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A comprehensive review of hospital strategic planning optimization through clinical engineering expertise

Review Article

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Abstract
Designing hospitals is a challenging task due to the critical nature of the services they provide. The hospital building must accommodate a variety of healthcare services, including medical imaging, sample analysis, surgical operations, and emergency care, to facilitate disease diagnosis and therapy. The efficient delivery of these services depends on multiple parameters, but effective strategic planning for hospital' rooms is crucial for success. While physicians, architects, and sponsors traditionally form the planning team, the role of the clinical engineer (CE) is often overlooked. However, CE possesses valuable expertise in healthcare technology and experience that can significantly contribute to the development of an ergonomically designed hospital, characterized by enhanced operational efficiency and optimal moral hygiene. This literature will delve into the reasons why the clinical engineer is the ideal choice for this role and highlight the benefits of selecting him to practice this specialty. Additionally, this study aims to loudly announce this fact and will propose recommendations to enhance the clinical engineer's capability to adapt to the future smart hospitals, which are considered the ultimate goal in healthcare facility planning.

1. INTRODUCTION

Healthcare facilities are among the most challenging architectural projects[1]. Multiple opposing factors have to be prioritized within the various involved sponsors. For example, the design is required to provide super-quality patient healing spaces, and efficient and ergonomic working conditions for physicians, nurses, engineers, and employees taking into consideration sustainability and enduring facility pursuits[2]. As a matter of life-saving, hospital design doesn't tolerate construction or infrastructure mistakes[3]. For that reason, a healthcare building takes a long time to design and construct. Besides, hospitals require special types of advanced ventilation means that allow a continuous feed of medical gases added to providing sustainable environmental conditioning for patients. The infrastructure for both life-saving equipment and medical information technology networking extends the required time for the plan and design phase[4].

The design of hospitals is conducted in consequent phases. It commences with a primary analysis of the sponsor's needs and ends withthe assessment of the turnkey building structure and operation[5]. The primary analysis and initial design predefine the goals and provides answers to basic questions such as: what the sponsor does want to achieve from the new healthcare facility, and why. During the preliminary phase of design, the strategic planner is engaged with the chief architect to come up with the available proposals for achieving the predefined goals. Following that, the strategic planner and his team decide step-by-step the planforthe healthcare facility. This plan includes the number of rooms, paintings, flooring materials, color schemes, electricity installations, furniture, andmedical equipment[6,7].

In terms of medical equipment, an updated knowledge of the state of the art of medical technology is required[8]. This knowledge enables a precise forecast and contemplative review of rising-up scientific novelties. This forecast strongly impacts the commencement of the planned medical facility, in addition, to articulating validations for the adoption of the original technologies or of the need to improve or swap current ones.Consequently, a proficient clinical engineer (CE) becomes a must in the planning of a hospital.

The CE's role, in hospitals, is significant in computing the lifespan of each asset. In addition, CE performs a cost-accountant analysis. This analysis encompasses criticism of the influence equipment has on compensation procedures such as cost-dependent or item-dependent purchase procedures. ProficientCE builds a market foretelling model for each potential piece of equipment that embrace the fair price and global annual expenses

of sustaining the administrative inventory gauged as well as new supplements reinforcing the strategic plan. CE participationis not restricted to only the plans of newly constructed hospitals but also tothe ones that are upgrading their medical technology policies[9]. This upgrade commences with a strategic plan[10]. The plan, in the upgradecase, is illustrating obvious ratification for administering the state-of-the-art medical equipment. It is a process in which the consideration of the governing issues and the crucial success aspects are trailed by a well-identified task of supplies apportionment and a designation of the ongoing enhancement in technology's operation. This process is individually tailored for each organization based on its goals and resources.The purpose of this paper is to announce a ringing declarationthat clinical engineer is an optimumnomineefor a medical strategic planner.

2. LITERATURE REVIEW

This section reviews the evolution of the clinical engineering discipline and job through some headlines: (1) CE definition, (2) key roles of CE in a working hospital, (3) CE interactions with other health care providers including physicians and nurses, and finally (4) the role of the CE in either new hospital establishment orrenovation work.

