Journal of Civil Engineering and Architecture Engineering

Volume No. 9
Issue No. 1
January - April 2025

ENRICHED PUBLICATIONS PVT.LTD

JE - 18,Gupta Colony, Khirki Extn,
Malviya Nagar, New Delhi - 110017.
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Journal of Civil Engineering and Architecture Engineering

Aims and Scope

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Journal of Civil Engineering and Architecture Engineering

Managing Editor
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Journal of Civil Engineering and Architecture Engineering

(Volume No. 9, Issue No. 1, January - April 2025)

Contents

Urban Fragmentation and Discontinuity: Paranhos Case Study

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A B S T R A C T

This paper aims to study design and urban planning tools able to create, enhance, transform or rescue the identity and cultural meaning of fragmented and discontinuous central/focal urban spaces. This work uses as a case study of Paranhos Parish in Porto, former peripheral area where, during the last fifty years has undergone relevant morphological and functional specialization changes. As a result, the region has lost its ability to define a central zone, with strong pulsar dynamic and able to structure the local character, making the territory a fragmented and discontinuous public space. Therewith, the cultural dimension and local meaning decrease significantly, been overshadowed by the heavy metropolitan road system. As it is a study focused on the design and urban planning, its methodology is supported by essays and empirical studies based on available built repertoire and designer cultural references. The narrative begins with a historical analysis, determining the evolution and current characteristics of the territory. Later, took place a study about the existing cores and the intrinsic urban dynamics developed, defining which has the most relevant social and cultural value – 'heart of the parish'. This step is complemented by a field research – interviews – on the main local agents and how the development of urban dynamics happens. Then, using an empirical analysis, it sets up the main promoters of the fragmentation of space and what their intrinsic characteristics. Finally, it is presented a proposal in public space able to create, enhance, transform or rescue the identity and cultural meaning inside parish focus point.

Keywords ***Urban Fragmentation, Urban Design, Local Meaning, Urban Core, Livability, Urban***

1. INTRODUCTION

Urban spatial disruption phenomenon is directly linked with intensive and extensive development of urbanization and agglomeration, mainly occurring during the second half of the twentieth century [1]. To meet the growing metropolitan demand for mobility and activity/functionality new infrastructure networks were created specialized urban zones and functional clusters of greater complexity and capacity. Thus, new dedicated areas were settled to fit certain urban functions, such as social housing, technological and university centres, clusters of shopping malls, airports, all been strongly supported by infrastructure networks, such as highways, bridges complex and road intersections, underground rails, train terminals and etc. [2]. Following to this process, some locations were eventually fragmented, breaking both its physical structure as its social and cultural dynamics. The deployed infrastructure became urban obstacles, creating empty spaces of low or non-use places, requiring the local agent a new reality dynamics and cultural relevance. This gesture shows the ideology of order and rationalism that guided general public power territorialisation policies during the twentieth century. As an example, we can mention the High Line in New York, the 'Minhocão' in São Paulo, Porto highway 'VCI' and the intense dissemination of specialized zones and functional buildings.

This work uses the case study of Paranhos Parish in Porto. Former peripheral area where during the last fifty years has undergone significant morphological and functional specialization changes. In contrast to the concept of 'non-places' of Augé [3], it is argued that the intensive road structures and majority of educational mono function surfaces are not the source for a lower sense of community and belonging, but a consequence of urban spatial fragmentation. In this sense, Paranho's faces a poor capacity to define a central 'pulsar' location with a strong local character, able enough to structure the parish connections. Hence, the actual spatial form contributes for the development of a fragmented and discontinuous urbanization.

As this work is focused on urban design, its methodology is supported mainly by empirical studies based on author's repertoire and background and others cultural references. As a design plan, the working structure develops based on a 'macro' to 'micro' scale, analysing first all relations and connections between the local area and the whole Porto municipality. The narrative begins with a historical analysis, determining the evolution and current Paranho's territory characteristics. Later, actual urban dynamics are studied, trying to comprehend how it developed in the parish, defining its most centralized and cultural value. This step is complemented by a field survey on the main local agents and how to develop local urban dynamics. Then, through an empirical analysis, it is set up the main promoters of the urban fragmentation and what is their intrinsic feature. Finally, an intervention proposal is drafted in the public space in order to support the development of a new magnetic centre for Paranhos.

1.1. Initial Remarks

As will be shown below, during the intensive urbanization period - a century and a half, Paranho's failed to concretely define a focal structuring centre. It is considered that this inability results from a lack of urban appropriation by local community [4]. Therefore, denies that the functional specialization of the territory lead to weaker personal relationships, lack of identity and local memory. Urban infrastructures such as VCI highway, Asprela University Campus and São João Hospital are relevant to Porto's metropolitan area, being able to build links with society [5]. Figure 1 shows the highway dedicated 'infrastructure' area on Paranhos intersection near Paranhos Church Square. Then emerge one question: Whereas the urban spaces are socially produced, and so socially absorbed, which phenomena cause the urban space fragmentation and disruption?

