MDR and XDR-TB: Revolutionising our approach to facility design for long-term care facilities

Improved infrastructure and services for South Africa

SA PARSONS, GR ABBOTT, P DE JAGER
CSIR Built Environment, PO Box 395, Pretoria, 0001
Email: pdejager@csir.co.za

Abstract

South Africa has a high and increasing burden of tuberculosis, both drug-susceptible and drug resistant strains. In 2005 at the WHO-AFRO Regional Committee meeting held in Maputo, 46 Ministers of Health unanimously declared TB an emergency in Africa. A resolution at this meeting declared that unless “urgent extraordinary actions” are in place, the situation will worsen and the 2015 Millennium Development Goals will not be met. South Africa has committed itself to addressing this national crisis.

The emergence of drug resistant strains of the disease has exacerbated the situation through posing a serious risk to public health. Drug resistant strains, multi drug resistant (MDR) and extensively drug resistant (XDR) TB strains can be acquired directly: MDR and XDR-TB are not necessarily acquired through defaulting on medication prescribed for drugs-susceptible strains of the disease. Experience has shown that drug resistant strains remain infectious for longer, are more time-consuming and costly to diagnose and result in significantly higher death rates. Some drugs can have severe side effects, increasing risk of defaulting and making it less feasible to treat in community settings. In addition, drug resistant strains of TB are far more expensive to treat than drug-susceptible strains.

To effectively address this public health crisis, the National Department of Health has determined that all confirmed XDR and MDR-TB patients are to be hospitalised at specialised MDR-TB units for a period of some months. However, existing long-term care facilities for the treatment of TB patients are frequently poorly designed to address needs of MDR and XDR-TB sufferers and the healthcare workers who take care of them.

The aim of this paper is to outline research aimed at determination of best-practice guidance for provision of appropriate building infrastructure for MDR and XDR-TB sufferers.

1. Multi-drug resistant TB

The South African government has adopted a multi-dimensional approach in order to improve the quality of care, which implies “stabilising the hospital sector” (DoH 1999:5). Even amid greater emphasis on primary healthcare (PHC) than ever before, hospitals remain the institutional heart of the South African healthcare system. While the clinic or the Community Health Centre (CHC) has gradually emerged as the mainstream in operationalising the PHC, it is unable to adequately operate, or respond to healthcare needs and demands of all patients, without backup from a first-referral or district hospital. In South Africa, the district hospital figures prominently in the struggle against communicable diseases.

Among the communicable diseases TB (and now drug resistant TB), is the most perilous after HIV/Aids. Globally, the institutionalisation of TB patients contributed to a more rapid decline in TB mortality after 1920, although segregation cannot be separated from other causes.

The historical benefits of TB sanatoria where segregating patients was central to treatment of TB have been questioned. Some have proposed that the segregation lessened the transmission of infection. The overriding objective, however, was to seek pragmatic solutions to the TB epidemic. In articulating its mission on the Tuberculosis Strategic Plan for South Africa, the National Department of Health emphasised the need to prevent TB and to ensure that those who do contract TB have easy access to effective, efficient and high quality treatment and care that reduces suffering.
South Africa is one of the 22 high burden countries that contribute approximately 80% of the total global burden of TB cases, having the seventh highest TB incidence in the world. During the past ten years the incidence of TB has increased in parallel to the increase in the estimated prevalence of HIV in its adult population.

Tuberculosis, as an infectious disease, is generally transmitted from one person to another through the air. The bacterium, Mycobacterium tuberculosis, becomes aerosolised in small droplets of water, or bodily fluid, when a person with the disease of the lung coughs, sneezes, laughs, or sings. Many of these respiratory droplets dry into ‘droplet nuclei’ and become airborne following room air currents.

Infection can occur when the bacterium or droplet nuclei are inhaled. The infection turns to disease when the body can no longer contain the infectious material in the lung. The infection then spreads, usually within the lung and possibly to other areas of the body. People with drug-susceptible and resistant strains of tuberculosis disease can therefore transmit the disease directly to as yet uninfected persons and infected patients can be re-infected with different strains of TB.