2.1 CLINICAL ENGINEER DEFINITION

CE is a specialized person who can support and achieve more progress in patient care by applying engineering and administrative proficiencies in the healthcare industry[11]. In addition, CE is also engaged in the advance of medical equipment as well as their optimal and secure use in hospitals[12]. In other perspective, the person who manages the medical technology and systems and interacts with end users in the field of health care with full responsibility because of his high level of education and experience is tagged CE[13]. Another authordefined CEas a special engineer who pays his full attention on the link between medical equipment and patients and utilizes the concepts of engineering in the administration of equipment and systems in medical environment[14]. In terms of technology assessment, CE usually collects and coordinates the data regarding new technologies to be able to manage, examine and discuss all the technology relevant benefits, costs, maintenance and repair[15]. In the smart hospitals, CE is required to safely save and obliteratepatient data from the devices in the intensive care screens, laboratory datafiles, radiology data records and any other equipment that holds patient data[16].

2.2. CLINICAL ENGINEER KEY ROLES

The main role of the senior CE in a hospital is to supervise the clinical engineering department that employs junior clinical engineers and biomedical equipment technicians (BMETs)[17]. In addition, the CE role is irretrievable in designing the infrastructure and spacing for newly adopted technologies[18]. A summary of the roles of the clinical engineer in the healthcare establishment is illustrated in Figure 1. The necessity for CE involvement in the healthcare team is crucial when the following complications were continually encountered[8]:

1. Recently adopted devices were not satisfactorily expended
2. Continuous user problems with new adopted technologies
3. Lengthy downtime for medical equipment and thus ownership losses
4. Incompatibility with accreditation organizations and guidelines
5. Accumulation of malfunctioned equipment and long repair waiting list
6. Maintenance expensesarising
7. Medical devices updating, substitution, and organization are not interlaced

To address these issues, an ongoingmedical industry evaluationplan is established with the following goals:

1. Collectingrelevantdataconcerning decisionsabout medical technologies
2. Generating anannual plan for technology substitution andlinked expenses
3. Establishing a criterion fortechnology evaluation with outcomesweights
4. Raising the assetfinancial plan process by incorporating the statusof art technology with futurerequirementslinked to diagnosis and therapy goals
5. Involving the aptitude of clinical engineering intopatient safety objectives.

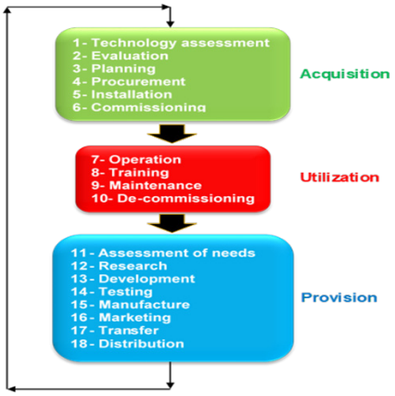

Fig. 1: summary of the major roles of a clinical engineer in the healthcare environment[19]

2.3. INTERACTIONS OF CLINICAL ENGINEER WITH HEALTHCARE MEMBERS

The interactions of CE with the healthcare providers for different activities are shown in Figure 2.This figure illustratesthe diversity of the CE's tasks.

2.3.1. HOSPITAL ADMINISTRATION:

CE puts his inputsin the design of clinical facilities, prepares and provides the required documentation to external accreditation and licensing agencies, and contributes in planning the cost effectiveness and the required annual budget report for medical technology maintenance and repair.

2.3.2. DOCTORS:

CE is required to follow up the technology innovations in medical techniques for diagnosis and therapy purposes. This follow up results in being prepared for the periodic upgrade and the development of the modern healthcare facilities.

2.3.3. NURSES:

CE has a good connection with nurses in order to provide basic training of efficiently operating medical technologies and teach them simple and basic troubleshooting for medical devices.

2.3.4. PATIENTS:

CE is responsible for achieving the safe healing environment via being strict to the standards of quality assurance and control of medical inventory.

2.3.5. MEDICAL TECHNICIANS& ENGINEERING AFFAIRS:

CE is leading Engineers/ technicians to be proficient in safe and effective use/maintenance of medical technology and systems via effective and permanent training.

