SUSTAINABILITY OF HOSPITALS

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Definitions

CA	Circulation area (German: Verkehrsfläche) Circulation area is defined by Din 277:2016-1 and is part of the net floor area as well as the technical area and the usable floor area. Circulation areas enables access to rooms within a building.
GFA	Gross floor area (German: Bruttogrundfläche) According to DIN 277:2016-1, the gross floor area is the total sum of all areas within a building including net floor area and construction area.
NFA	Net floor area (German: Nettoraumfläche) Net floor area is the sum of circulation area, technical area and usable floor area. According to DIN 277:2016-1, the net floor area is part of the gross floor area.
TA	Technical area (German: Technikfläche) Technical area is defined by DIN 277-1 as a specific part of a building which is reserved for technical installations.
UFA	Usable floor area (German: Nutzungsfläche) According to DIN 277:2016-1, usable floor area is part of the net floor area. The area includes all usable areas except of circulation areas and technical areas.

List of abbreviations

BBSR	Federal Institute for Research on Building, Urban Affairs and Spatial Development (German: Bundesinstitut für Bau-, Stadt- und Raumforschung)
BW	Baden-Wuerttemberg
cf.	Compare (Latin: confer)
DIN	German Institute for Standardization (German: Deutsches Institut für Normung)
e.g.	For example (Latin: exempli gratia)
et al.	And others (Latin: et alli, et aliea)
Fig.	Figure
KHG	German hospital financing law (German: Krankenhausfinanzierungsgesetz)
KhBauVO	Hospital building regulation (German: Krankenhausbauverordnung)
NRW	North Rhine-Westphalia

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Abstract

Sustainable Planning for Hospitals. An analysis of the general layout conditions and area efficiency characteristics of hospitals in Germany.

Starting point:

Hospitals are an essential element of every healthcare system and have priority in the healthcare industry. Healthcare buildings have highly complex infrastructures, making future-oriented economic planning extremely relevant for their long-term sustainability. As facilities, hospitals are open 24/7, 365 days a year and used by countless patients, employees, visitors and suppliers. More than 1.1 million employees work in over 1.900 hospitals to guarantee high quality medical care all over Germany (cf. Statistisches Bundesamt, 2015). All hospitals have to handle those individual challenges regarding the building plot, form of hospital buildings (comb structure, linear structure), the progression of medical technologies and patient wishes (cf. McKee, M. and Healy, J., 2002).

Problem definition:

The big challenges for hospitals in Germany are currently the demographic shift of the population from rural exodus and the development of medical technologies (cf. Reifferscheid, A. et al., 2015). This paper will examine the effects of numerous changes in healthcare development and will give an overview of various typologies of hospital buildings and their area efficiency.

State of research:

The regional planning of healthcare buildings is of critical importance for politics, people and the economy. According to my research, there are various scientific publications which deal with this topic in Germany as well as on an international level (e.g. McKee, M. and Healy, J., 2002).

Objective:

The overall objective of this research is to investigate the area efficiency of various hospitals and wards, which is based on an analysis of different typologies of hospitals in Germany. The analysis will evaluate and collate area efficiency characteristics from other hospitals gaining an overview of the situation of area efficiency in German clinics. Furthermore, the relation will be established between all areas of specific wards and nursing and medical staff by considering the number of square meters per employee.

Methodology:

Review of the literature, analysis of various hospital layouts, structural surveys of hospitals in Germany and interviews with the CEOs, project leaders and employees, architects and the local administrative unit were conducted in order to focus on area efficiency.

Keywords:

Healthcare, hospital design, sustainability, area efficiency, Germany

Introduction

A hospital is defined as ‘An institution which provides beds, meals, and constant nursing care for its patients while they undergo medical therapy at the hands of professional physicians. In carrying out these services, the hospital is striving to restore its patients to health’ (Miller, S., 1997). Clinics are one of the most complex buildings and are an essential element of every healthcare system. In these facilities patients get the possibility to recover, give birth or take advance of terminal care accompanied by doctors, medical staff and non-medical staff (cf. KHG, 1972).

Healthcare is a major source of employment with a large labor force, of which the hospital sector represents the most visible concentration. Facilities are open 24/7, 365 days a year and are used by numerous of patients, medical and nursing staff and visitors. In Germany, more than 1,1 million employees work in 1,956 hospitals to guarantee good quality medical care (cf. Statistisches Bundesamt Deutschland, 2015).

Hospitals must cope with the challenge of continuous development. More patients are treated in fewer hospitals in less time. Since the introduction of the hospital planning instrument (Krankenhausbedarfsplanung) the number of hospitals have decreased from 2,411 hospitals in 1991 to 1,956 in 2015 which shows a reduce of 19 percent (cf. Statistisches Bundesamt Deutschland, 2015). However, the German healthcare system enables every patient best medical care and good reachability. According to the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) 97.5 percentage of the German population reaches a hospital within a driving time of 20 minutes (cf. Schlömer, C. and Pütz, T., 2011).

Since 2006, both the number of hospitals as well as the number of hospital beds are decreasing, which contrasts with the constant increase of patients. Reasons for the juxtaposition are both the increase of outpatient treatments and the decline in the length of stay. Whereas in 1991 the average hospital stay was two weeks, as of 2015 patients stayed only 7.3 days in hospitals (cf. Statistisches Bundesamt Deutschland, 2015).

Another change concerning hospitals in Germany is the increasing privatization of clinics, which leads to faster care; 15 percentage of the hospitals were private in Germany in 1991 in contrast to 35 percentage in 2015 whereas the number of hospitals owned by the public sector or independent non-profit organizations has decreased since 1991. The development of hospital institutions in Germany from 1991 till 2015 is shown in appendix A (cf. Grieß, A., 2015).

