Design of Rapidly Assembled Isolation Patient Ward – IT-Supported Collaborative Design Process between Architects and Medical Officers

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Summary

An important feature of the 2003 SARS outbreak in Canada, Singapore, and Hong Kong was that many health care workers (HCWs) developed SARS after caring for patients with SARS. This has been ascribed to inadequate or ineffective patient isolation. However, it is difficult for dense cities to provide sufficient isolation facilities within a short period of time. This has raised concerns from the public for new strategies in the planning and design of isolation facilities. Considering that SARS or other infectious diseases could seriously damage our society's development, isolation facilities that could be rapidly and economically constructed with appropriate environmental controls are essential. For this reason, the design team of the Department of Architecture collaborated with a special task force from the Faculty of Medicine, who are the frontline medical officers treating the SARS patients, to design *Rapidly Assembled Isolation Patient Wards*.

Both architecture and medicine are well established disciplines, but they have little in common in terms of the mode of knowledge construction and practice. This induced much intellectual exploration and research interest in conducting this study. The process has provided an important reference for cross disciplinary studies between the architectural and medical domains.

1 Introduction

Severe Acute Respiratory Syndrome (SARS) stroked the globe in the spring of 2003. A total of 4,288 SARS cases were reported within the first month of the outbreak. An important feature of the outbreak in Canada, Singapore, and Hong Kong was the continual infection of health care workers (HCWs) after caring for patients with SARS [Lee 2003; Poutanen 2003]. This revealed the deficiencies of the current medical facilities and imposed significant challenges in the effective treatment of infectious disease. Therefore, prompt establishment of effective and efficient medical facilities for future unexpected infectious disease is essential.

Hospitals treating SARS were mostly general hospitals that were not designed for treating such highly infectious diseases. Infectious disease is a special field in medicine that has more scrupulous requirements for hospital layout, facilities, equipment, and practice guidelines than those of general hospitals. The practice of isolating part of a general hospital for treating SARS could help only in isolating the patients, but not the viruses or similar infectious agents that could be carried away through ventilation systems, mobile equipment, clothing, or human beings themselves. Several studies have been carried out on the modification of practice, systems, and facilities of current hospitals to support the needs of isolation. For example, the Hong Kong University has studied the layout of ventilation systems; the City University of Hong Kong has developed a sterilization system for the exhaled air from infected patients. Yet, these studies have mainly focused on piecemeal retrofit solutions for existing facilities that leave the long-standing problem unsolved. Though the Xiaotangshan SARS hospital in Beijing has demonstrated a successful example for infectious disease control where no HCWs were infected throughout the period of service, it is an exceptional case. The low density environment, stringent administrative control, and most importantly the resources devoted to its establishment were tremendous. It is not an applicable model for densely populated cities like Hong Kong. This has raised concerns from the public for new strategies in the planning and design of isolation facilities. Considering that SARS or similar infectious diseases could seriously damage our society's development, isolation facilities that can be rapidly and economically constructed with appropriate environmental controls are essential. For this reason, the project team of the Department of Architecture collaborated with a special task force from the Faculty of Medicine, who are the frontline medical officers treating the SARS patients, to design Rapidly Assembled Isolation Patient Wards.

2 Methodology

For a thorough consideration of both the architectural and medical aspects, the research team conducted case studies, interviews, and literature review. We also applied computational fluid dynamics to assess the ventilation strategy, which is a crucial concern in the design of the proposed medical facilities.

2.1 Case studies

The Prince of Wales Hospital (PWH) in Hong Kong and the Xiaotangshan SARS Hospital (XTS) in Beijing were studied. PWH was the first hospital in Hong Kong to manage SARS cases. The aspects of medical practice and architectural design of the PWH that contributed to the infection of HCWs provide significant information for the design of new medical facilities. XTS, dedicated to SARS treatment, was built in 7 days by over 7000 construction workers. No HCWs were infected within the 50 days of service [Sina News 2003; Xinhuanet 2003]. Therefore, aspects of its layout, construction, and work pattern serve as important references for the study.