2.3.6. HEALTH AGENCIES AND ORGANIZATIONS:

CE has a good cooperation with health agencies since via adept at the standard instructions of Safety, quality control, infection control and hygiene.

2.3.7. CLINICAL RESEARCHES:

CE assist in various clinical research work using the experience that grew up during the long time spent in operating and managing the medical equipment and devices.

2.3.8. HEALTH TECHNOLOGY SUPPLIERS:

CE is the main point of contact with medical technology suppliers because of the responsibility of keeping the technical validity of the hospital devices as maximum as possible. Moreover, CE needs to recover and fill back all the consumable of the medical inventory.

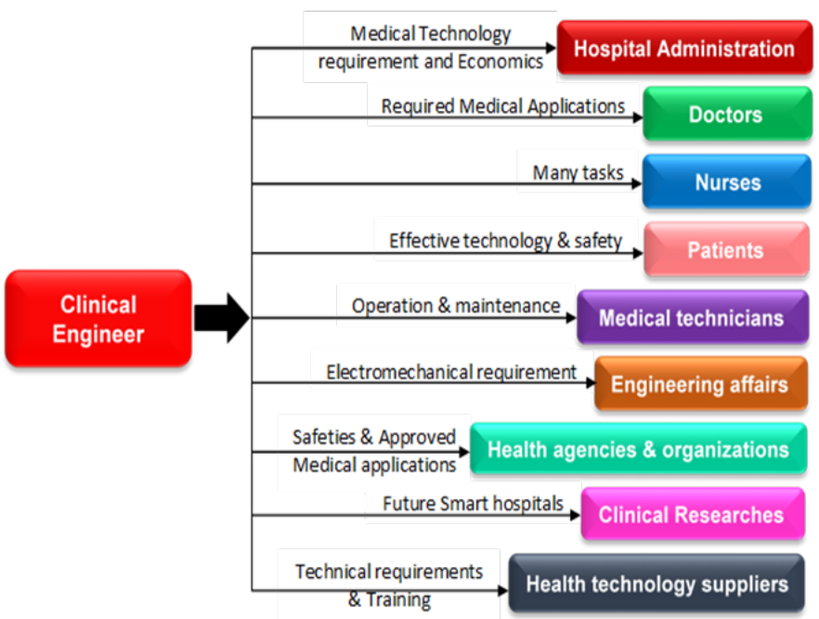

Fig. 2: the interactions of the clinical engineer with other members in the healthcare provision team

2.4 CLINICAL ENGINEERING IN HOSPITAL NEW CONSTRUCTION AND RENOVATION:

To the best of our knowledge "The role of clinical engineering in construction and renovation is limited to medical equipment selection in the middle east and the developing countries. Clinical engineers have many opportunities to become valued members in the design team for new hospital construction and current ones' renovation projects. To open up these opportunities, clinical engineers must expand their knowledge of the design and construction process and should expand their roles further than adopting medical equipment. They also need to insist on active involvement at every stage of the design and construction process. For that purpose, the academic education firms should include the hospital strategic planning in their programs as educational Topic [13,18].

3. METHODOLOGY

This study devoted multiple means to achieve its purpose. 1) A written questionnaire was delivered to 203 biomedical engineering fresh graduatesfromten universities in Egypt. 2) An advancedquestionnaire was organizedto120 senior engineers whomspecialties are diverse. 3) Field visitsfor13 consultant offices design and planning teams who were involved in building or renovating hospitals in four governorates in Egypt.

3.1GRADUATE BIOMEDICAL ENGINEERS QUESTIONNAIRE

The questionnaire was built in purpose to measure the basic understanding of the fresh graduates' biomedical engineers (BM) for the fundamentals of clinical engineering and its role in hospitals design and renovation. The list of questions is divided into two sections. The first section is composed of three questions focusing on the qualifications and the role of the clinical engineer in the medical facility. The second section is composed of five questions regarding hospital design, planning, and various hospital departments' requirements in terms of space, location, accessibility, and equipment. The 203 answers for this questionnaire were collected via successive meeting with BM engineers in scientific and career fair events that are held in the Egyptianuniversities and the Egyptian engineering syndicate between 2021 and 2023.The questions that are forwarded to the graduate biomedical engineers and the scores they gotare listed in Table 1.