Further developments such as development in medical technology and always changing disease symptoms influence the constant change in the entirety and in the architecture of hospitals in Germany. Over the last years´ hospital buildings have been changing a lot to constantly adapt to new circumstances. The sustainable planning of hospitals and the constant modernization of already existing buildings enable the possibility to cope with changes.

Hospital design is often confronted with the difficult task of combining the general welfare of human-beings with sustainability and versatility. A versatile hospital has a long-term durability; parameter such as sustainability, expansion potential, modifiability, versatility of use and installation and reduction of medicine technical systems play a significant role.

The purpose of this research is to present a general insight into area efficiency of different hospitals and wards demonstrating how sustainable architecture is used to support logistic processes of doctors and nursing staff.

Problem definition

Based on sociological, medical, operational and economic developments the structure, architecture and organization of hospitals have been changing a lot and are going to change in the next decades (cf. Labryga, F., 2011, cf. Debatin, F. 2010).
Hospital building is a typology which needs to deal with those changes to correspond to the current state of the art. Many hospitals are grown structures and their flexibility and sustainability is limited to those changes.

Even more the sustainability of hospitals depends on its location and the inherent hospital functions as well as realized planning decisions in the past and its future perspective. Figure 1 shows the different cycles of life expectancy regarding the influence on hospital buildings in general.

> 100 years:	The location of a hospital is the most permanent factor. Many hospitals exist over many decades, mostly longer than 100 years.
< 100 years:	Live expectancy of a hospital construction is 50 and more years.
< 30 years:	Live expectancy of the building infrastructure constitutes 25-30 years.
< 15 years:	Medical facilities have a cycle of 10-15 years.

Fig. 1: Different life cycles affecting hospital buildings (cf. Gmür, S., 2011)

The location of a hospital is permanent and only convertible in rare circumstances so that modifiable hospital structure is the factor which needs to deal with the constant change of building infrastructure and medical facilities. External factors also influence the building structure of hospitals now and in the future so that a sustainable planning is essential (cf. Gmür, S., 2011).

Sociological development: Sociological developments influence hospital buildings in many ways. The demographic change causes a shift in age structure of the German population. Due to the decreasing birth rate and an increasingly aging society, obstetrics wards will be reduced and geriatric medical treatment will be expanded. Furthermore, the patient´s clinical pictures modify and comorbidities occur such as dementia and diabetes. This means that the future patient is not only older but also more multi-morbid (cf. Reifferscheid, A., 2015).

Statistics show that younger segments of the population migrate to bigger cities. This trend towards urbanization has led to a merge between many rural hospitals in order to survive. Contrastingly, hospitals in urban areas need to specialize or offer additional treatments to compete in the market. (cf. Reifferscheid, A., 2015, Neubauer, G. et al. 2006).

Medical development: Medical technology is a profitable sector all over the world whereby the medical industry and operators work closely together. Progress in medical care and advances in research around symptoms have led to a surge in new medical technology used for the treatment of patients. Those medical technologies generate a better image resolution, are more versatile, durable and faster and adhere to the strict restrictions. The procedure is gentler and energy-reduced.

Further, telemedicine relieves exchange between experts who are distributed spatially and guarantees a high quality medical care in rural areas (cf. Labryga, F., 2011).

Operational development: The operational structure of hospitals will develop in a way that enables interdisciplinary work so that information, knowledge and resources between different wards can effortlessly exchange. Another suggestion is that instead of wards the hospital reorganizes its structure and combines connected wards to a specialized centrum named for example children clinic. The number of outpatient treatment in contrast to impatient treatment will increase caused by high medical care (Neubauer, G, 2006).

Economic development: The economic situation of hospitals is influenced by two statutory regulations. Current operation costs are financed by health insurance companies and investments are supported by subsidies of each federal state. This model of dual financing is influenced by the implementation of the DRGs System (Diagnosis Related Groups) in 2003 because the federal state provides hospitals less progressive investment resources. Hospitals hardly have the financial resources to plan and finance long-term changes (Meuser, P., 2011a).

Personnel costs represent 65 percent of the total costs of a hospital; limited resources result in, inter alia, reduction of nursing staff.

Political influences: Rules and regulations constitute the legislative basis for every planning process in Germany. Various regulations coordinate the construction process in different ways such as guidelines of the

European Union, federal laws and regulations of the federal government, various laws and regulations of the individual German states and further legal bases. Apart from general stipulations, some federal states in Germany have special regulations setting out additional requirements for hospital. A consistent planning instrument for hospital construction does not exist in Germany. (Meuser, P., 2011b).

Future-oriented planning includes all knowledge of hospital planning and significant factors which provide a master plan of extensible architecture. Many various influences affect not only the sustainability but also the efficiency of the hospital management and the sustainability of hospital design. The hospital life expectancy is 50 years and more whereas external influences are fast-paced. The analysis of areas in various hospitals might be an indication of how well buildings react to different changes and how flexible and sustainable their designs are.

Hypotheses

Some typologies of hospital buildings (comb structure, linear structure) have better support than others, with specific coordinated movements that improve the daily routine work for medical and nursing staff. Besides the form and structure of hospitals, the position, arrangement and size of the different wards guarantee efficiency and structured logistic processes. A future-oriented planning of hospital architecture or reconstruction will impact the future success of the hospital. The architecture and building structure might be an important factor whether a hospital persists or not. The research investigates hospital buildings and wards by their layouts determining various efficiency factors according to areas and the number of staff.