2.2 Interviews

Interviews with the frontline SARS HCWs helped in identifying the pros and cons of current medical facilities from the user's point of view. The interviewed doctor and nurses provided valuable information concerning the practical details of handling the patients, as well as the physical and psychological needs of both the HCWs and patients.

2.3 Literature review

The literature review paid special attention to the layout, air pressure control, construction technology, and human factors of medical isolation facilities. It included architectural standards for medical facilities, safety requirements for biomedical and microbiological laboratories (BMBL), and special information regarding SARS treatment as issued by the Centers for Disease Control and Prevention (CDC) as well as the World Health Organization (WHO).

2.4 Computational Fluid Dynamics Simulation

The effectiveness of the ventilation strategy was assessed by means of computational fluid dynamics (CFD) simulation. CFD was used to predict and visualize the airflow patterns corresponding to various design options, for comparison with the intended design performance. The principal CFD software was FLUENT 6.0, which provides flexible grid generation and a sophisticated algorithm to account for turbulence. Indeed, turbulence is an important consideration in ventilation-related architectural design. To model the complex situation in the medical environment, a multiphase time-dependent simulation was employed to take into account the exhaled vapor as well as heat dissipation from the patients.

3 The rapidly assembled isolation patient ward

The patient ward was designed as a plug-in system for existing structures. It was formed by combining a series of basic modules that could be flexibly arranged to adapt to various uses. The simple linear arrangement increases the adaptability of the system to different environments. To facilitate the construction process, existing buildings could be evacuated to host the linear isolation patient ward. In that case, construction for building services systems could be minimized, and the modules could be prefabricated and assembled on-site by non-specialized workers. The whole system could be multiplied with increasing needs.

Considering that ventilation is crucial, particularly for infectious disease control, we have paid special attention to the room layout and settings of all vents. CFD simulations verified a clear pressure distribution pattern in the connected patient ward environment. Air generally passes from fresh air inlets first to medical staff, then to the patients, and finally leaves the ward though the exhaust air outlets. The distribution of inlets and outlets took into account both the sitting and lying position of the patients so that exhaled air could be effectively removed regardless of their posture. With multiphase time-dependent simulation, the distribution of exhaled water vapor from patients was also assessed, since it may have a high virus concentration. Results showed that the vapor mainly concentrates near the heads of the patients and is extracted within a short time.