Source: Google earth

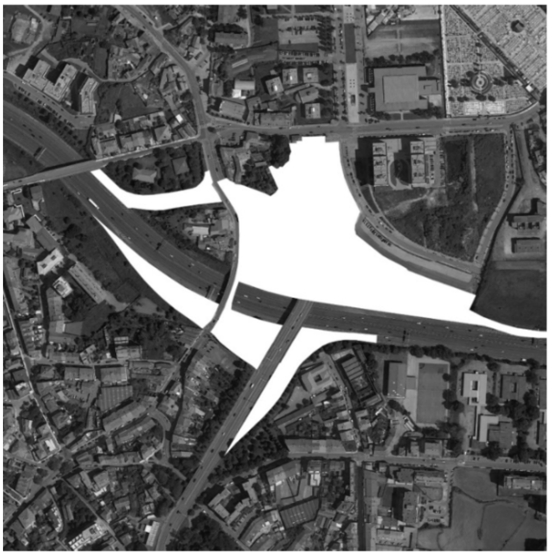


Figure 1. Integrators or shredders? Non-places or fragmented spaces?

To address this question, we seek to clarify Porto and the Paranhos parish urbanization process. This analysis occurs in double scale – metropolitan and local – as it is impossible to understand the social behaviour inside the 'partial' without the 'complete' area.

As an example, it is cited the urban transformation of Cais da Ribeira – Oporto - during the last two centuries. Initially, Cais da Ribeira social built space were exercised by an intense port activity, being occupied by trading boxes, goods, mules and pack animals, transportation machines and a wide range of workers. When Leixões Port was constructed, in the late nineteenth century assuming the lead role for freight transportation, it became an idle public space in the middle of a highly urbanized environment. Due to the low spatial regulation, the area became occupied by private cars – especially during the second half of the twentieth century, when general workers income got higher and cars easily affordable. Currently, following new revitalization policies on Porto's central area and adaptation to tourist activities, the site become a supporting area for restaurants and coffee shops terrace in the Ribeira.

Thus, following will be conducted a brief study about Paranho's spatial social production evolution and its intrinsic characteristics and functions.

2. Urban Social Production

Still in the early nineteenth century, Porto held an urban structure with pre-industrial characteristics. Urbanized area was restricted to the current historic core, predominantly comprising the parishes of Sé, São Nicolau, Vitoria, Miragaia and Santo Ildefonso. Other urban areas were developed outside the realm of Porto, like Foz, near São João Batista Fortress and the central area of Matosinhos. The outskirts remained rural, accompanied by an urban settlement scattered along ancient roads.

At that time Paranhos not legally incorporated Porto municipality areas, a fact that would only run in the year 1837. The spatial social production had not been significantly altered, and the functions committed on the territory distinguished between agricultural fields and roads to the northern Portuguese kingdom. With the advance of industrialization and population growth, urban scenario slowly changed. It is evident here the changing from the "old city" to "industrial city". Initially, the urban expansion took place along the ancient roads, such as: Rua de Monte Burgo (to Vila do Conde), Rua do Amial (to Braga) and Rua Costa Cabral (to Guimarães). For this reason, a greater concentration of buildings with typology similar to the recorded in the central core of Porto – volume, deployment on the ground and land uses, and the emerging of a nineteenth century urban pattern production developed along those three axis. As the urbanization process advance over urban axes - arranged parallel in the municipal territory, the other internal areas still retained its agricultural function, preserving a low occupation density.

Also, new industrial plants were installed hospitals and health centres, new cemeteries and water distribution in the newly incorporated Porto's areas (especially Campanhã, Paranhos and Massarelos parishes). Paranhos stand out for Arca D'agua water fountain - major source of Porto's public water supply, Paranhos cemetery, the Campo Largo Lindo, 'Nova Empreza Industrial de Curtumes' (1920) - installed in Rua do Amial, Hospital Conde de Ferreira (Rua Costa Cabral) and Quinta do Covelo.

In the late nineteenth century, municipal authority opened the Estrada da Circunvalação – ring road, aiming to overtax all imported goods. One can make an analogy between the old medieval walls and the Ring Road - a new physical separation between Porto and its rural or outside area.

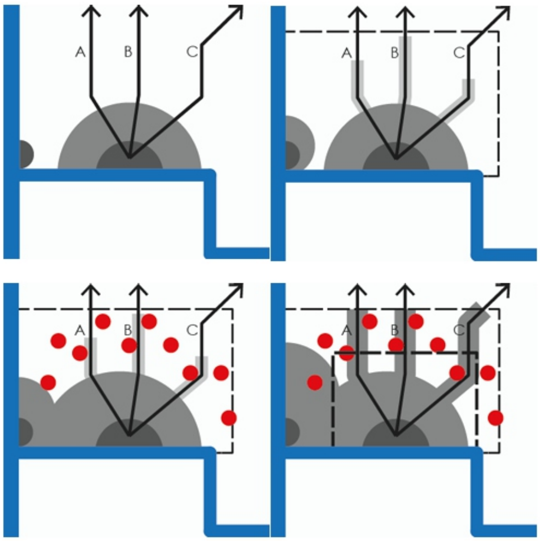
Supported by national and local economic development, the outlying parishes accelerate urbanization process and population density. This process was boosted by the arrival of new industrial workers with low income, seeking for affordable dwellings or empty lands. Already in the first decades of the twentieth century, Porto's suburban landscape was completely different and also well specialized. While Campanhã reported strong industrial development, Paranhos shows ability for public housing and working class dwellings – initially single family units and later collective blocks. During so called 'New State' political regime, new 'Economic Districts' were built, namely Azenha, Paranhos, Amial and Amial II, Costa Cabral and Outeiro and Regado. The massive residential buildings construction gave a strong dormitory neighbourhood character. It was possible due to the wide availability of undeveloped land next to the road corridors – connecting the periphery and Porto central area – and the low land value and public property tax due to the lack of public infrastructure on those areas. Thus, Paranhos established itself as a territory with diffuse and dispersed spatial patterns, organized by well-defined radial axes, isolated housing blocks and some remaining farmland.