The following hypotheses give an impression of how efficiency of hospitals is measurable based on various key figures referred to the layout.

1. Hypothesis:
   There is an optimal design to reach the most sustainable effort for hospital architecture. This is dependent on size, number of beds and level of specialization.

2. Hypothesis:
   Newer hospital buildings are more efficient and sustainable in terms of their structure and layout. Regarding the future, new hospitals are more flexible and expandable in reacting to different developments in Germany.

3. Hypothesis:
   Some wards of a hospital are more efficiently structured than others. Area efficiency is better in more specialized wards (e.g. surgery) than in less specialized wards (e.g. obstetrics and gynecology).

4. Hypothesis:
   Nursing staff and medical staff take care of a similar number of square meters per ward.

State of the art

The regional planning of healthcare buildings is of high interest for various stakeholders like politics, industry, economy and people. According to my research, there are various scientific publications which deal with this topic in Germany as well as on an international level.

Numerous international and national publications have been published referring to hospital-related topics.

Selection of international literatures as follows:

- Dilani, A., 1999; McKee, M. and Healy, J., 2002; Van de Zwarte, J., 2014; Verderber, S., 2010

Selection of national literatures as follows:

- Debatin, J. F. et al, 2010; Klauber, J. et al (ed.), 2015; Meuser, P. (ed.), 2011; Nickle-Weller, C. (ed.); Wischer, R. and Riethmüller, H.-U., 2007

Selection of rules, regulation, guidelines and statistics as follows:

- DIN 277-1, 2016; DIN 13080, 2016; KhBauVO, 1978; DESTATIS, 2015

The published literature mainly focus on topics such as healthcare of the future, hospital management and general German hospital reports.

Method

The analysis of architecture and numerous area characteristics is based on a sample of four hospital buildings whose building forms, sizes and specializations vary. Hospitals in Germany are organized in different facilities of stationary care. The research works with an analysis of general hospitals as figure 2 shows.

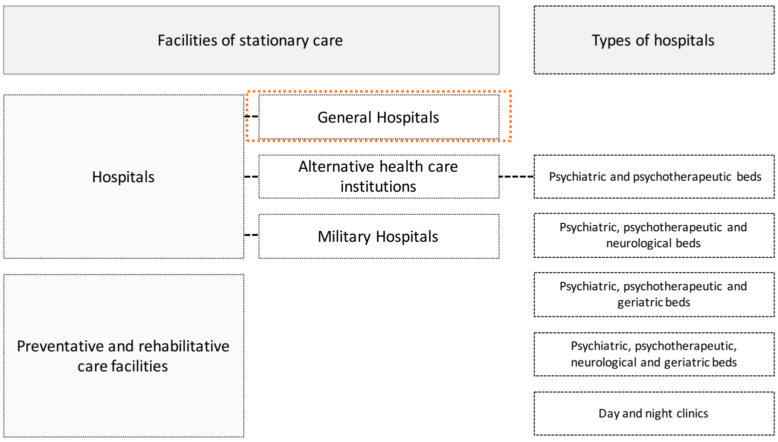


Fig. 2: Facilities of stationary care and types of hospitals in Germany (complied by the author)

It will be focused on structural characteristics and area efficiency factors of those four hospitals as shown in figure 3.

1. Structural characteristics

- Depending on location, year of construction, size and specialization the building design of hospitals differs. Typical architectural typologies are e.g. comb, double comb, campus and linear typology.

2. Area efficiency factors

- The examination of area factors is a method to evaluate sustainability of a hospital and wards by their area efficiency, as figure 4 shows, determining various characteristics.

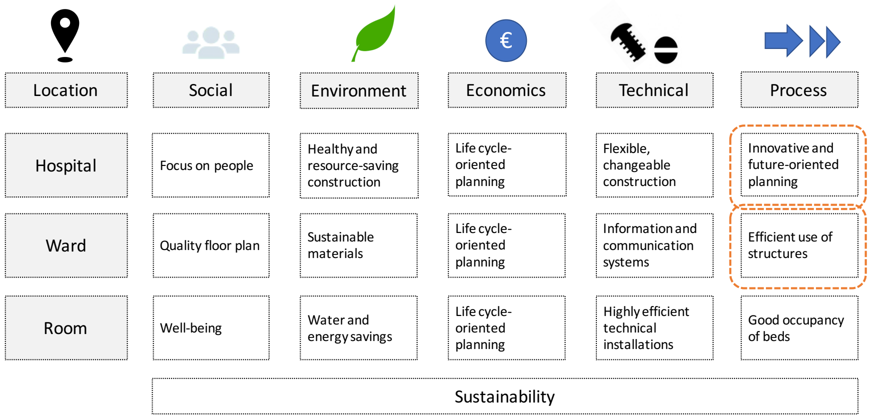


Fig. 3: Sustainable characteristics according to hospital design (complied by the author)

In Germany, an essential guideline for building structures is DIN 277:2016 part 1 which structures buildings in various areas such as figure 4 shows. In DIN 13080:2016 hospitals more detailed structured in different functional areas (functional area 1.00 to functional area 8.00) which assume specific responsibilities such as diagnosis and therapy. Functional areas from 1.00 to 7.00 correspond to the UFA and functional area 8.00 conforms to TA in DIN 277 (cf. fig. 5). The various wards in Germany counting to the functional area 1.00 in DIN 13080 and to UFA in DIN 277.