Table 1: Graduate biomedical engineers questionnaire and the marked scores

Sections		Subject	Questions	Correct answers/ total answers	Percentage ratio
1	1	Fundamentals of clinical engineering and its role in medical facilities	Is maintaining medical equipment the only responsibility for clinical engineer in a hospital?	83/203	~ 41 %
	2		Is the clinical engineer involved in maintaining patient safety inside medical facilities?	67/203.	~ 33 %
	3		Are the engineering/ technical skills the only qualification for clinical engineers?	105/203	~ 52 %
2	1	Basic understanding of hospital design and planning	State three of the diagnostic departments in a general hospital.	53/203	~ 26 %
	2		State three of the therapeutic departments in a general hospital.	67/203	~ 33 %
	3		Where should be the radiology department within the hospital building?	51/203	~ 25 %
	4		What is the impact of a hospital design with one entrance gate on the emergency department?	20/ 203	~ 10 %
	5		How do the clinical engineer secure the supply of medical gases to the patients in the hospitals?	27/203	~ 13 %

3.2 SENIOR ENGINEERS QUESTIONNAIRE:

The questionnaire was constructed deliberately to gauge the apprehension of engineers who have diverse specialties (architect, civil, electrical, and mechanical)and had the opportunity to work in hospital design, planning and renovation. The roll of questions is split into two parts. The initial part is composed of eight questions that

highlight the prime design and planning requirements of medical facilities. The following part is composed of five questions that put spot onthe healing environment requisites. The 120 responses for this questionnaire were amassed via consecutive meetings with engineers in 2022 and 2023 within training programs sponsored by the Egyptian Society of Engineers. The questions that are directed to the senior engineers and the scores they got are inTable 2. The questionnaire was answered by 118 engineers who have divergent backgrounds, and working in 12 distinct governorates in Egypt and 2 engineers from Sudan. The numeral distribution of the engineers versus their work location is shown in Figure 3.

Table 2: senior engineers questionnaire and the marked scores

Sections		Subject	Questions	Correct answers/ total answers	Percentage ratio
1	1	Design and planning requirements of medical facilities	What are the main requirements in the design of patient room?[20]	49/120	~ 41 %
	2		What is the optimum number of patients in the hospital room? (single, double, or multiple)[20]	67/120	~ 33 %
	3		Is it required to have a sleeping bed for the patient's companion?[21]	105/120	~ 87.5 %
			Do plainor pattern paint colors are more relaxing inside hospitals?[22]	62/120	~ 52 %
			Is it obligatory or optional to have sound insulation in the patients' rooms?[23]	75/120	~ 62.5 %
			Is direct or indirect lighting more preferred in patients' rooms?[24]	102/120	~ 85 %
			Is individual or central air conditioning more preferred inside the hospitals?[25]	72/120	~ 60 %
			Is the ring-bill an appropriate way of calling medical assistance for patients?[18,26]	107/120	~ 89 %
2	1	Healing environment requisites	Is set-menu or open-menu more preferable for serving food for patients in the hospitals?[27]	53/203	~ 26 %
	2		Which is preferable hospitals: playing classical slow music or silence?[28]	67/203	~ 33 %
	3		Is the landscape in the hospital design considered a significant or optional healing factor?[29]	51/203	~ 25 %
	4		What are the main considerations that should be considered for the hospital furniture selection?	20/ 203	~ 10 %
	5		What are the smart technologies that need to be considered in the hospital?	27/203	~ 13 %