Disease caused by TB bacterium resistant to at least two of the most potent first-line drugs (isoniazid and rifampicin), is called multi-drug resistant TB (MDR-TB).

MDR-TB is a man-made problem, largely being the consequence of human error in any or all of the following: Management of drug supply, patient management, prescription of chemotherapy and patient adherence. Treating MDR-TB takes longer and requires drugs that are more toxic, more expensive, and generally less effective particularly in persons with HIV infection.

The problem of drug resistance in TB has been compounded by the emergence of extensively drug-resistant (XDR) TB, defined as MDR-TB in association with in vitro resistance to any of the fluoroquinolones plus one or more of the injectable second-line anti-TB drugs. Patients with XDR-TB are extremely difficult and expensive to treat and exceptionally high mortality (exceeding 90%) has been recorded in XDR-TB patients with HIV co-infection in South Africa.

Given the potential negative social, epidemiological and economic impacts of inadequate treatment of drug resistant, MDR-TB and now XDR-TB (M(X)DR-TB), a systematic review of the quality of care delivered by M(X)DR-TB referral facilities has come under focus. Besides the importance of undertaking continuous drug susceptibility tests on all confirmed drug susceptible patients and all M(X)DR-TB patients, the SA National Department of Health’s policy is that all confirmed drug resistant patients are to be referred to M(X)DR-TB facilities for a period of at least six months and thereafter discharged for ambulatory care at the nearest health facility with ongoing treatment and psychosocial support provided. Discharge from the M(X)DR-TB facility is subject to proven TB culture conversion as identified by the supporting diagnostic laboratory service.

In addition to establishing appropriate infrastructure to support the roll-out of the National TB Control Programme with specific relevance to managing drug-resistant TB strains, objectives are to develop, publish and promote strategies, initiatives and guidelines to assist administrators of TB programmes, health service and facility planners and designers, healthcare managers, healthcare workers, and other stakeholders in the public, private, and non-governmental health sector, involved with the planning for the provision of in-patient care for M(X)DR-TB patients, to become mindful of the fundamental facility design and management requirements that will reduce possible cross infection or transmission of the disease.

2. Capacity challenges

Capacity challenges not only affect the healthcare sector, but also built environment professionals. Strategic planning of building infrastructure, building procurement, briefing, design, construction, commissioning, operation, maintenance and disposal of buildings –
especially complex public buildings such as long-term care facilities for M(X)DR-TB require specialised knowledge and skills.

To effectively address the infrastructure needs of the public health crisis spawned by the TB epidemic, a rapid response is required. The long periods associated with conventional construction methods and government procurement methods for buildings are not suited to the urgency of the situation.

Given the special context and urgency, a coordinated programme for establishing enabling systems and processes, providing implementation support, developing capacity and providing institutional support for the National TB Directorate has been initiated.

3. International guidelines for provision of building infrastructure

Available international guidelines for managing patients with M(X)DR-TB at health facilities stress the importance of isolating TB patients from other patients and the use of negative pressure isolation rooms with barrier nursing. However, the scale of the epidemic, the sheer number of patients identified, and the reality of working within an existing hospital service, requires that a different type of approach is necessary for South Africa and similar resource limited countries sharing similar high levels of incidence.

Research is being undertaken by the CSIR to understand the complexity of accommodating M(X)DR-TB patients referred for treatment in health facilities. South African guidelines for planning, design and management new facilities will be developed as an outcome from this research.

4. A strategic approach to addressing the challenge

Due to the urgent need M(X)DR-TB bed capacity, the national crisis has led to the infrastructure focus being on design for long-term care facilities.

It should be noted, that the strategic approach cannot be developed in isolation: Figure 1 demonstrates that such facilities do not play a singular (or isolated) role in the delivery of health service. Whilst the M(X)DR-TB centres operate as referral facilities, their need to interface with the primary health system at district level, is essential to the overall service delivery strategy.