Spatial social production came to be changed again from the second half of the twentieth century. Powered by Porto industrial activity decline and accelerated suburbanization on outside municipality, Porto became a strong magnetic reference for its metropolitan context. The same socio-economic dynamics recorded internally in Porto during the nineteenth century was reflected in its new metropolitan scale. Thus, municipal urban space scale changed, getting new roads, public and private facilities of greater complexity and capacity and specialization of urban land. This period reports the change from the 'industrial city' to the 'modern city'.

Initially, Paranhos received the Escola Industrial do Porto (1952) facilities – currently ISEP – and the new São João Hospital (1959). During this period all new buildings found themselves isolated and scattered throughout Paranhos territory, with low occupancy rate inside potentially buildable land. During the 60's was built the Via de Cintura Interna

(VCI), Porto's urban highway, connecting the Arrábida Bridge (Gaia) to Areosa (Av. Fernão Magalhães). Unlike other urban roads, VCI has technical and physical characteristics similar to the Americans urban 'Highways'. As opposed to Estrada da Circunvalação, VCI was built 'inside' Porto, creating section and fragmentation on internal urban fabric. Similarly, along the highway a number of road junctions also provide a breakdown in urban structure, separating Porto urban space into two distinct parts: internal and external.

Finally, during the last three decades the new Asprela University Campus took place inside Paranhos. Except for the pre-existence of the Hospital São João and the Medicine Faculty, the 'first' school to settle in Asprela was Porto's Economics School in 1974, initiating the occupation of idle land that still plentiful in the region. One should also refer the construction of A3 motorway (Porto-Valença) and the Subway D line (Hospital São João – Santo Ovídeo). Figure 2 shows a concise four diagram graphic of Porto urbanization process, highlighting the three ancient roads and the two main infrastructure barriers, VCI and Estrada da Circunvalação.



Source: Authors

Figure 2. Porto spatial social production development over XX century

3. Finding Paranhos Central Pulsar

Due to Paranhos wide territorial extension, several locations with high potential to assume the condition of 'central pulsar' were identified. Following will be presented the studied areas, a brief description of each individual case and which territory was chosen.

3.1. Urban Axes: Monte Burgo, Amial E Costa Cabral

The urbanization along the main Paranhos urban axes powered the development of a strong and complex social dynamics. As stated above, Monte Burgo, Amial and Costa Cabral streets suffered a relatively similar occupation process that recorded in Porto central area. So, along these routes there's a high density of dwellings, inhabitants, shops and everyday services, as post offices, banks agencies, butchers, bakeries and coffee shops and others shops in general. However, Amial Street stands out for miscegenation between different social classes and age groups, wider road and sidewalks – which allows one side parking, attracting more commuters and promoting local business – and a huge diversity of business and public interest services. Nearby the street, there are private dwellings and collective housing with early nineteenth century typology and other collective 70s typology, forming a diverse and heterogeneous social characteristics population. Likewise, the proximity to ISEP and Asprela University Campus allows the integration among young people, adults and seniors, catalysing region's social diversification. There are also two high schools – private and public, kindergartens, hotels and churches.

3.2. Gardens, Squares and Public Areas: Jardim Da Arca D'agua (Praça 9 de Abril), Largo Da

Arca D'agua (Praça 9 de Abril), Largo Da Igreja De Paranhos

During the nineteenth century and the early twentieth, Paranhos played an important urban technical infrastructure role: one of the main public water supplying system for fountains. Among the existing sources, Arca D'agua garden stood out for its capacity and water quality. Initially, a new underground storage systems and distribution galleries - Cedofeita region and Boavista were built beneath the site. As urban sprawl approached to the region, its single functional role and geometry were altered. At the beginning of the twentieth century Arca D'a agua landscape had a several change, owning a Square status and setting a new order for urban occupation on the surroundings for the following years.

Road and pathways from Arca D'agua lead to Porto central area (Rua do Vale Formoso), Largo de Lindo Campo Largo (Rua Costa e Almeida) and Paranhos Church Square (Rua Delfim Maia). On the other hand, the other square or gardens also communicate themselves through Rua da Igreja de Paranhos, forming a geographical triangulation. This reference morphological condition recurs in various urban models and is present from smaller scale clusters - religious triangle of São Paulo Paraitinga - to the great monumental perspectives of Versailles, Washington and Buenos Aires.

Paranho's reference triangle is also home of Paranhos Church Square, chosen location to play the role of 'central pulsar'. The similarities between the Square and the parish go far beyond simple sharing the place name. As well as the parish, the location social urban context changed radically over the last century, showing the transition between the 'old town' and the 'modern city'.

For decades, there was low presence of the public power in the region, leaving Paranhos Church Parish acting as a primary social institution in the neighbourhood. For its implementation, were choose a high area overlooking Asprela agricultural fields and with good access to Campo Lindo, Arca D'agua and Amial. First, as a result of population growth and Porto urban expansion to the peripheries, the adjacent lands intensify the urbanization, strengthening referential importance of urban space and its centralizing capacity.

However, the VCI prevented physical communication between Jardim da Arca D'agua and Largo de Campo Lindo (also the visual continuity of Rua do Amial axis) and intensified traffic of motor vehicles in Paranhos Church Square. The space that was formerly occupied by people and community activities (activities similar to those currently practiced in Jardim da Arca D'agua) was occupied by cars and metropolitan mobility systems.