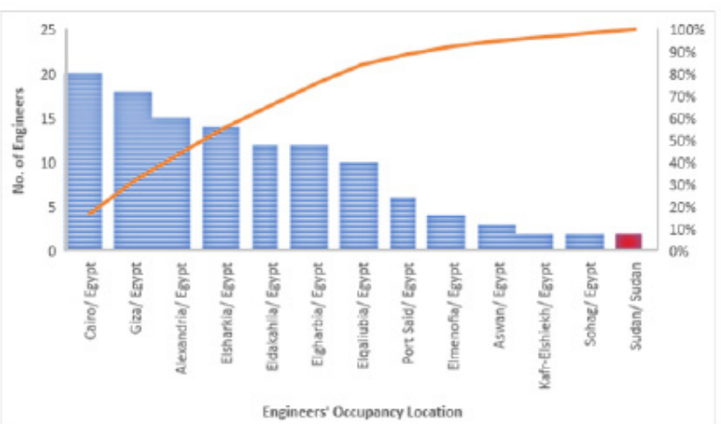

Fig. 3: the number of engineers versus the occupancy location whom were asked to answer the hospital design questionnaire

3.3. CONSULTANT OFFICES FIELD VISITS:

The purpose of the visits was to make a survey regarding the way of designing new hospitals or renovating old ones. The main investigator of this study focused on completed projects which were designed and planned by these consultant offices. The goal of the discussion was either there was any consultancy made by clinical engineers in the design phase in the projects of healthcare buildings. Table 3shows the occupation of the consultant offices in various governorates of Egypt, and the number of projects they did earlier.

Table 3: The egyptian consultant offices and the number of projects executed by them

#	Governorate/ Country	Number of Consultant Offices	Number of completed Healthcare Projects	Healthcare projects planned with clinical engineering experience
1	Cairo/ Egypt	5	14	6
2	Giza/ Egypt	3	8	3
3	Alexandria/ Egypt	1	4	1
4	Sharkia/ Egypt	4	6	2
Total	4 Governorates	13	32	12

4. RESULTS

A statistical analysis was performed for the answers of the questionnaires which were given for fresh graduated/ junior engineers, the senior engineers.The visits for the consultant offices were exploited in building field knowledge regarding the of plan and design healthcare projects in Egypt. The analysis results are described as follows:

4.1. GRADUATE BIOMEDICAL ENGINEERS QUESTIONNAIRERESULTS

The questionnaire is divided into two groups of questions as shown earlier in Table 1. The first group focused on the fundamentals of clinical engineering and its role in medical facilities. The second group shed light on the basic understanding of hospital design and planning. The participants' knowledge, in the topics of this questionnaire, were analyzed according to their correct answers with the following grades shown in Table 4.

Table 4: the criterion of grading thequestionnaire for fresh graduate biomedical engineers

#	Grade	Number of correct answers	Percentage
1	Great	7 or 8	≥87.5 %
2	Good	5 or 6	≥62.5% and <87.5%
3	Average	4	= 50%
4	Poor	2 or 3	≥25% and <50%
5	Very poor	0 or 1	<25%

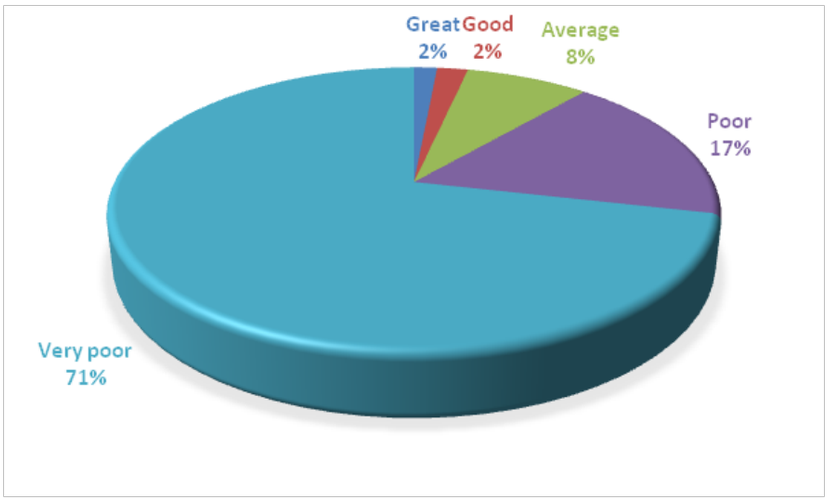

Fig. 4: shows the results of the questionnaire that was answered by 203 fresh graduate/ junior engineers regarding clinical engineering and its role in the design and plane phase of healthcare buildings.