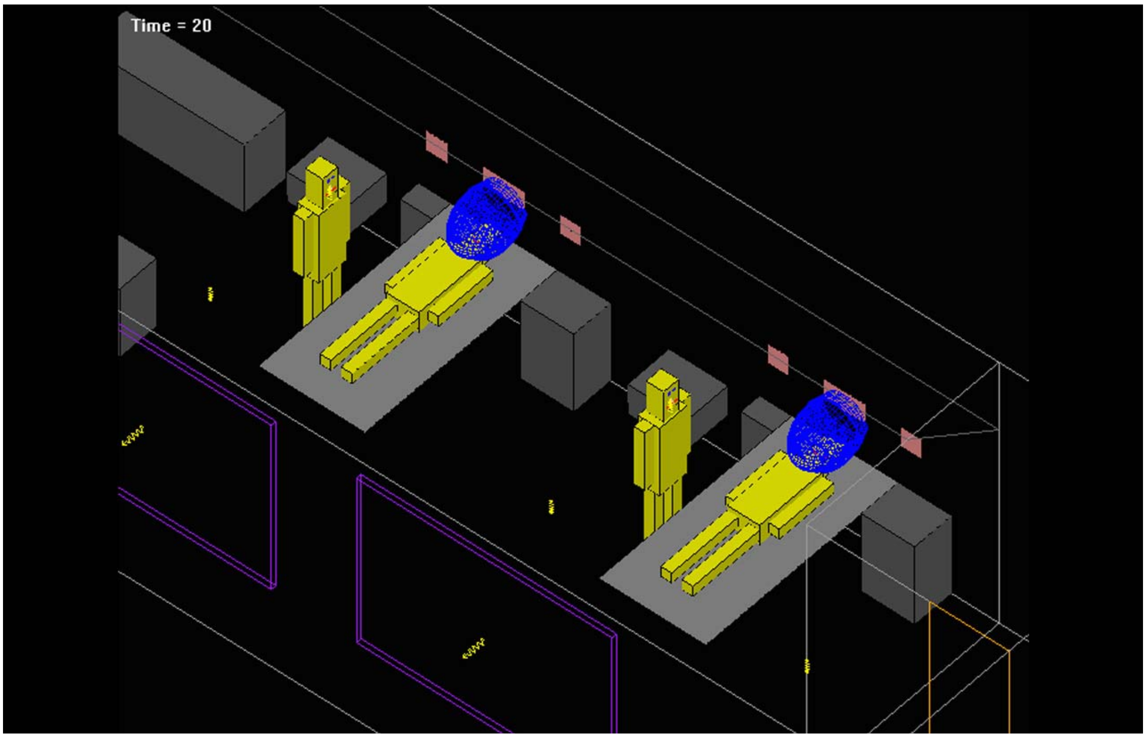
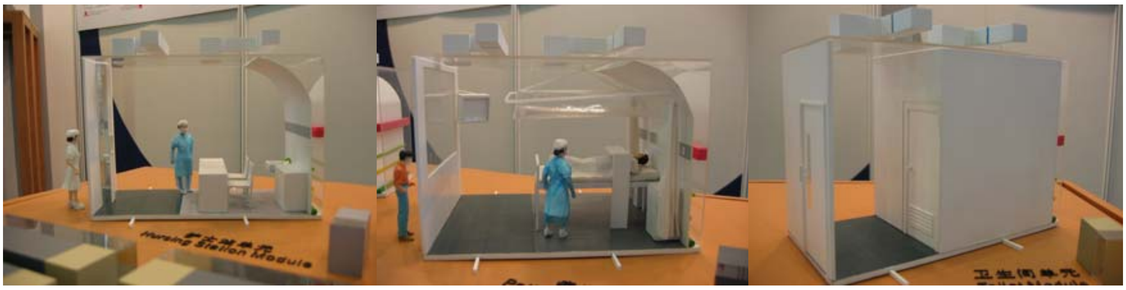


Figure 1: Applying multiphase time dependent Computational Fluid Dynamics simulation to assess the distribution of water droplets from the patients. The blue meshes indicate the dispersion of droplets emission from the patients.

Apart from the functional requirements of architecture and medicine, the design also took into account the physical and psychological needs of the HCWs, the patients, and their kith and kin. The HCW-patient ratio could be flexibly changed with the arrangement of the basic modules. Design details facilitate the needs of nurses working in pairs, keep patients connected to the outside with entertainment facilities, and accommodate visits by kith and kin.

The flexibility of the ward offers potential implementations in various locations and medical uses. With appropriate modifications, the rapidly assembled isolation patient ward could serve as a mobile medical facility for emergencies.



Nursing Station Module Patient Ward Module Toilet Module

Figure 2: The modules could be flexibly arranged to adapt to different conditions.

4 Findings and discussion

Though the hospital is not a new architectural type, domain knowledge for designing and planning effective isolation facilities has not been common between practitioners of medicine and architecture. The training and practice modes for the two disciplines have little in common and their practitioners tend to have strengths developed in different dimensions. Considering that the project team involved specialists from rather different domain backgrounds, the team members faced several challenges.