Unlike Augé 'non-places' concept, this process does not mean a loss of identity and social condition, but rather a change in its urban function and social appropriation of urban space. Similarly, the occupation of idle land of Asprela by a single activity - education - it is not an emptying of urban social dynamics, as advocated by Augé.

3.3. Metro Stations: Hospital São João, I.P.O. E Polo UniversitÁRio

Paranhos is served by Porto Metro D Line - Santo Ovídeo/Hospital São João, and three main stations are located inside demarcated Asprela University Campus. At first glance, it appears that both situations shares a wide and plenty public space, with the potential to promote the emergence of new social dynamic. However, while establishing a strong relationship between the town and the entire Porto metropolitan context, the stations are unable to build a solid narrative enough to play a leading role and urban reference.

Hospital São João Station has a strong metropolitan mobility character, offering a rich urban interface between different modes of public transportation. Apart from the existence of Porto´s most important Hospital, it is placed on a wide urban area facing Estrada da Circunvalação and an exclusive bus lane with several stops and feeding lines. This situation breaks any effort to establish a reasonable permeability between the Station and the surroundings and a central focus capacity.

In the case of Polo Universitário Station, it is placed beneath a wide open area with a number of vacant plots and mono functional buildings. This scenario creates a rough visual and physical permeability with no potential to establish any focusing role or pulsar centrality.

Beside the two mentioned before, IPO Station seems to have more potential for leading some centrality. The Station is placed next to a medium size shopping mall, with a supermarket and a low budged hotel. Through ISEP and University Portucalense, commuters can reach Azenha collective houses and Rua do Amial. It is remarkable that IPO Station gather the most relevant aspects for being the pulsating Station, but it is insufficient to be defined as the Parrish central pulsar.

4. Design Basics

The proposed design plan for Paranhos Church Square has the following strategy: approach the physical and functional components of the built urban space. In this way, we seek to reduce the effects of territorial fragmentation imposed by the VCI and create a space that works the transition between the urban area and the mono functionality educational zone (Asprela University Campus).

First, it is intended to reduce the impact, noise visual and physical, played by the urban express highway.

Therefore, it is proposed to channel VCI between Rua Delfim Maia and Rua Faria Guimarães, allowing visual and physical space continuity and creating new urban 'land'. This model is inspired by the Ronda de Dalt in Barcelona. As well as the VCI, the expressway surrounds Barcelona urban area alternating between high and low densely urbanized areas. In excerpts with high urban concentration the route goes down and offers some sort of public facility to street level. Running this model allows to 'create' new potentially buildable land, which, from its full employment, reduced sense of visual and functional discontinuity.

Easing the physical impact of the VCI is not enough to revitalize Paranhos Church Square. There's a need to change the function of urban space. Thus, its characteristic of road access to the VCI is disqualified, returning the space taken by streets to pedestrian and community activities. Wherefore, it is proposed that access to VCI and Faria Guimarães Street be shifted to Rua Alfredo Allen axis, relieving the intense flow of vehicles in Paranhos Square. Also it proposes the removal of walls and fences of private alignment of the Church of Paranhos, integrating the building with the 'new' Square that opens, and greater physical permeability between Square, university residence and the public open area of metro station.

This work has no intension on discussing the ideal model of occupation on new urban land 'created'. As the spatial social produced of Paranhos is diverse and dispersed, it is possible to defend numerous types of occupation, being very personal and with a high degree of technical detail discussion. So, beside the morphology and geometric shape, it was conduced a simple exercise about what kind of use and function the new empty area could develop. Figure 3 and 4 shows the two most relevant options, a 'regular' urbanization and a new public park over VCI area. Regarding that a stronger relationship between Paranhos Church and Campo Limpo Square and Jardim da Arca D'agua consist a relevant issue, the first option seems to work a better behaviour. As suggested by the graphic composition, filling all voids with urbanization decrease the visual impact played by the emptiness and enhances space continuity. Figure 3 is composed by a compound of some crop images from Matosinhos south area (regular rectangular urbanized pattern – 85 x 180 m) and a crop image from Parque da Cidade. Figure 4 is only composed by Parque da Cidade cropped image.