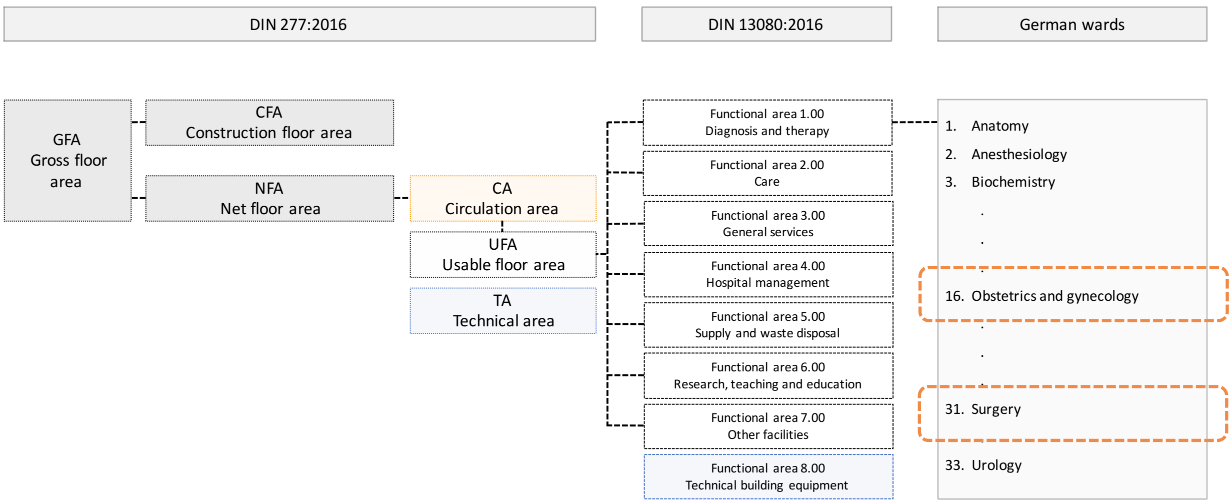


Fig. 4: Structure of buildings´ areas by DIN 277, structure of hospitals' areas by DIN 13080 and the various German wards (complied by the author)

The four different hospitals have been analyzed by their functional areas in general and by specific wards such as surgery and obstetrics and gynecology. Based on a quantity determination according to DIN 277 (fig. 5), the overall objective of this research is to establish connection between the various areas and to compare the results of the different hospitals. The research of hospital building typologies and the relation of different wards (obstetrics-gynecology and surgery) to another could support hospital planning processes and might make a statement concerning sustainable utilization, arrangements and changes in hospital areas.

The basis of the following consideration is the calculation of usable floor area according to either gross floor area, employees and number of beds. The results present an overview on the distribution of area efficiency in German hospitals.

Hospital characteristics in according to DIN 277/ characteristics of different wards in according to DIN 277

- gross floor area in relation to usable floor area

  $\frac{GFA}{UFA}$ = area efficiency factor

- usable floor area in relation to circulation area

  $\frac{UFA}{CA}$ = area efficiency factor

Hospital indicators in according to DIN 277 and number of employees/ wards indicators in according to DIN 277 and number of employees

- usable floor area in relation to the average number of doctors

  $\frac{UFA}{average\ number\ of\ doctors}$ = square meters of usable floor area per doctor

- usable floor area and circulation area in relation to the average number of doctors

  $\frac{(UFA+CA)}{average\ number\ of\ doctors}$ = square meters of usable floor area and circulation area per doctor

- usable floor area in relation to the average number of nursing staff

  $\frac{UFA}{average\ number\ of\ nursing\ staff}$ = square meters of usable floor area per nursing staff

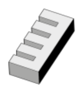
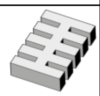
- usable floor area and circulation area in relation to the average number of nursing staff

  $\frac{(UFA+CA)}{average\ number\ of\ nursing\ staff}$ = square meters of usable floor area and circulation area per nursing staff

Analysis
Structure characteristics

In the following table four different hospitals are characterized by their federal state, year of construction, type of construction, type of form, number of stories, number of beds and hospital owner.

Table 1: General information on the different hospitals (complied by the author)

Hospital	Federal State	Year of construction	Type of construction	Typology *	Number of stories	Number of beds	Hospital owner
Hospital A	BW	2009-2013	New construction	Carpet 	8	770	Public
Hospital B	NRW	2009-2014	New construction (extension)	Comb 	6	185	Public
Hospital C	NRW	1932, 1968 1983, 1987, 1988, 2007, 2009	Reconstruction and extension	Campus 	5	474	Independent non-profit
Hospital D	NRW	2004-2008	New construction	Double comb 	6	864	Public

* Prasad, S., 2008

Area efficiency factors

The analysis of numerous area characteristics and indicators (see appendix B) is based on a sample of four hospital buildings whose building typology, size and specializations vary. The area efficiency factor of hospitals will be shown in classification to efficiency factors of offices and laboratories. The analysis will evaluate and collate area efficiency characteristics and indicators from other hospitals gaining an overview of the situation of area efficiency in German clinics. Furthermore, the relation will be established between all areas of specific wards and nursing and medical staff by considering the number of square meters per staff (see appendix C).