![Figure 1: M(X)DR-TB facilities form an integral part of the health service delivery strategy.](image)

The National Department of Health’s Strategic Plan requires that all confirmed M(X)DR-TB patients are to be referred to MDR-TB units for hospitalisation for the extended period as noted above. After being discharged, patients require ongoing treatment and psychosocial support. The community-based care and follow-up systems at local level will also require strengthening. The plan further identifies the following priority measures for MDR-TB hospitals: to improve ventilation and ensure isolation. The constraints of the situation pose serious challenges to the practical feasibility of these strategic objectives.

The National Department of Health notes that “Given the potential negative social, epidemiological and economic impacts of inadequate treatment of MDR-TB”, a systematic review of the quality of care delivered by MDR-TB centres is required.

5. Existing healthcare estate

The strategy to hospitalise M(X)DR-TB patients for extended periods, places an additional burden on existing facilities.

Like most social infrastructure in South Africa, the current healthcare estate is a contingent mix of ageing and new building stock mostly designed prior to the emergence of the drug-resistant TB epidemic. Isolation of TB patients in health facilities has been by exception: adopting an approach to isolate M(X)DR-TB patients (which implies provision of single rooms) generally cannot be supported within existing infrastructure.
As social infrastructure represents a significant capital investment and given the competition for resources, incremental replacement over time, will be the only affordable option. A CSIR study showed that a single bed configuration of rooms would represent a significant increase in building area compared with a multi-bed model, and a corresponding increase in capital and maintenance costs. However, long term costs in reduced cross infection (patient to patient and patient to staff) have been shown to reduce the cost of care and most likely to reduce the pool of infected patients.

6. Infrastructure for improved outcomes

Hospitalisation for M(X)DR-TB places unique demands on infrastructure. During the time of hospitalisation there will be periods of intensive treatment (and illness) and periods during which patients may feel quite well whilst still needing treatment. This has an impact on the amenity required to house such long-term care M(X)DR-TB patients, in that the facility must accommodate occupational health services, recreational services and other opportunities for patient care, dignity and well-being. The patient’s physiological, psychological and spiritual needs during this extended stay must be accommodated in the design and management of the facility.

Some of the identified problems related to patient needs are isolation of economically active sufferers from their working environment, and interruption of schoolwork in children. The provision of education and development programmes for adults and children alike, library and multi media facilities have the potential to reduce isolation, stigmatisation, and to contribute to a positive frame of mind are therefore just some of the issues that can be addressed via facility design.

International research into evidence-based design has concluded that well designed built environments can play a critical role in improving healing outcomes. Infrastructure has an important role to play in this respect. M(X)DR-TB long-term care facilities should not only address the needs of patients and their families, but also the needs of healthcare workers.

7. Infrastructure for staff recruitment, retention, productivity and safety

Healthcare workers are exposed to higher risk of infection than the general population, especially those employed at M(X)DR-TB facilities. International research has shown that infrastructure has a part to play in staff recruitment, retention and productivity. South Africa has been experiencing an extended challenge in respect of attracting and retaining qualified healthcare professionals.

While the most significant factor is salaries and benefits, especially in relation to many overseas destinations, many experts emphasise that pay is not the sole motive for leaving the country.

Other factors include poor work environments characterised by heavy workloads, lack of supervision, and limited organisational capacity. There are also environmental considerations; workplaces may be dangerous due to condition, functional or environmental design, or a lack of supplies to protect workers from occupational exposure to diseases like tuberculosis.

8. Existing TB infection controls to minimise risk of exposure

In its ‘Guidelines for Preventing the Transmission of Mycobacterium Tuberculosis in Health-Care Facilities’, published in 2005, the US Centers for Disease Control (CDC) indicates that a TB infection control program should be based on a hierarchy of control measures. These include:

- Administrative measures such as work practices, policies and procedures, education and training, Tuberculosis screening of healthcare workers, and appropriate utilisation of existing facilities.
- The implementation of environmental controls.
- Personal respiratory protection in specified areas where there is a high risk of tuberculosis exposure.

