Dresden, Germany.

3. Results

Due to the complexity of radiotherapy departments, their room variety, and multiple functions, it is not possible to directly compare all departments by their floorplans. To analyze the floorplans and derive typologies, levels of abstraction are necessary. In the following multiple levels of abstraction are introduced.

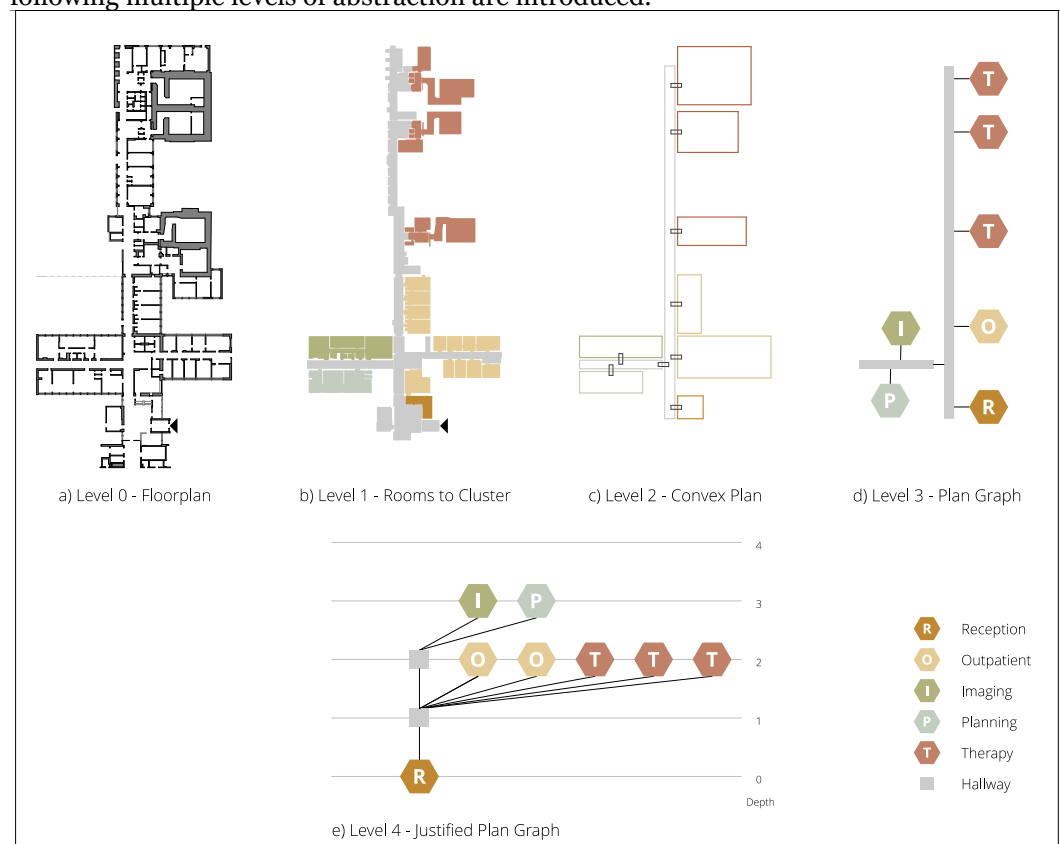


Figure 1. Level of Abstraction

In preparation, the floorplans of all radiotherapy departments were simplified into shapes of spaces by showing walls as thick lines with openings for doors and thin lines for windows (Fig. 1a).

3.1. Clusters: Level 1 of Abstraction

As a first step, the rooms were grouped into clusters corresponding to their function in the therapy process. According to DIN 13080 (DIN 13080, 2016), it is advised in hospital planning to group rooms together to achieve a structural basis for ensuring safe and efficient treatment and work processes.

In clustering, objects that are similar to each other according to a defined criterion are grouped into one cluster. In this case, rooms corresponding to the same function in the treatment process are sorted into one cluster. The International Atomic Energy Agency (IAEA) has developed five key functional areas in radiotherapy: reception, administration and waiting areas; clinical consulting areas; the two treatment suites (external beam radiotherapy and brachytherapy); the imaging and treatment planning area (IAEA, 2014). For

developing clusters for room constellations in radiotherapy departments, a closer look was given to the process and its user groups. The process of radiotherapy departments can be sectioned into the following sub-processes (Müller-Polyzou et al., 2019):

The first sub-process comprises the arrival and admission of the patient to the radiotherapy department. This includes the *reception*, which is a central element of the department, and the workstation of the medical and administrative assistants. In addition to this, the archive and offices for administration purposes are corresponding (cluster represented as “R”, see Fig. 1).