The area efficiency factor of gross floor area to usable floor area gives a first classification of area efficiency within a hospital.
Hospital A is a new constructed hospital which was completed in 2013 and built in carpet structure. The analysis of area characteristic of the new constructed hospitals referring GFA/UFA shows an area efficiency factor of 2.39. Hospital B was completed in 2014 and is a new constructed extension attached to a still existing hospital. Hospital B was built in comb structure and the general analysis of area characteristic referring GFA/UFA shows an area efficiency factor of 1.97. The last extension and reconstruction in form of a campus structure of hospital C took place in 2009. The total area efficiency factor of the hospital amounts 1.74. Hospital D is a new constructed hospital which was finished in 2008. The typology of the last hospital is a double comb design and its efficiency factor of GFA/UFA is 1.94. The scattering of efficiency factors of the hospitals shows little variation as in figure 5 shown whereby the median is at 2.0. The analysis of efficiency factors of offices resulted in values of 1.42 to 1.92 (BKI, 2015 and BKI, 2017) whereby the distribution is low and lie below the efficiency factors of hospitals. The spreading of efficiency factors of laboratories shows a higher dispersion in contrast to the results of hospitals and offices. The results of laboratories present values from 1.39 till 2.23 and an outlier with a value of 4.27. The outcome demonstrates that the median of efficiency factors of hospitals lie around 2.0. The dispersion is in contrast to the dispersion of offices higher but in contrast to the dispersion of laboratories lower.

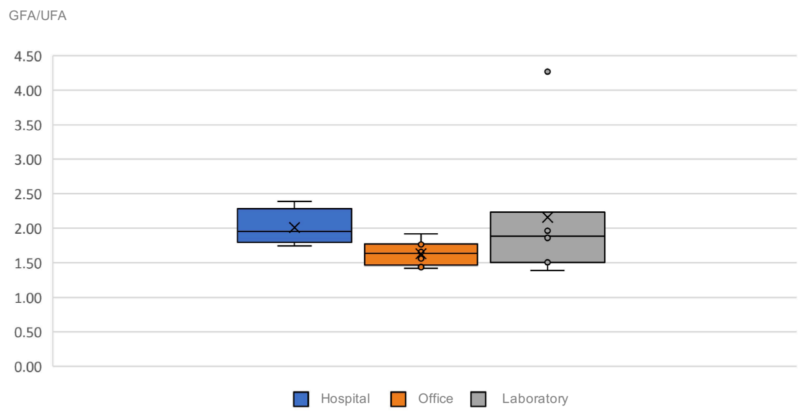


Fig. 5: Boxplot diagram of efficiency factors of different building types (n=4, n=10, n=7) (complied by the author)

The general analysis of area characteristics of hospital A referring GFA/UFA shows an area efficiency factor of 2.39. The efficiency factor of the ward of obstetrics and gynecology reaches a value of 1.92 in contrast to the ward of surgery with a factor of 1.64. The general analysis of area characteristic of hospital B referring GFA/UFA shows an area efficiency factor of 1.97. In contrast to the characteristic of the entire hospital, the area factor of obstetrics and gynecology lies above 1.97 with a value of 2.16 whereas the factor of the surgery ward has a value of 1.82. The total area efficiency factor of hospital C amounts 1.74 whereas the efficiency factor of obstetrics and gynecology is 2.10 and of surgery 1.80. The general analysis of area characteristic (GFA/UFA) of hospital D presents an area efficiency factor of 1.94. In contrast to the characteristic of the entire hospital, the area efficiency factor of obstetrics and gynecology is 1.61 and the factor of the surgery ward is 1.67.

The relation of usable floor area to circulation area demonstrates how sustainable and efficient circulation areas are organized within a hospital. The efficiency factor of UFA/CA of hospital A is with a value of 1.43 lower than the factors of obstetrics and gynecology and surgery with a value of 3.09 and 2.83. The area efficiency factor according to UFA/CA of hospital B places with a value of 2.10 between the efficiency factor of surgery with 2.64 and obstetrics and gynecology with 2.08. The efficiency factor of UFA/CA of hospital C yields a value of 3.18 whereas the values of obstetrics and gynecology result in 2.31 and of surgery in 2.99. The value of usable floor area to circulation area amounts a higher value on the obstetrics and gynecology with 2.96 than on the surgery ward with 2.52 whereas the value of the efficiency factor of the total hospital is 1.90.

Various values of area efficiency factors are shown in the boxplot diagram (fig. 6) to demonstrate the degree of dispersion. The scattering of GFA/UFA and UFA/CA shows in according to more specialized wards a lower dispersion.

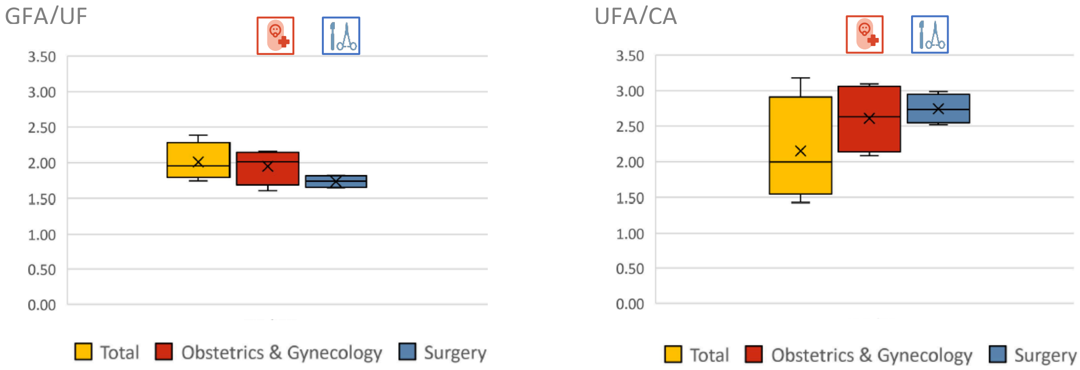


Fig. 6: Boxplot diagram of efficiency factors of different hospitals in general and wards (n=4) (complied by the author)

The number of square meters per doctor or staff regarding to the usable floor area of a specific ward within the hospital varies. In general, it can be said that one medical staff provides more space than one nursing staff.