The second level of the hierarchy, namely the environmental controls, utilises engineering methods to prevent the spread and reduce the concentration of infectious droplet nuclei. These controls include:

- Direct source control using local exhaust ventilation
- Controlling the airflow within buildings to prevent contamination of air in areas adjacent to the infectious source, via contaminant source isolation techniques when designing appropriate ventilation systems
- Dilution and removing contaminated air via controlled (artificial), ventilation systems
• The removal of contaminants from the air via filtration. The CDC allow the use of portable High Efficiency Particulate Arrestance (HEPA) filter units in TB isolation rooms, as a means of achieving the desired air change rate for the occupied space, thus augmenting the mechanical ventilation system.

The theoretical removal of droplet nuclei by ventilation follows an exponential die-away curve, which can be described by the expression:

\[ \frac{N_t}{N_0} = e^{-kt} \]

Where:
- \( N_0 \) = initial concentration of droplet nuclei
- \( N_t \) = concentration at time \( t \)
- \( K \) = rate of removal in air changes / hr

When converted to natural logarithms, the above equation becomes:

\[ \ln N_0 - \ln N_t = Kt \]

Hence:

\[ K = \frac{\ln N_0 - \ln N_t}{t} \]

Now since logarithms to the base \( e \) = 2.3 times logarithms to the base 10,

\[ K = 2.3 \left( \frac{\log_{10} N_0 - \log_{10} N_t}{t} \right) \]

K therefore depends on the die away curve after droplet nuclei have stopped being generated.

From tests carried out by Riley, O’Grady et al, using counts of infectious airborne samples taken every five minutes with a one-minute interval between samples, giving an interval of six minutes, an average slope of 1.0405 in 12 minutes was obtained. Thus resulting in \( K = 12 \) air changes per hour (approximately). This is the result of removal of droplet nuclei by actual dilution ventilation and natural death. This is the rate of air changes per hour that has been used by CDC.

Acceptable levels of room ‘air cleaning’ in most South African healthcare facilities cannot be accomplished by artificial dilution air ventilation alone. Its efficacy is limited by engineering constraints and by cost. The removal of diluted air contaminated with infectious particles requires extremely large ventilation rates to minimise risk.

Whilst the disadvantages of reliance on natural ventilation for infection control may include climate dependence and impact on patient comfort, the low cost of installation, operation and maintenance should be considered. The rapid recent escalation in the cost of electricity and frequent power outages especially in rural health settings further support the need to design, wherever possible, for natural rather than artificial ventilation.

For natural ventilation to work effectively, it must be considered from the earliest stages of the facilities design development. When developing the design concept for a naturally ventilated building, three basic steps need to be taken:

1. The desired airflow patterns from inlets to outlets (windows) through the occupied spaces need to be defined. This is closely related to the form and organisation of the building, which in turn depends on the use patterns and even configuration of the site.

2. The principal driving forces, which enable the desired airflow pattern (air changes) to be achieved, must be identified. Certain strategies tend to be wind-driven; others stack-driven. In a good design, the dominating driving forces are in sympathy with the intended flow rate and distribution.

3. Size and locate the openings (windows) so that the required flow rates can be delivered under all operating regimes.

The ventilation efficiency of naturally ventilated building is dependent on:
- Wind direction
- Building geometry
- Interior obstructions and flow paths
- Inner and outer temperature (buoyancy)
- Type and degree of envelope permeability.

It is essential therefore that research be undertaken to develop methodologies and tools to assist with the design and development of M(\&X)DR-TB facilities to ensure that the rates of air changes required for infection control purposes, can be achieved by natural means.

9. Strategic support of the South African National Control Programme towards its rapid response to MDR-TB

Recognising the urgent need for additional appropriate infrastructure for MDR-TB, the
The development of TB and M(X)DR-TB infrastructure database and database of non-governmental organisations involved with TB infrastructure related activities.

Work is currently well advanced in many of these areas. A full assessment was undertaken at the Church of Scotland Hospital in KwaZulu-Natal, a facility where incidences of XDR-TB transmission had been identified, focussing on a number of areas impacting on risk and design suitability. By following the patient referral pathway through the hospital and using the techniques of ‘root cause analysis’ and the methodology of Hazard Analysis and Critical Control Point (HACCP), areas were identified where there is an above normal risk of cross-infection and where special precautions need to be taken. These points were plotted onto a plan of the facility (Figure 2) and detailed assessments were then undertaken of the critical control points. A risk assessment tool was developed from this study.