In the next step, the patient continues with the *imaging* sub-process. Here, a Computed Tomography (CT) scan is completed as the basis for three-dimensional, highly conformal radiation treatment planning. This cluster combines a room constellation of the CT room, a control room, and changing cubicles. This is also the workstation for the medical radiation assistants. The replicability of the patient’s positioning is a crucial prerequisite for therapy. To achieve this, positioning aids are used and produced or adapted for the patient. This is performed by medical radiation assistants and/or medical physicists. (cluster represented as “I”, see Fig. 1).

The medical physicists create a treatment plan based on the CT scan and the physician’s treatment prescription. The radiation oncologist needs to approve the treatment plan. The *planning* process is digital and can be done on any workstation, however, mostly interdisciplinary workspaces are provided. (cluster represented as “P”, see Fig. 1)

These three sub-processes *administration*, *imaging*, and *planning* are prior to the radiation therapy. The next sub-process is the application of the *therapy*, which is performed in the therapy room. There are multiple therapy methods and different radiotherapy devices. The most common radiotherapy equipment in 33 European countries, according to data from the Directory of Radiotherapy Centres (DIRAC) from 2012, is medical accelerators, with a majority of linear accelerators. For this study, only therapy rooms with linear accelerators were considered due to their comparability in location, process, and structure. Brachytherapy was excluded due to its possibility of being located individually off-site. Corresponding to the therapy room are a control room and two changing cubicles. According to the individual therapy plan, therapies can last several days or weeks during which the patient regularly receives his fractioned treatment. (cluster represented as “T”, see Fig. 1)

After the last therapy session, the patient will continue to come to follow-up appointments. In the beginning and during the entire treatment, the patient will have regular and additional examinations and meetings with the radiation physician. These appointments are done in the *outpatient* department (cluster represented as “O”, see Fig. 1).

Summarized, there are five clusters to consider: *reception*, *outpatient*, *imaging*, *planning*, and *treatment*. Additional clusters for personal rooms (e.g., offices and break rooms) and service rooms (e.g., storage, engineering, and technical rooms) need to be mentioned. Still, they are not considered in this study due to the flexible and non-collective location of the rooms. With the definition of the clusters, the rooms of each clinic were assigned (Fig. 1b).

3.2. Convex plan: Level 2 of Abstraction

For further analyzing the spatial patterns of radiotherapy departments and accomplishing comparability abstractions of room details, sizes, and forms are necessary. In the next level of abstraction, findings were developed with the quantitative tool of Space Syntax (Haq & Luo, 2012). By applying the method of Space Syntax, aspects of geometry and dimensions are abstracted.

Due to the complexity of radiotherapy departments, their various rooms, and the means to develop typologies, the method of space syntax was conducted on a cluster level rather than a room level. In Level 2 of abstraction, the floorplans were configured into convex plans. With these convex maps, the architectural plan translates into a diagram that reflects the configuration of selected properties of that plan and assists in the identification of spaces and connections (Ostwald, 2011). The properties interesting for the research are the configuration and relations between the clusters. As originally described by Hillier & Hanson (1984), convex spaces are defined by “no line drawn between any two points in the space goes outside the space” (Hillier & Hanson, 1984). For this research, the clusters are summarized as single convex spaces, whereas the hallway connecting the clusters might need to be broken down into several convex spaces to maintain and analyze the depth of its spatial configuration. (Fig. 1c)

3.3. Plan Graph: Level 3 of Abstraction

Space Syntax analyzes spatial patterns by transforming spaces and their access to other spaces into topological graphs as nodes and lines by abstracting geometrical aspects of length, width, and distance (Hillier & Hanson, 1984). In Level 3 of Abstraction, the plan graph is drawn over the convex map. The plan graph does not differentiate between the size or vertical orientation of space; it records the existence of space (node) and its connection (line) to any other space (Ostwald, 2011). It is also not relevant what connects two spaces, only that the connection exists. Graphically, this abstraction transforms the convex plan into a diagram of nodes connected by lines (Fig. 1d).

3.4. Justified Plan Graph: Level 4 of Abstraction

In the next step, the plan graph can be separated from the floorplan since the length of lines, symbolizing the distance of nodes, is not relevant to the method of Space Syntax. For developing the Justified Plan Graph (JPG), any node is drawn at the base, forming the carrier. From the carrier, all nodes in direct adjacency are set to depth 1. The directly connecting nodes from these are set to depth 2, and so on (Hillier & Hanson, 1984). For this study of comparability and categorization, reception was set as the carrier.