Calculating the number of square meters of the total usable floor area per medical and nursing staff of hospital A proves that 105.38m^2 per medical staff is 27.4% more than 76.51m^2 per nursing staff. Looking at obstetrics and gynecology and surgery the values lie below the number of square meters of the total usable floor area per doctor and staff. On the surgery ward, staff and doctors assume responsibility of 30m^2 more than on the ward of obstetrics and gynecology with 90m^2 per doctor and 43m^2 per staff. In contrast to the values of (UFA+CA)/doctor and (UFA+CA)/staff, one doctor and one staff is responsible for 40m^2 more square meters on the surgery ward than on the obstetrics and gynecology ward. The total square meters of usable floor area and circulation area per doctor of hospital A are 179.17m^2 and per staff are 130.10m^2.

The area of the obstetrics and gynecology of hospital B ward of which one doctor is responsible for is 110.76m^2; it is less than the number of square meters on the surgery ward with a value of 121.78m^2. The total value of the entire usable floor area in relation to the entire number of doctors amounts to 200.24m^2 per doctor and 62,14m^2 per nursing staff. By looking at the values of UFA/staff it is conspicuous that the square meters per staff of the obstetrics and gynecology ward and of the surgery ward is significantly lower in according to the value of UFA/doctor. The value of UFA/staff of the surgery ward is 30.04m^2 per staff and of the ward of obstetrics and gynecology 25.52m^2 per staff. Totalizing circulation area and usable floor area, the area is between 10% and 12% per staff higher and between 28% and 32% per doctor higher in contrast to UFA/staff and UFA/doctor.

In hospital C the average number of square meters one doctor has to take care of incorporate 173.85m^2 and the number of square meters per nursing staff approximately incorporate 49.2m^2. At the obstetrics and gynecology ward the area per doctor reveals only 48.04m^2 whereas on the surgery ward the area per doctor amounts 119.83m^2. Looking at the amount of area per staff the result varies. On the obstetrics and gynecology ward the relation of area to staff is 17.73m^2 and on the surgery 36.32m^2. Calculating the usable floor area and circulation area together the number of square meters per employee is higher. The average number of square meters per doctor amounts 228.51m^2 and per staff 64.66m^2. Considering the different wards show that the number of square meters varies according to ward and occupational group. On the surgery ward the number of square meters per doctor provides 159.93m^2 and per staff 48.48m^2 whereas on the obstetrics and gynecology ward the number of square meters per doctor amounts 68.84m^2 and per staff 25.41m^2.

The relation UFA/doctor and UFA/staff of the total hospital shows that the staff prevent twice as much square meters than the doctors. The number of square meters of usable floor per staff is 51.13 and the number of usable floor area and circulation area per staff is 78.09. On the obstetrics and gynecology ward the relation UFA/doctor to UFA/staff is approximately twice as much. The difference varies between 84.51m^2 per doctor and 41.07m^2 per staff. On the ward of surgery, the number of square meters of the usable floor area per doctor and staff proves that 79.79m^2 per doctor is more than three times more than 24.70m^2 per staff. Looking at the square meters of UFA+CA/doctor the results nearly vary on both wards. On the surgery ward one doctor deals with 111.46m^2 and with 113.07m^2 on the obstetrics and gynecology ward. The difference of square meters per staff between both wards appears quite differently. On the surgery ward one staff takes responsibility for 34.5m^2 whereas on the obstetrics and gynecology ward the staff takes care of 54.95m^2.

Various values of area efficiency factors are shown in the boxplot diagram (fig. 7) to demonstrate the degree of dispersion. The scattering of the values of areas per doctors shows in according to the values of areas per nursing staff a higher dispersion.