Source: Authors

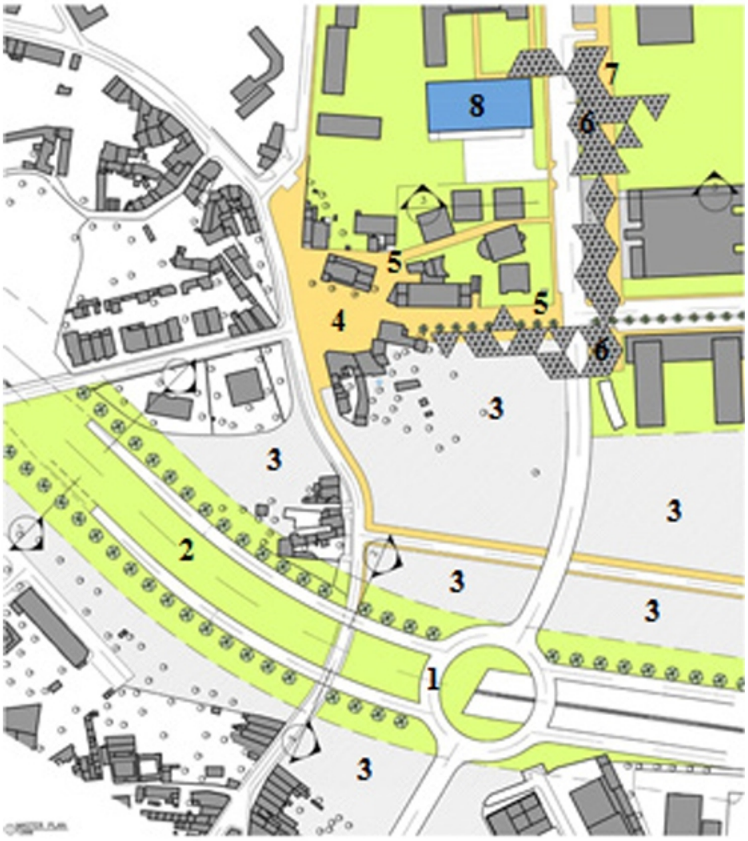
Figure 3. Regular' urbanization

Source: Authors

Figure 4. New public Park

Thus, the final proposal should look to 'sew' the spaces between the Paranhos Church Square, Jardim da Arca D'agua, Campo Lindo Square and Asprela University Campus and return the formerly pedestrian urban space and filling all voids that decrease physical and visual connection. The design plan also assumes the need for a more functional and visual approach between the Paranhos Square and Asprela area.

Following, a brief description of the proposed design plan for Paranhos Church Square, some technical drawings and all main structures or measures to be taken.



Source: Authors

Figure 5. Proposal master plan

5. Design Proposal

The new design proposal that seeks to 'create' and enhance a new pulsar centrality on Paranhos it is represented by figure 5. The master plan – figure 5 – shows the design proposal, fitting all relevant changes on the chosen area and nearby surroundings. As this work aim only to provide some conceptual design basis, there are no further detailing drawing. Some samples and existing references will be used to give a more sharp and precise idea about the detail design proposal and materials to be used.

The new pulsating urban centre of Paranhos Parrish consists of the full extent of Paranhos Church Square till the intersection between Rua Alfredo Allen and the Rua Dr. Manuel Pereira da Silva. Through this proposed design interventions, comprising Paranhos Church Square and some nearby surrounding areas, emerge a chance to increase the local potential and strength site memory, social dynamics and build a meaningful and magnetic spot on the neighbourhood (Parrish) following a brief description of all design proposals.

5.1. New Highway Intersection

As stated previously on chapter 4, setting up a new arrange for the existing traffic management and road infrastructure performs a crucial role on providing fundaments for the development of a new central pulsar for Paranhos. Attempting to reduce the urban highway visual and physical barriers it is proposed an alternative road intersection structure comprising the VCI highway, Rua Faria Guimarães (way to Porto downtown) and Asprela University Campus major access. The new road intersection will be accomplished through a partial channelling of VCI (between Delfim Maia Bridge and Faria Guimarães Bridge) and a by passing all traffic distribution to a new roundabout. This initiative rearrange and replace the existing road connection of Paranhos intersection, removing a huge amount of roads, tunnels and bridge that support a complex multiple route choice. Thus, this initiative enables to decongest Rua da Igreja de Paranhos, partially Rua Dr. Manuel Pereira da Silva, promote and enhance traffic circulation throughout the area maintaining efficiently the existing multiple route choice and decrease physical and visual barriers.

The roundabout it is placed following the intersection of VCI and Rua Faria Guimarães road axis. Composed by three lanes, each one with three meters and a half, a protected area with one meter on each side and an outer radius forty-two and a half meters, a fine traffic circulation is granted inside the new proposed road intersection. Adopting three lanes allows performing one emergency lane, feeding São João Hospital with an express ambulance alternative route.

All highway access to the roundabout have two lanes and
6% slope, while Rua Faria Guimarães have four lanes and 7% of slope, allowing 60 KM/H speed on all routes and access .The new road infrastructure design proceeded to extent Rua Alfredo Allen width in seven meters in western direction without affecting any existing buildings or spoiling private property: This action seeks to provide a total of four traffic lanes - two for each direction – mirroring the same traffic width and configuration existing along Rua Faria Guimarães axis. To ensure these initiatives a removal of one parallel parking on Rua Alfredo Allen must be considered, counting the loss of 29 public parking spaces.

Adopting this new traffic system and others infrastructure, necessary conditions to remove heavy vehicular traffic from Paranhos Church Square will be created, allowing a deeper design intervention that deals more with social and cultural dynamics.

5.2. Public Open Park

As a result from VCI channelling and rearranging all roads access, some 'new' land emerge inside the existing urban fabric. Those lands are divided into two categories, non-buildable and buildable. To avoid noise pollution, intensive traffic disturbs, light pollution and even some legislation issues, all land located between the two roundabout access as well as a ten meters width strip along those roads will be set as non-buildable land. So, inside this area will be prohibited to develop any kind of building addressing housing, offices, shops and industries. This land will remains under public domain and will give a place for an open public Park, allowing the continuous development of urban fabric and spatial permeability.

The new public Park will be equipped with leisure and physical activities furniture, sports facilities and a landscape design that integrate all functions and the existing building surroundings.

5.3. New 'Land' with High Urban Potential

Taking advantage from the brief land occupation exercise on chapter 4 (figure 3 and 4), it is determined how all remaining land (where 'regular' buildings can occur) should be developed. For this area is intended to set a 'regular' urbanization, free market-led development comprising mainly daily urban functions, both social and private housing or student residences, shops and services. By adopting this concept, all lands will be given to private development and there is no concern about any predefined design constrain.