4.2. SENIOR ENGINEERS QUESTIONNAIRE RESULTS

The questionnaire is divided into two parts of questions as shown earlier in Table 2. The initial partaccentuated on the Design and planning requirements of medical facilities. The other partasked the participant aboutthe healing environmentrequisites. The engineers'knowledge wasscrutinized based on the most recent published research results that were found in the literature reviewaccording to the best of our knowledge with the following grades shown in Table 4:

Table 5: the criterion of grading thequestionnaire for fresh graduate biomedical engineers

	Grade	Number of correct answers	Percentage
1	Great	12 or 13	≥87.5 %
2	Good	9, 10, or 11	≥62.5% and < 87.5%
3	Average	7 or 8	≥ 50% and < 62.5%
4	Poor	5 or 6	≥25% and < 50%
5	Fail	0 to4	<25%

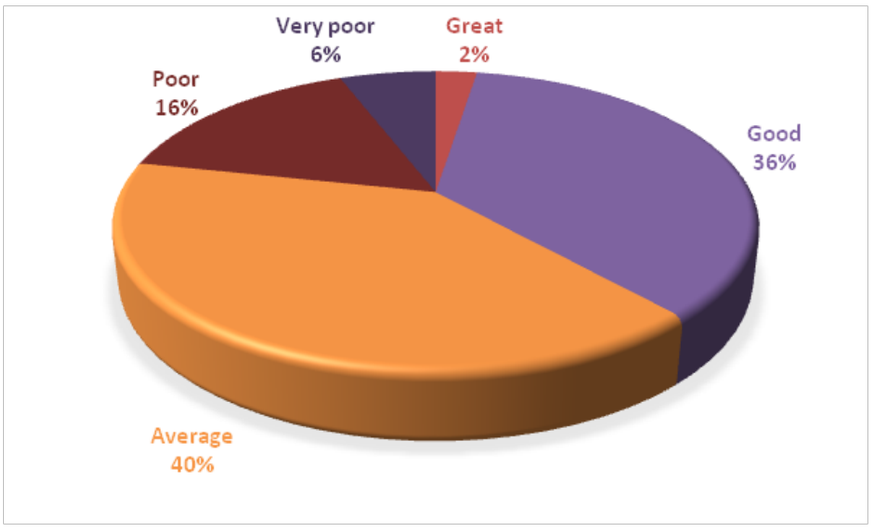

Fig. 5: figure 4: shows the results of the questionnaire that was answered by senior engineers regarding

4.3 FIELD VISITS FOR CONSULTANT OFFICES

The main investigator collected data from the field visits for the consultant offices and the healthcare buildings that they designed from scratch or for renovation purposes. The role of clinical engineering in the design phase was below 50% in the 4 main governorates in Egyptincluding the capital.Figure 5 shows the occupation of the consultant offices which were included in the study and the percentage of clinical engineering contribution in the design and planning of new healthcare buildings or renovating old ones.

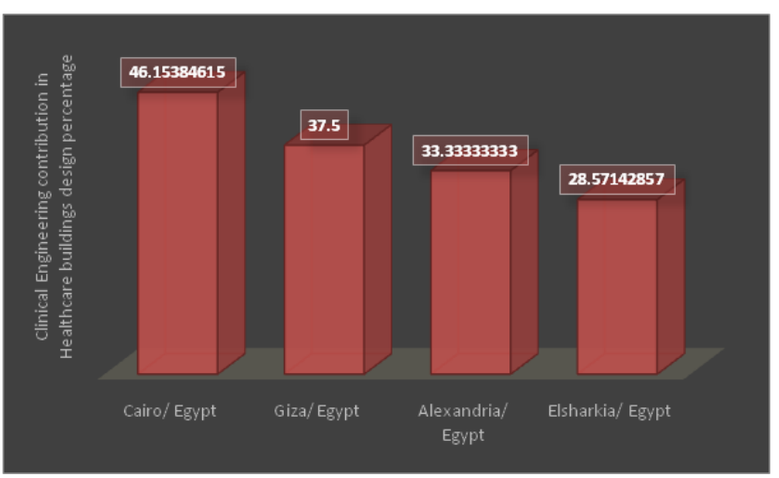

Fig. 6: Shows the perecentage of the contribution of clinical engineering in the design and planning og healthcare establshment or rennovation

5- DISCUSSION AND CONCLUSION

The results of a questionnaire that was administered to 203 fresh graduate/junior biomedical engineers to measure their knowledge relevant to Clinical Engineering and hospital planning and design, showed that 2% of the engineers rated as "Great," 2% rated as "Good," 8% rated as "Average," 17% rated as "Poor," and 71% rated as "Very Poor."