4.1 Establishing common ground for discussion

Before the establishment of the project, there was much discussion among civil society regarding the feasibility of new structures for isolation. From the medical point of view, a completely separated isolation facility is essential for unknown infectious disease. However, significant time is required for construction and preparation before a new medical facility can be put into service. This demonstrates the need for building the necessary medical facility prior to the next unpredictable outbreak of infectious disease. From the architectural point of view, temporary structures are commonly designed and deployed for situations of occasional use. Simple structures that could be rapidly deployed as needed should be a more cost effective solution than elaborate permanent structures that would usually be under-utilized. Fundamental differences in professional perspective between medicine and architecture led to diverging approaches to the development of the project.

Both medicine and architecture involve wide scopes of knowledge, but they have little scope in common. Practitioners of the two disciplines can have different understandings and perspectives of the same problem domain. In approaching this problem, each discipline tended to suggest solutions and methodologies based on its own established paradigms. Without a common understanding, recommendations that sought to resolve conflicts were very limited and sometimes considerably incongruent. This caused such significant difficulties for integration that the whole design cycle occasionally became stuck in the mud.

To overcome these obstacles, the project team carried out an in-depth case study of the PWH. The team members identified problems based on the expertise of their respective disciplines. These perspectives were then discussed thoroughly to exchange points of view. Problems identified in each professional domain were clearly expressed. Without much reliance on information technology, the case study and intensive in-depth discussions facilitated the exchange of domain focuses and concerns.

Objectives such as efficiency, economy, and accuracy were defined in the aspects of air pressure control, construction, and human factors. Pressure control is a mandated requirement in the design of medical facilities while the construction and human factors are basically recommendations of the project team.

4.1.1 Pressure control

Pressure control aims to control the flow of contaminated air, to prevent infection from spreading to the clean zone, health care workers, and other personnel. The current design standards regarding ventilation focus on the air change rate, but this considers only the volume ratio of the incoming air with the room size. It fails to consider stagnation, turbulence and flow pattern, which are crucial factors in the effectiveness of virus removal. Therefore, there was a thorough study of the settings and locations of vents, and the configuration and arrangement of the ward, which affect significantly the airflow pattern inside the ward.

4.1.2 Construction

Considering that the evolution of new infectious disease is unpredictable, establishing a permanent isolation hospital or transforming part of a general hospital might not be flexible and economical enough to meet the immediate demands for treating an unknown infectious disease. Therefore, a medical structure that could be effectively and efficiently constructed when needed became a main concern of the study. This raised several issues concerning:

- the training of non specialized workers and medical team for operating the system;
- the association of the new structure with existing medical facilities;
- the assembly of the new structure and the skills of the workers required;
- the connection between the structural components, and;
- the connection process;
- the machinery and site preparation for the facility erection; and
- the storage and transportation of the basic modules.

4.1.3 Human factors

Human factors focus on the user aspects and the operation schedule. Currently, there is a long work schedule for HCWs. The long hours and the unidentified infection mode have put significant pressure on the HCWs. Meanwhile, limited understanding of the acuity and the potential of the disease has had an adverse psychological impact on the patients and families. The tense medical environment not only affects the performance of the HCWs, but also has a negative impact on the progress of the medical treatment. This relates to the setting and provision inside the ward as well as the association of the ward with other facilities.

4.2 Representing design information and technical data for communication

In the early design process, abstract diagrams and simple sketch plans were used for discussions. Comments by the medical professionals were limited to the layout of equipment that was clearly illustrated. Feedback of design information regarding the spatial relationships of different zones and adaptability to the operating procedures was difficult to obtain. The medical professionals had difficulty understanding the diagrams and visualizing the designed 3D airflow from 2D drawings. The design team tended to merge technical considerations into the design schemes that could hardly be depicted or comprehended by others not specialized in the building industry. For example, the sizing of vents was calculated and reflected in the 2D drawings, but these could hardly be analyzed by the medical professionals. Conversely, the medical team had difficulties communicating their professional knowledge to the design team.