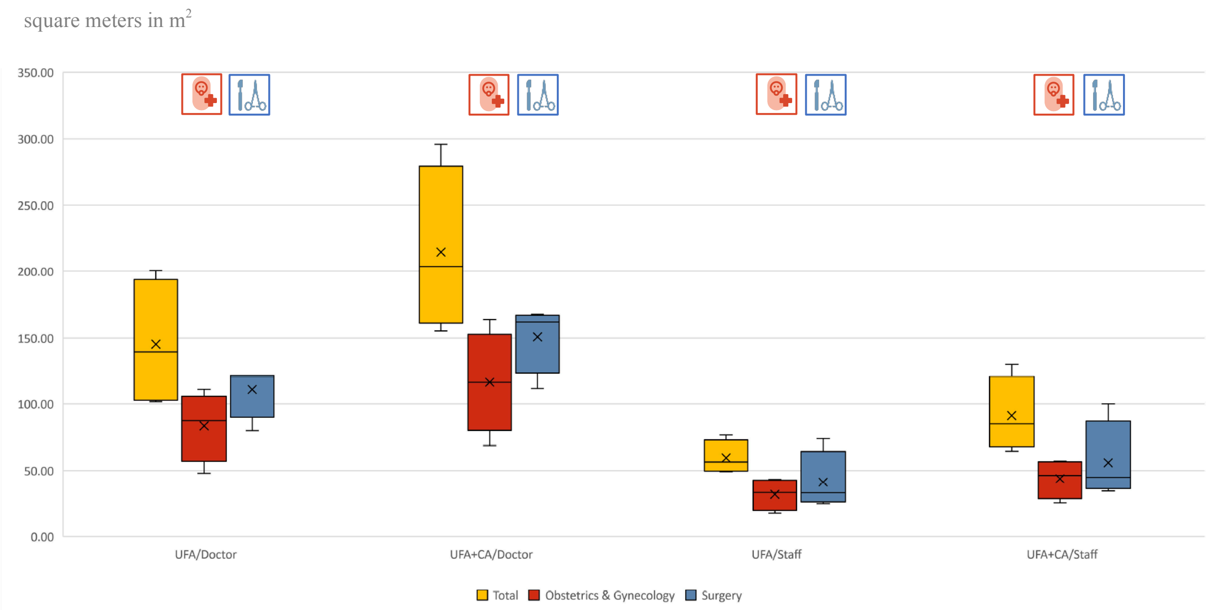


Fig. 7: Distribution of square meters per either medical or nursing staff of the entire hospital (yellow), ward of obstetrics and gynecology and ward of surgery (n=4) (complied by the author)

Results

In the hospital sector the area efficiency factor provides information concerning gross floor areas in relation to usable floor area. The relation incorporates how efficient and sustainable the floor plan of a hospital is organized. Values up to $\leq$ 2.0 mean that the relation of gross floor area to usable floor area is efficient. In general, the factor easily proves the sustainability of areas of an entire hospital. Not only the area efficiency factor of the entire hospital was proved but also the characteristics of various wards such as obstetrics and gynecology and surgery. The total values of the four different hospitals varies from 1.74 to 2.39. Hospital C was built in 1932 and has a constant over the years extended building structure. The typology of design structure of hospital C is called campus structure which suggests that the hospital was not planned in its entirety but reaches the best efficiency value. In contrast to a grown structure the other hospitals incorporates structures as comb structure, double comb structure and carpet structure. These structures have the advantage being extensible. The hospital with the most inefficient value is hospital A with a factor of 2.39. It needs to be proved if the carpet structure is not the optimal design for hospital architecture. The values also show that the comb structure is more efficient than the double comb structure. To prove Hypothesis 1 more samples of hospitals needs to be investigated to decide.

Newer hospital buildings are the more efficient and sustainable in terms of their structure and layout could not be proved. The best area efficiency factor achieved hospital C which was built in 1932 and is constantly modernized. Similar results achieved hospitals D and B with factors of 1.94 and 1.97 which were built 2008 and 2014. Hospital A were built in 2013 and gained an efficiency factor of 2.39. The analysis shows that the construction year is not important for its efficiency and sustainability in terms of its structure and layout so that hypothesis 2 could be disproved.

Looking closer into different wards, the results evidence that the area efficiency of the surgery ward is in three cases more efficient than the values of the total hospitals. The only exception is the value of surgery of hospital C which is not as efficient as its total value. The efficiency factor of the obstetrics and gynecology ward provides values from 1.61 to 2.16. The second index identified the causal interrelation between usable floor area and circulation area. The higher the circulation efficiency factor is the more sustainable is the ratio of usable floor area to the circulation area. Through a conscious interaction with the configuration of circulation areas, medical and nursing staff cover no long distance to the patients or treatment rooms. Improving the operational efficiency by area optimization supports work processes and saves time. The values of hospitals A-D vary in a wide range from 1.43 in Hospital A up to 3.18 in Hospital C whereas on the wards the dispersion of the factors is lower. Various values of area efficiency factors demonstrated the degree of dispersion. The scattering of GFA/UFA and UFA/CA shows in according to more specialized wards a lower dispersion so that Hypothesis 3 is proved. More specialized wards (e.g. surgery) are more sustainable according area efficiency.

In general, it can be said that doctors of a hospital have more responsibility over more square meters than the nursing staff. The dispersion of the number of square meters of the surgery ward one staff has responsibility for stretches more than the spread of square meters of the obstetrics and gynecology ward. Looking now at the dispersion of square meters per medical staff, the distribution measures contrary; the range of square meters stretches more on the obstetrics and gynecology ward than on the surgery ward. The distribution of square meters per medical staff within an entire hospital differ significantly. The sample of investigated hospitals must be extended to achieve an exacter result, but nevertheless the hypothesis 4 could be disproved by verifying that nursing staff take care of a little number of square meters per ward.

Conclusion

Hospitals are an essential element of every healthcare system and have priority in the healthcare industry so that the regional planning of healthcare buildings is of high interest for various stakeholders like politics, industry and economy. Many various influences affect the sustainability of hospital design and layout structures such as sociological, medical, operational and economic developments. The analysis elucidated the effects of varying changes in healthcare developments and gave an overview of various typologies of hospital buildings referring to their area efficiency. Furthermore, the sustainability of different hospitals and wards (obstetrics and gynecology and surgery) was proved by containing key figures to compare the results to another.
The comparison demonstrated that more specialized wards (e.g. surgery) are more sustainable according their area efficiency whereas typology and year of construction have not clearly proved yet.

To prove the sustainability of different hospitals by analyzing the area efficiency more hospitals need to be examined to receive a representative sample and make a scientific statement; for an empirical analysis, more hospitals and wards with various sizes, number of beds need to be investigated.
The international comparison might support the investigation of sustainable hospital architecture and give new impulses for hospital design in Germany. The comparison could support hospital planning processes and might make a statement concerning sustainable utilization, arrangements and changes in hospital areas. The results might present an overview on the distribution of area efficiency in German hospitals.