4. Discussion

After presenting the previously defined levels of abstraction, the floorplan analysis was conducted, and with these aspects of analysis, the utility of the levels was verified.

4.1. Descriptive analysis: Hallway structure

With the second level of abstraction and the analysis of hallway configurations, qualitative and descriptive findings were produced. In this analysis, the focus was set on the orientation and pathway of the hallway and the arrangement of the clusters along the hallway. Particular attention was given to the reception and the therapy cluster due to their importance to the department. Due to the comparability of floorplans in the Level 2 abstraction, it was possible to develop five typologies of hallway configurations.

Typology 1 (see fig. 2) describes a continuous hallway without junctions from which all clusters are directly accessible to one or both sides. Typology 2 describes the hallway given in Typology 1 with the special feature of the therapy cluster being approached at the end of the hallway as a vertical structure. With Typology 3 clusters are accessible through multiple parallel hallways. All these hallways relate to a hallway on one end, where the reception is located. Typology 4 is based on the existing masterplan guidelines (IAEA, 2014). It describes departments with two parallel hallways ending in a connecting hallway with a reception on one end and the therapy cluster on the other. Finally, Typology 5 includes departments with a round-going hallway. The therapy cluster is accessible from the center of the hallway.

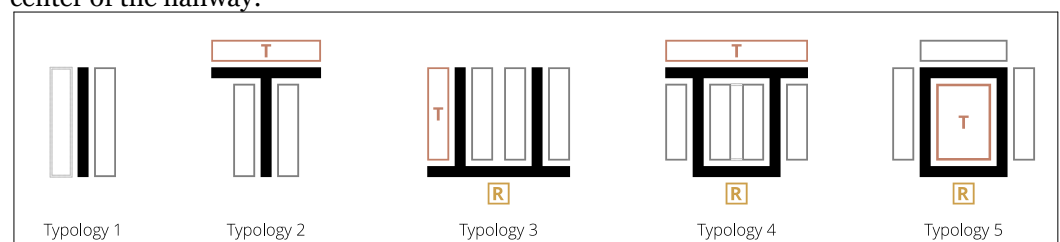


Figure 2. Typology Hallway Structure

The five typologies of hallway structures were the basis for categorizing the floorplans of the analysis. In the next chapter, the floorplans will be sorted into the developed typologies, and with this process, the typologies will be reviewed.

4.2. JPG into Hallway Typologies

As part of the floorplan analysis, the JPGs in Level 4 of abstraction are sorted into the developed typologies. The reception, as the central point of reference for patients and personnel, was set as the carrier to obtain comparability for sorting.