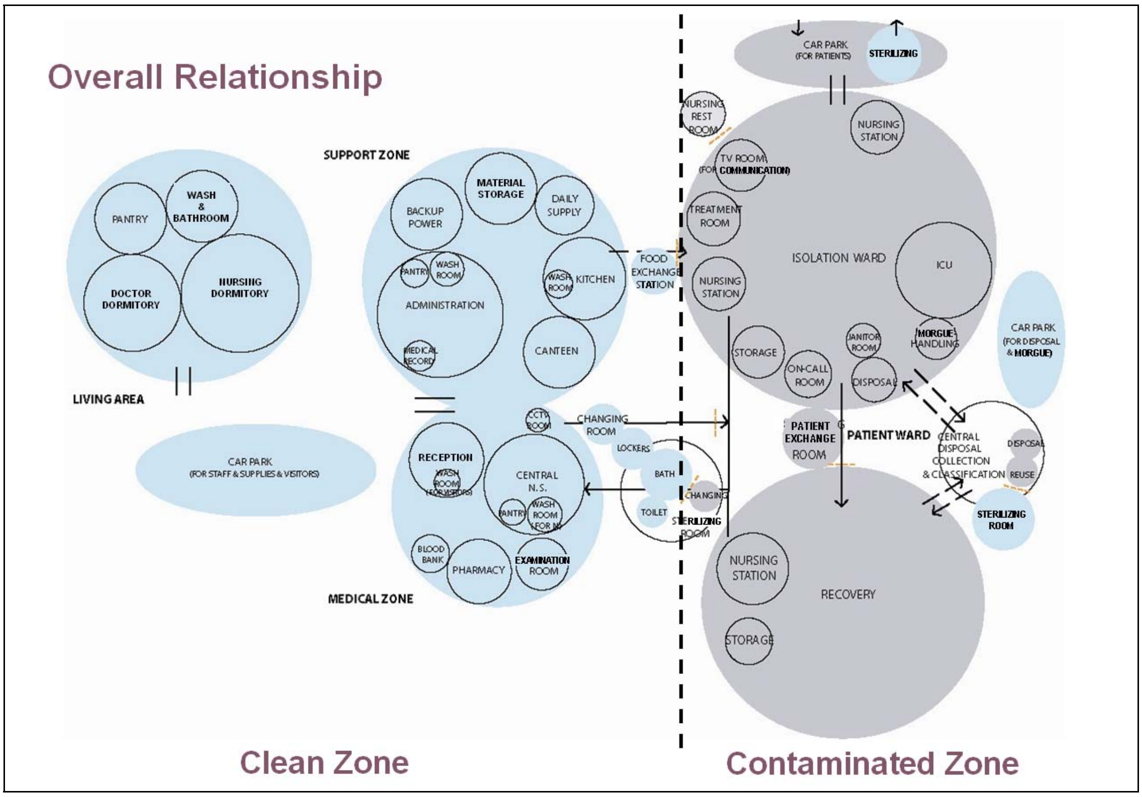


Figure 3: Bubble diagram commonly used in architectural discipline that cannot be easily comprehended by medical professionals

Medical training emphasizes clinical pictures, observed phenomena, and records of seen subjects, while architectural training focuses on virtual thinking and visualization of unseen objects. The differences in training yield a difference in the reliance on design information and technical data. The three-dimensional thinking of architects enables them to easily analyze simple sketch plans, while medical professionals require realistic three dimensional representations and full technical data to comprehend a design solution. As a result, the design team relied on 3D illustrations for spatial information representations as well as technical information for effective communication with the medical team.

Though the 3D representation facilitated the communication process, it had some drawbacks. Stringent technical requirements such as sizing were initially documented in 2D drawings. This necessitated frequent conversion between 2D and 3D design data for communication with the medical professionals. Considerable detail had to be included in the 3D representation since the medical professionals tended to compare the virtual environment with the physical environment they are familiar with. The medical discipline requires high precision, so airflow pattern simulation was essential even during the early design process. These requirements for precise, detailed 3D representation contributed to a slow design cycle particularly in the early design phase when few design components were firmly established.