Based on these results, it appears that the vast majority of the fresh graduate biomedical engineers surveyed have a very poor understanding of Clinical Engineering and hospital planning and design. This raises concerns about their ability to effectively design and implement healthcare facilities. Further education and training may be necessary to improve their knowledge in this area. Additionally, it may be necessary to re-evaluate the curriculum of biomedical engineering programs to ensure that graduates have the necessary skills and knowledge to perform their job duties effectively. This could include partnering with healthcare institutions to provide more hands-on and practical training in the field.

The results of a questionnaire which was administered to 120 senior engineers to measure their knowledge relevant to hospital planning and design, showed that 3% of the engineers rated as "Great," 43% rated as "Good," 48% rated as "Average," 19% rated as "Poor," and 7% rated as "Very Poor."

Based on these results, it appears that the majority of the engineers surveyed have a good or average understanding of hospital planning and design. However, a significant portion of the group (26%) rated their knowledge as "Poor" or "Very Poor," indicating a potential need for further education or training in this Field.

The findings of the study indicate that the overall response rate to the three clinical engineering knowledge-related questions was 41%, as presented in Table 1. Furthermore, the targeted group of senior engineers lacked this knowledge, which highlights the potential for expanding the role of clinical engineers in hospital planning and design. Additionally, clinical engineers possess a high level of familiarity with the healthcare environment. Enhancing the skills and qualifications of clinical engineers through the proposed framework is expected to result in optimal planning and upgrading of hospital facilities, thereby contributing to the overall improvement of the healthcare sector in Egypt.

The results related to the visit to consultant offices that presented in Figure 5 highlights the lack of involvement of clinical engineering in the design phase of healthcare buildings. This is a cause for concern as it can lead to a number of issues such as inefficient use of space, inadequate equipment planning, and lack of consideration for patient and staff safety.

The low percentage of clinical engineering contribution in the design and planning of healthcare buildings is an indication that there is a need to raise awareness about the importance of clinical engineering in the design process. Healthcare buildings are complex structures that require careful planning and design to ensure that they meet the needs of patients, staff, and visitors. Without the input of clinical engineers, there is a risk that these buildings may not be designed to meet the specific needs of the healthcare environment.

To address this issue, it is important to establish guidelines that ensure the involvement of clinical engineers in the design phase of healthcare buildings. This can be achieved through collaboration between consultant offices and clinical engineers to ensure that their input is effective and meaningful. Additionally, it is important to provide training to consultant offices on the importance of clinical engineering in the design process and to encourage them to seek the input of clinical engineers in their projects.

In conclusion, the results of the study highlight the need for greater involvement of clinical engineers in the design phase of healthcare buildings in Egypt. It is important to raise awareness about the importance of clinical engineering in the design process and to establish guidelines that ensure their involvement in healthcare building projects. Through collaboration and training, we can ensure that healthcare buildings are safe, efficient, and meet the needs of everyone who uses them.

6-RECOMMENDATIONS

1- It is recommended to incorporate hospital facilities planning as a subject in the academic curriculum for under-graduates of biomedical engineering programs.

2- It is recommended to include "clinical engineering" as a subject in the academic education for under-graduates of biomedical engineering programs.

3- It is recommended to establish regulations and policies that mandate any consulting office seeking to provide consultancy services for healthcare facilities to provide a training certificate in hospital facilities planning issued by a recognized authority in Egypt.

4- It is recommended to include the planning certificate in the Code of Egypt.

5- It is recommended to register hospital facilities planning as a specialized branch of biomedical engineering.

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