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Appendices

Appendix A
Statistical data

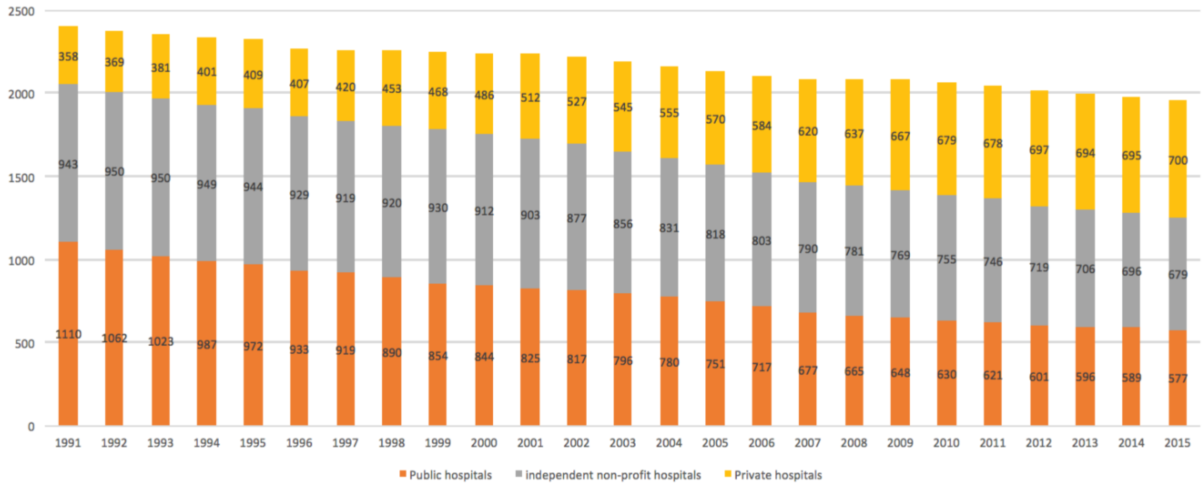

Fig. 8: Development of public, independent non-profit and private hospitals in Germany from 1991 till 2015

Appendix B
Statistical data

Table 2: Characteristics of hospitals (complied by the author)

Index	Hospital	Total
GFA/UFA	A	2,39
GFA/UFA	B	1,97
GFA/UFA	C	1,74
GFA/UFA	D	1,94
Index	Office	Total
GFA/UFA	A	1,47
GFA/UFA	B	1,44
GFA/UFA	C	1,56
GFA/UFA	D	1,42
GFA/UFA	E	1,92
GFA/UFA	F	1,65
GFA/UFA	G	1,66
GFA/UFA	H	1,62
GFA/UFA	I	1,79
GFA/UFA	J	1,76
Index	Laboratories	Total
GFA/UFA	A	1,96
GFA/UFA	B	1,50
GFA/UFA	C	1,39
GFA/UFA	D	2,23
GFA/UFA	E	4,27
GFA/UFA	F	1,88
GFA/UFA	G	1,86

Appendix C
Statistical data

Table 3: Characteristics and indicators of hospitals (complied by the author)

Index	Hospital	Total	Obstetrics & Gynecology	Surgery
GFA/UFA	A	2.39	1.92	1.64
GFA/UFA	B	1.97	2.16	1.82
GFA/UFA	C	1.74	2.10	1.80
GFA/UFA	D	1.94	1.61	1.67
UFA/CA	A	1.43	3.09	2.83
UFA/CA	B	2.10	2.08	2.64
UFA/CA	C	3.18	2.31	2.99
UFA/CA	D	1.90	2.96	2.52
UFA/Doctor	A	105.38	90.11	121.35
UFA/Doctor	B	200.24	110.76	121.78
UFA/Doctor	C	173.85	48.04	119.83
UFA/Doctor	D	101.65	84.51	79.79
UFA+CA/Doctor	A	179.17	119.23	164.18
UFA+CA/Doctor	B	295.73	163.93	167.98
UFA+CA/Doctor	C	228.51	68.84	159.93
UFA+CA/Doctor	D	155.25	113.07	111.46
UFA/Staff	A	76.51	43.34	73.85
UFA/Staff	B	62.14	25.52	30.04
UFA/Staff	C	49.20	17.73	36.32
UFA/Staff	D	51.13	41.07	24.70
UFA+CA/Staff	A	130.10	57.35	99.91
UFA+CA/Staff	B	91.78	37.77	41.43
UFA+CA/Staff	C	64.66	25.41	48.48
UFA+CA/Staff	D	78.09	54.95	34.50

Appendix D
Statistical data

Table 4: Area data with n=4 (complied by the author)

Hospital	Ward	GFA (in m²)	UFA (in m²)	CA (in m²)	Fulltime doctors*	Fulltime staff*
A	Total	105000.00	43987.00	30805.00	417.43	574.90
	Obstetrics & Gynecology	4075.93	2117.67	684.23	23.50	48.86
	Surgery	4295.61	2615.19	922.79	21.55	35.41
B	Total	38000.00	19309.02	9207.78	96.43	310.72
	Obstetrics & Gynecology	5221.34	2414.49	1159.20	21.80	94.62
	Surgery	5721.92	3141.85	1192.04	25.80	104.60
C	Total	48348.10	27739.60	8720.77	159.56	563.87
	Obstetrics & Gynecology	1319.85	628.30	272.15	13.08	35.44
	Surgery	2419.65	1342.05	449.19	11.20	36.95
D	Total	68286.13	35187.22	18556.68	346.17	688.25
	Obstetrics & Gynecology	2089.49	1301.46	439.87	15.40	31.69
	Surgery	2381.93	1424.21	565.30	17.85	57.66

*Deutsches Krankenhausverzeichnis, 2017