5.4. Paranhos Church Square

The follow-up steep to traffic reduction and road infrastructure amenities, structuring land uses and urbanization process is actually to provide an urban design proposal for the chosen area of Paranhos Church Square. As the heavy traffic circulation was removed from Rua Dr. Manuel Pereira da Silva and it intersection with Rua da Igreja de Paranhos, it is proposed to prohibit vehicles traffic along the street's first section. Both sidewalks must be integrated by levelling the road, replacing finishing material to make it homogenous. Oddly from the existing site, this attempt to create a real public space to host Paranhos Church. Also, strong enough to boost local development and attract private investment on surroundings.

Another relevant issue is the removal of a small wall that surrounds Paranhos Church. This action promotes a higher physical and visual integration between the Church and the immediate neighbourhood though the 'new' square created, enhancing its initial social value.

Such design measures could be found on many others places around Europe, mainly nearby Churches and historical squares. In general, this kind of new urban spaces gives support to perform small events, usually promoted by the local actors or the Parrish organization. Thus, a wide free area is needed and must be ensuring enough space for a huge diversity of events and folk's activities. By adopting this concept, new urban furniture, such as benches, bins, public lighting and water fountain, should be placed considering both daily and special events needs and constrains.

It is important to mention that for loading and unload services for restaurants, shops and religious events, it is proposed the installation of anti-parking system, allowing freight vehicles to access buildings and controlling the traffic in the levelled area.

To extend Paranhos Church Square as much as possible in the direction of Asprela University Campus, 'sewing' a strong relation – visually and physically – between both areas, a line of small/medium size trees took place following the existing south sidewalk alignment of Rua Dr. Manuel Pereira da Silva. All trees are set with a regular distance rhythm, about 10 meters, going from the pedestrian section till the traffic open section. Though, visual and physical permeability between Asprela and Paranhos Church are increased through continuity.

5.5. Paths and New Connections

To enhance visual and physical permeability it is proposed to open a new pedestrian path connecting the backs of Paranhos Church and University

Rooms/E-learning café. For so, one vacant and apparently abandoned building should be demolished. Hence, not only allows a better mobility within region but increase local relationship and approximate a well socially diverse population. Initially, most existing buildings are kept as well as their functions.

5.6. Square Cover and Sun Shading

Another measure to enhance and promote visual and physical permeability between Asprela and Paranhos Church Square is a proposal for a cover surface along Rua Alfredo Allen subway station open area, especially between Polo Universitário station entrances. The proposed surface will cover a large area, mostly sidewalks, walking areas as described in the master plan drawn. It will be composed of a light steel structure with wooden components regarding to not fully close the ceiling, offering sometimes fully open areas and other partially closed, with some framing for sun shading. An overall free height of seven meters allows the performance of many events as well as sheltering some daily activities and new social dynamics.

By adopting this concept, some daily social routines and dynamics from the urbanized Paranhos area are mixed with the mono-functional educational activity from Asprela University Campus, building a place for cultural and social exchange. If supported by some permanent activities, this place can assume an integrative role on the surroundings.

5.7. Small Shops

To enhance social dynamics and promote the development of a new 'urban' activity in Asprela University Campus, it is proposed to establish simple Kiosks under the covered area in Rua Alfredo Allen. The Kiosks structures should be based on naval container dimensions or may be slightly bigger or smaller depending on usage. This kind of infrastructure is pretty common on some highly dense urban areas, such as Tokyo, Xanghai, New York and others places, providing several layout options and technology to support a big number of activities.

For Polo Universitário station it is proposed a diverse functional occupation, admitting shops, cafes, small restaurants – fast food or any other kind of cooking that don´t demand high exhaustion – and any other daily activity. Cafes and small restaurants should be allowed to occupy some nearby areas with tables and chairs, providing a reasonable space to work and receive costumers. There´s no interest in overcrowding the covered station 'plaza' as well as setting no rules for the Kiosk structure. The number of Kiosks will attempt to ensure a good pedestrian circulation, taking in consideration both shops/restaurants costumers and Asprela Campus as well as Metro Station commuters, and the 'public' space occupied by tables and chairs. It will also provide a clear and safe passage to Metro Station stairs and all educational buildings located around. Concerning about the Kiosk physical structure and finishing material or individual customizing, a structural template model should be follow to ensure some regularity on Kiosks shape. All other customization and finishing materials must be allowed, giving to all owners the ability to promote their trademark as expected.

5.8. Parking Building

Finally, it is proposed to build a new parking garage to replace the existing uncovered parking lot between the Faculty of Psychology and the University Residence, all

public parking spaces removed due to Rua Alfredo Allen widening and enhance site existing capacity. The new building should have a volume with low visual impact and about six meters high, with three working slabs - two indoor and the latest uncovered. Currently, in the area there are two uncovered parking, a formal, with 71 places available and another informal with about 50 places, totalling 121 parking places. Through the new landscaping and implementation of the garage building 345 parking spaces will create, increase the current number by 224. This measure seeks to reduce the number of vehicles irregularly parked in the area, offer better conditions for incoming cars and support for Porto's subway network and commuters.

If more parking places appear to be necessary two alternatives emerges as possible solutions. Firstly, an underground parking can be constructed beneath the proposed parking building. So, it is recommended that the structural plan consider this further expansion. Another solution is to occupy the existing open parking lot from Dental Medicine School (actually with 73 parking places). It should consider another low visual impact building with no more than six meters height.