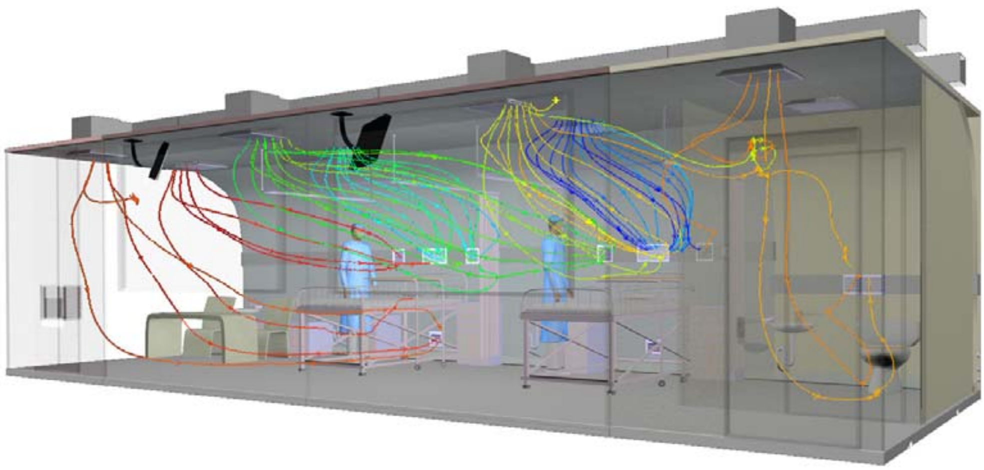


Figure 4: Overlaid image of computer rendering and CFD simulation for the proposed rapidly assembled isolation patient ward design

4.3 Solving the design problem

In the preliminary discussion, the design team presented an integrated solution for the patient ward. However, the medical team responded that the information was insufficient for them to form a clear concept regarding the suitability of the design towards achieving its various objectives. The major reason was that there was not enough quantified data on the efficiency and effectiveness of the strategies for comparison with the existing condition. For example, the ventilation strategy was initially presented as drafted arrows on sketches. The medical team needed to know how the strategy would solve the stagnation and flow pattern problems before they could agree to it. This raised two issues in solving the design problem: a) the integrated approach vs. feature-oriented approach; b) reliance on simulation for scientific support.

4.3.1 The integrated approach vs. feature-oriented approach

In medicine, problems are generally isolated as individual issues for treatment. The cross impacts of the treatments are then studied to investigate side effects and possible improvements to the overall solution. Conversely, architecture begins with intuition and established overall paradigms that have evolved through experience with similar projects. Individual details are fine-tuned after the overall solution is established.

Building performance is a dynamic outcome of various interrelated components. Changes in any one component can impact multiple aspects of the overall performance. For example, distributing the same flow volume to a different number of vents would change the pressure difference across the vents and hence change the airflow pattern. Through experience, the design team has found that an integrated approach yields an integrated solution though care has to be taken to avoid oversights of small design details. In contrast, with a feature-oriented approach, the overall performance and quality of the final design scheme are not always commensurate with the efforts devoted to microscopic investigations [Tsou, Lam 2001]. The feature-oriented approach is often easier to start with, since the integrated approach requires a comprehensive understanding of the domain knowledge from the outset. Nevertheless, the feature-oriented approach ultimately requires similar expertise in weighting the various components to yield a balanced solution.

This study adopted the integrated approach. Considering the tight time schedule of the study (4 months) and the time required for computer simulation, it was more efficient to rely on human expertise in the early phase of design when there was an acceptable confidence level. Full simulations of the overall environment were carried out later to fine-tune the design and select the settings of various parameters. Consequently, the design team had to rely on frequent discussion with the medical partners to facilitate common understanding. At the same time, the concerns and focuses of both disciplines were expressed more thoroughly.