Figure 2: HACCP points at Church of Scotland Hospital.

Initial work has been undertaken for the development of a framework, database and GIS planning toolkit to support strategic decision making for TB infrastructure. In addition to mapping the location of the network of facilities required to support TB services (PHC clinics, hospitals, M(X)DR-TB centres, laboratories and drug distribution centres), data has also been collected of the location of TB patients in the Umzinyathi District (KZN Department of Health data) and this is being plotted against various population, income and access layers. Various data on the condition, utilisation, functionality, risk and standard of facilities is also being plotted on the maps to provide quick planning overviews. A capital and operating cost prediction model has also been developed to support the budgeting and planning process.
10. Establishing improved infrastructure

While specific focus has been given in preceding sections to ventilation as a key risk factor that must be clearly researched and addressed in the design of M(X)DR-TB facilities, research has identified a number of broad guiding principles that must inform planning and design of new facilities and the adaptive reuse of existing facilities. These principles can be grouped into the following broad categories:

- Risk management – including managing exposure to airborne pathogens by patients and staff
- Healing environment and patient focused care – including the design of individual spaces and the provision of adequate support accommodation
- Affordability and sustainability
- Rapid delivery of infrastructure
- Potential reuse once the original purpose has been met.

These principles have been used in the design of a standardised prototype facility developed by the CSIR for use in the Global Fund projects. The design (Figure 4) is currently being analysed and optimised before construction. A variety of tools are being used including computational fluid dynamics for airflow and ventilation modelling of patient rooms and congregate areas to ensure that window designs and positions and room shapes are optimised. Other assessment tools include solar gain and heat load, shading and lighting optimisation. Adaptations will be required to satisfy regional climatic conditions. Post-occupancy studies are planned that will both compare actual to predicted performance as well as compare the proposed design to the design of other similar facilities.

The design makes provision for a mixture of single and double rooms and provides an acute section as well as post acute sections for male and female patients built around semi-private courtyards. Control of all three patient areas is provided from a central nursing station. All rooms have windows on both sides allowing for the effective natural ventilation. In addition, a range of patient support accommodation – including dining and recreation rooms, library and computer room (many patients are business people who need to be able to continue an involvement with their business while on treatment), laundry and self-catering section to promote self-motivation. A clinical support block with provision for consulting, physio- and occupational therapy, an outside visitors unit and a quiet room for religious use are also provided.

Another focus area of development has been in the optimisation of the procurement and construction process. The use of an innovative form of contracting will link to the use of a lightweight steel frame and cast in situ light weight concrete infill process as opposed to the standard brick and mortar process usually used in South Africa. It is expected that a combination of these initiatives will cut construction delivery time by more than half and that the full 1500m$^2$ units can be built within a six-month time frame.

11. Conclusion

The emergence drug-resistant strains of TB have posed a serious threat to public health. In many respects it is preferable to invest money not in addressing M(X)DR-TB once it is manifest as...
illness, but in preventing the spread of the disease.

Unless urgent and effective action is taken, however, the epidemic will undoubtedly worsen. Investment in safe and appropriate building infrastructure that will support necessary infection control measures where needed, and in a timely manner, is essential for supporting all service delivery endeavours: be they prevention or treatment.

Formulating and adopting the above strategy to support of the South African National Control Programme towards its rapid response to MDR-TB, is now beginning to unfold within the health and built environment sector. Awareness is being raised as to what role infrastructure plays in improving service delivery, health outcomes and mitigating risk in the face of epidemiological crisis.

Practical measures are being implemented to systematically address challenges. Research questions are being addressed and preconceptions tested. An attempt is being made to formulate responses, which are relevant to particular context and circumstance. But, while momentum is developing behind this effort, there remain many backlogs, challenges and complexities.

Recognising the unique demands of M(X)DR-TB in the context of South Africa is revolutionising our approach to facility design for long-term care facilities, and social infrastructure more generally.

12. References