6. Conclusions

Based on understanding the pattern of spatial social production and all agents for urban space fragmenting, the final design intervention proposal seeks to define Paranhos Church Square as the central pulsar and a structuring Paranhos player. Using urban design as basis tools, we recommend two main measures and actions to enhance the urban space quality and encourage the development of integrated urban dynamics and potential new local activities. The first measure is to reduce the impact from the poor quality expressway access and move the heavy traffic from the Paranho's Church Square to the new area of Polo da Asprela. This action seeks to manage the congestion in Paranhos area, creating a favorable environment for social network and exchange. The second seeks to develop several supportive infrastructures to encourage a new social interaction between Paranho's Church and the Polo da Asprela area.

However, changing the landscape and proposing new activities should generate impacts on each member of the society, causing new identity connections, memories, and social ties. This work regards precisely this dichotomy between the urban fragmentations and the strengthening of the community socio emotional consciousness. As recent studies suggest [6,7,8], promoting quality of life and encouraging social interaction should reduce the sense of isolation and act as a catalyzer for spatial social production and inclusive of urban spaces.

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Life-Cycle Costing Integration with Bridge Management Systems

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A B S T R A C T

Many countries are using bridge management systems (BMSs) as the main toll for the effective management of their bridges. Although many BMSs contain some forms of life-cycle cost analysis (LCCA), the use of LCCA in bridge engineering is scarce and LCCA has mainly been applied to support decisions related to existing bridges. This paper discuss the need of a BMS with an integrated LCCA tool that can assist decision makers at all levels and within all phases in selecting the most cost-effective solution from an array of applicable alternatives. The paper introduces the Swedish Bridge and Tunnel Management System (BaTMan). A comprehensive LCCA implementation scheme will be illustrated, taking into account the bridge investment and management process in Sweden. The basic LCCA analysis tools as well as other helpful techniques are addressed. A real case study is presented to demonstrate the recent improvement of BaTMan particularly in the function of specifying the most-cost effective bridge repair strategy. The bridge user cost is included in the LCCA. The parameters that can influence the final decision are addressed and sensitivity analyses to study their impacts are performed.

Keywords Bridge, Life-Cycle Costing, LCCA, LCC, Infrastructure, Management, User Cost, Decision Support Systems, Rehabilitation, Repair

1. Introduction

1.1. General Background

Generally, bridge investment and management decisions are multi-alternative-oriented. Life-cycle Cost (LCC) is the cost of an asset, or of its parts, throughout its life cycle whilst it fulfills the performance requirements. Life-cycle costing, sometime called life-cycle cost analysis (LCCA), is a methodology for systematic economic evaluation of the LCC over a specified period of analysis as defined in the agreed scope (4). In many countries, bridges are mainly managed using bridge management systems (BMSs). Many BMSs contain some forms of LCCA. However, the use of LCCA in bridge engineering is scarce (3, 7, 5 and14). The missing of a comprehensive framework details the possible applications of LCCA for bridges during their entire life is a major obstacle hinder the implementation of LCCA in bridge engineering. The lack of proper LCCA techniques that satisfy the establish procurement procedures within public agencies is also an obstacle hinder the use of LCCA in bridge engineering. LCCA in many BMSs has mainly been applied to support decisions related to existing bridges. This paper discusses the need of a BMS with integrated comprehensive LCC tools that can assist decision makers at all levels and within all phases in selecting the most cost-effective alternative.

1.2. Aim and Scope

The project presented in this paper is financed by the Swedish Transport Administration (Trafikverket). The project aims at enhancing the bridge investment and management decisions by upgrading and expanding the use of LCC in the Swedish Bridge and Tunnel Management System (BaTMan). This paper broadly demonstrates the possible LCC applications for bridges and mainly focuses on the LCC implementation to specify the most cost-effective bridge repair strategy. A real case study will be presented to demonstrate the recent improvement of BaTMan practically on that LCC application.

1.3. Basic Components of a BMS

A BMS with an integrated comprehensives LCC tool can be defined as a rational and systematic approach to organize and carry out all the activities related to managing a network of bridges, including optimizing the selection of maintenance and improvement actions in order to maximize the benefits while minimizing the life-cycle cost. The development of BMSs with integrated LCC tool has been necessitated by the large imbalance between the need for extensive repairs or replacements in a large bridge stock and the limited budget available to municipalities and agencies for implementing the required repairs. The purpose of a BMS is to combine management, engineering and economic input in order to determine the best actions to take on a network of bridges over time (1). A BMS should include the following basic components: data storage, cost models, deterioration models, and optimization models (1), Figure 1.

The heart of a BMS is a database derived from the field inspections (17). The integrity of a BMS is directly related to the quality and accuracy of the bridge inventory and physical condition data obtained through field inspections. Information such as the bridge name, number, location, drawings, and inspection records are stored in the data base. Considering the updated inspection records, the bridges and their individual structural members are conditionally rated according to specific methodologies.

1.4. Previous Research

BMSs as well as bridge life-cycle cost analysis (LCCA) have been subjects of intense interest long time ago. Several important new research-and-development studies have provided essential tools and resources which previously were unavailable (e.g. those in the references' list of this article).

Many BMSs have been developed in different countries. Most of them address three aspects of bridge management: assessing bridge conditions, modelling future deterioration behaviour, and the decisions to maintain, repair, or rehabilitate (1, 5 and 10). Many agencies have adopted BMSs that operate at the network level to assist inbudget allocation and prioritization within an agency's total inventory of bridges (3).NCHRP Report 590 (16) describes the development of methodologies for network- and project-level optimization of multiple, user-specified performance criteria.Several bridge LCC case studies have been presented in different research papers. NCHRP Report 483 (3) describes a great research effort leading to a recommended methodology and includes a guidance manual for carrying out LCCA. However, the criteria for the project selection are not clear in that report particularlywhen comparing investment projects having unequal life-spans. Techniques that highlight the feasibility of the LCC results are also missing in that report.