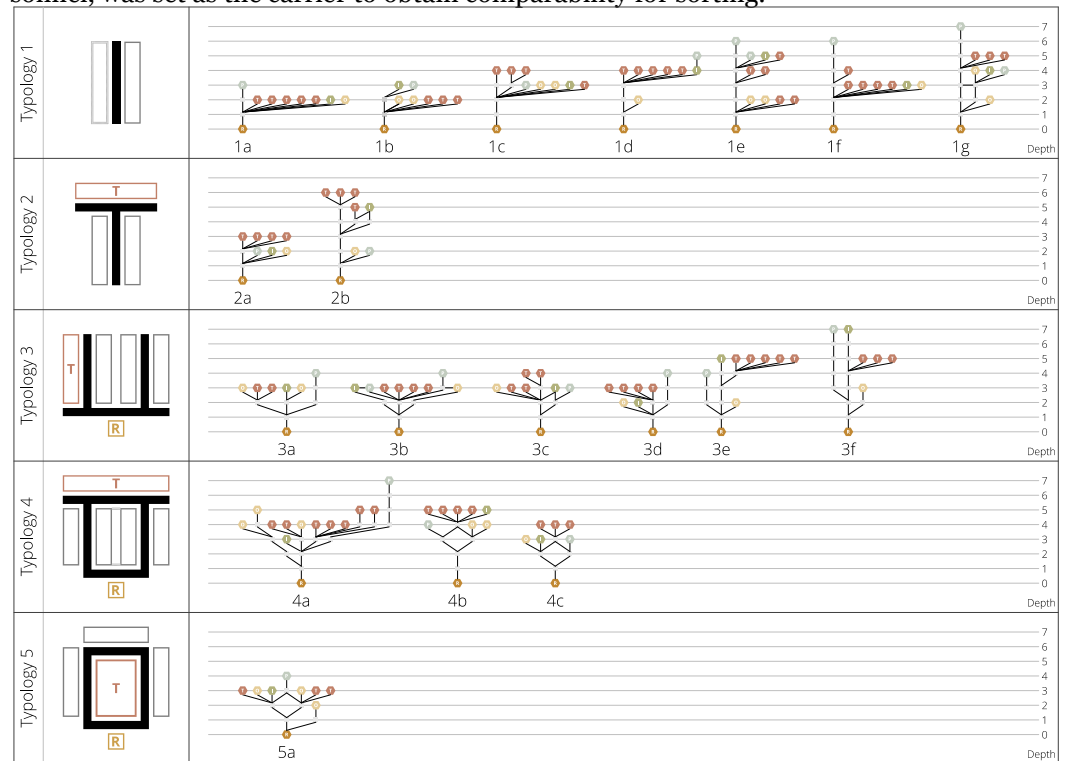


Figure 3. Justified Plan Graph categorized in Hallway Typologies

Most floorplans were categorized as Typology 1, followed by Typology 3 (see Fig. 3). These two are the most found structures in this analysis of built radiotherapy departments in Germany. In the next chapter, the sorting process is reflected, and typologies are reviewed.

4.3. Reflection of Typologies

It was possible to sort the analyzed floorplans into the developed typologies. With Level 4 of abstraction and possible comparability, the typologies can be reviewed for their applicability.

As previously described, Typology 2 is a special feature of Typology 1, with the configuration of the therapy cluster at the end of the hallway. With the JPGs, it becomes evident that this feature and its connectivity cannot be differentiated in this abstraction. Therefore, a clear distinction between Typologies 1 and 2 might not always be possible.

For multi-story departments like 3e or 3f (see Fig. 3), it might be necessary to develop a separate typology. The JPG focuses on room connections so that the connectivity is not differentiated between horizontal or vertical branching. Therefore, multi-story departments are automatically assigned to Typology 3. For further analysis, it is better to use an additional typology for these multi-story departments to analyze the difference in integration and connectivity between these two variations.

Complex and large departments like 4a (see Fig. 3) might be seen as a mix of typologies and are hard to sort distinctively. In this case, the main structure was examined and defined as Typology 4.

In general, the developed typologies can be found in the analyzed departments. Further analysis needs to be conducted to verify the findings.

5. Conclusions

With this comparative floorplan analysis, classification of radiotherapy departments into typologies based on organizational and spatial characteristics was developed.

The utilization of room clusters is a useful tool to abstract the complexity of radiotherapy departments and focus on the spatial relationships in the department. Further

levels of abstraction were developed to achieve comparability among departments and to enable further floorplan analysis. The abstractions are used to exclude metric features like size and distance to enable an analysis of the relationship and connectivity between two elements. The developed typologies enable the classification of floorplans that can be further analyzed in comparison. To verify the typologies, it is attempted to use a larger sample size of radiotherapy departments for the floorplan analysis. This study defines the first phase of developing typologies to achieve the aim of establishing recommendations and planning requirements for radiotherapy departments.

For additional research, space adjacency analysis from the Space Syntax method can mathematically analyze the JPGs of Level 4 of abstraction (Haq & Luo, 2012). By converting the relationship of adjacency into values of relative asymmetry, the floorplan analysis can be enhanced to quantitatively describe and analyze the physical layouts of spaces. With this numerical analysis, the values of spatial visibility, accessibility, integration, connectivity, and the relationship between clusters and rooms can be examined.

Space Syntax can further be used in the analysis with the original idea of understanding the sociology of space by applying the numerical calculations to the social needs of the space and its users (Haq & Luo, 2012).

Additionally, further research will be conducted by looking at the abstraction phases and typologies and putting them into context with workflow and individual travel paths of all user groups.

Considering the COVID pandemic the question and essentiality of flexibility and variability were emphasized for the planning of healthcare facilities. To assess the existing and/or essential flexibility, one possibility is the usage of an assessment tool (Brambilla et al., 2021). This needs to be considered and evaluated in further analysis when developing requirements for organizational, functional, and operational flexibility in architecture. In addition to organizational qualities, the macro areas of social and environmental aspects must be considered (Brambilla et al., 2020).

This study provided the basis for the floorplan analysis and makes further analysis on integration, comparability, and connectivity possible to develop evidence-based planning requirements and guidelines.

Contributor statement

The main author and lead researcher for this research study was Carolina Kolodziej. The supervision and mentorship were provided in the fields of medicine and radiotherapy by Esther G.C. Troost and in research, architecture, and healthcare design by Gesine Marquardt.

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