4.3.2 Reliance on simulation for scientific support

Medicine is an evidence-based discipline. For unfamiliar subjects, quantified data is particularly important to serve as a basis for diagnosis. The medical team involved in this project generally had little understanding of the ventilation requirements for medical facilities. Yet, they did understand quantitative comparisons. Since the design team has accumulated considerable experience in ventilation, the conceptual ventilation strategy was based on inherent knowledge. CFD simulations were carried out mainly to provide technical data for quantitative comparison with the statutory requirements of the medical partners.

To the design team, the simulation mainly served as an evaluation tool and later a verification tool for the detailed design. For the medical professionals, the simulation tool, in a way, provided significant scientific data on the design's effectiveness through the "exploration" process. Though they might have limited understanding regarding the implications of the simulation results, they did have a comprehensive idea of the performance of the proposed strategy by comparing the simulation results with the stated requirements.

In this study, the concern of the design team for the airflow *pattern* was discrepant with the focus of the stated ventilation requirement for a basic air change *rate*. However, assumptions made in the simulations could not fully characterize the dynamic conditions in the ward (e.g. coughing was not included). Therefore, the simulation data is best suited for qualitative comparison. Especially in the early stages, the design team did not intend for the simulations to generate precise numerical data for quantitative comparison. It was not until the later design stage, when fine tuning of the system was required, that the quantitative assessment of the simulation became important.

4.4 Transforming medical practice into design requirements

In local general hospitals, each patient ward holds around 20 to 30 beds arranged in clusters for easy supervision by the stationed nurses. Health care workers frequently visit the ward for cleaning and delivering supplies. To limit cross contamination during the SARS outbreak, stringent administrative measures were adopted that mandated thorough sterilization of all staff and resources entering and leaving the ward. This significantly increased the consumption of sterilization materials and protective clothing, yet failed to eliminate the chances of cross contamination due to frequent contact of stationed nurses and patients with other HCWs. To address the functional need, a fundamental change in the ward's functional layout was required. This, at the same time, challenged the HCW's established mode of practice.

Considering that medical practice is a well-established profession, any changes regarding its procedures and hence the functional arrangements of medical facilities have to be carefully considered before being implemented. Because convincing justifications have to be demonstrated to shift the established paradigm, this should be handled by active administrative means.

The research team employed 3D representation and CFD simulation to visualize the linear patient ward layout and its corresponding airflow pattern for discussion. The representation provided a medium for understanding the problem domain and the respective solution. It facilitated the exploration of different approaches in reaching the solution and led to a paradigm shift in the design and operation of an isolation ward.

5 Conclusion

In bridging the gap between the design activities of architects and the medical practice of HCWs, the project team explored various means of representation to achieve a mutual understanding of the problem domain and solution. For senior team members who are experts in their respective disciplines, it would sometimes take more effort to expand their established modes of knowledge construction and practice to grasp these representations. The young researchers were generally more receptive to different domains of knowledge and modes of representation. Yet, the senior team members did acquire the expertise to broaden the scope of the studies.

Information technology contributed significantly in developing technical details and communicating abstract information. However, for exchanging fundamental knowledge, discussions among experts provided a more effective channel as the issues could be expressed more explicitly. The deep understanding of the experts promoted the flexibility of expression to achieve comprehension across disciplines.

Information from the frontline HCWs regarding functional and spatial arrangement, control mechanism of infectious disease, construction methodology, and human factors, has provided significant guidance for improving the design and operation of medical facilities and equipment. This project also introduced a different dimension in intellection between the two broad disciplines of architecture and medicine. It has encouraged rational reference for architecture and design sensibility for medicine, and has provided a solid foundation for further multi-disciplinary studies.

6 Acknowledgement

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