An obvious gap between the practice and the theory of LCCA was detected and discussed in (7and 5). Even though BMSs and LCCA are interrelated, many bridge management researches have treated them as separate aspects; therefore, neither may lead to the best usable decision-support tools. Some bridge inventory and inspection systems do not make use of LCC. Current challenges involve making sense of the increasing volume of information and integrating and processing it to help manage bridges through their life cycle as effectively as possible(10).Web-based BMSs with cradle-to-grave, integrated, and comprehensive LCC tools may provide an opportunity to greatly improve this situation.

1.5. The Swedish BMS

Trafikverket is the largest bridge manager in Sweden. The latest update of Trafikverket's BMS is called a Bridge and Tunnel Management system (BaTMan), which was introduced in 2004. Today, BaTMan is handling the management of 29,736 bridges with a total bridge area of 7,562,070 m2 and a total bridge length of 658,986 m. BaTMan is a computerized Internet based system, which means that users can always have access to updated information about the actual bridges on-line (https://batman.vv.se/). Furthermore, the system is furnished by a separate navigation tool (WebHybris) that can easly access the BaTMan's database and answer any related question for any research or management purposes. BaTMan is recognized as the best-known software-based digital BMS in Europe (8).

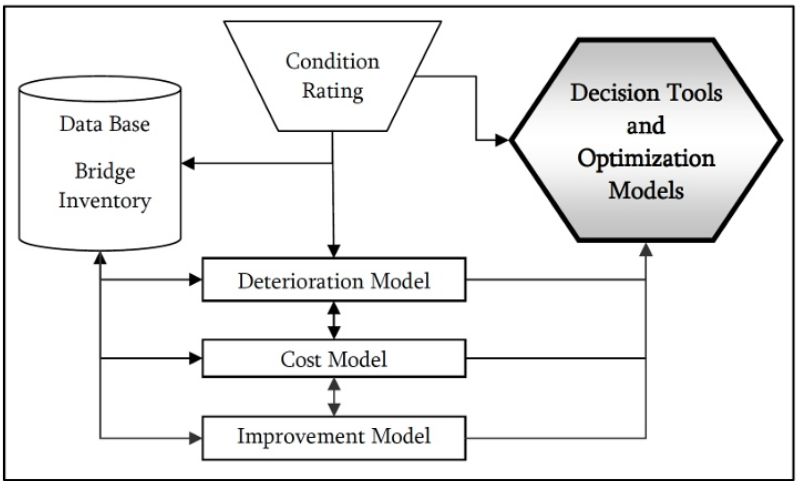

Figure 1. the Basic components of a BMS (AASHTO, 2001)

Table 1. the condition class system(CC) used in BaTMan

Condition Class	Assessment	Description
3	Defective function	Immediate action is needed
2	Defective function within 3 years	Action has to be taken within 3 years period
1	Defective function within 10 years	Action has to be taken within 10 years period
0	Defective function beyond 10 years (No damage at time of inspection)	No action is needed within the coming 10 years

The system is a tool for operational, tactical and strategic management where the complete system encompasses systems and tools for collecting, storing, processing, analyzing and presenting administrative, technical and inspection data (2).The system includes codes and manuals to provide guidance for carrying out bridge management activities as properly and as uniformly as possible. The inspection manual gives information on bridge types and their structural members and types of damage and their causes (11). Along with the inspection manual there is a measurement and condition assessment manual, which includes methods and codes for measuring and assessing the physical and functional condition of bridges (13). All information is given on repair, strengthening, and maintenance, including their costs.

The main purpose of the bridge inspections is to establish the physical and functional conditions of a bridge individual structural members and accordingly the entire bridge. The physical condition is determined with reference to the development of previous or new damage and certain known deteriorating processes. The functional condition is described by the bridge inspector in terms of condition class (CC). The CC describes to what extent a certain structural member satisfies the designed functional properties and requirements at the time of inspection (9). In BaTMan, the bridge inspectors are responsible for assessing the residual service life of the bridge structural members as well as the entire bridge. Along with the inspectors' own experience, well-developed tools based on well-established methods and techniques are used to assess the CC for the bridge individual structural members. In contrast to many BMSs, BaTMan does not contain deterioration models. However, some devices used for inspection consist of integrated deterioration models that can assist in anticipating the future performance of the inspected structural members. It can be said that the assessment of condition classes is composed on previous and current measured values (the physical condition) and the inspector's competence in the propagation of different deterioration processes.The CC for a structural member can be registered on a scale of four. Table 1presents and describes the BaTMan's CC system.

Using this CC system, the functional conditions of the structural members will automatically be translated to numerical numbers that can easily be used in the LCC analysis, Table 1. This CC system is a good feature in BaTMan in comparison with the condition rating system used in Pontis (a full-featured BMS used in more than 40 state departments of transportations in USA), (5).

2. Bridge Life-cycle and the Possible Applications of LCCA

LCC is appropriately applied to compare project implementation alternatives that would yield the same level of service and benefits to the project user. The agency that uses this tool has already decided to undertake a project or improvement and is seeking to determine the most cost-effective means to accomplish the project's objectives. To effectively implement LCC for bridges, it is important to be aware of the different bridge investment phases and their internal activities. It is also important to be familiar with the various types of bridge contracts. Figure 2, described in more details below, shows the typical Swedish bridge investment phases, the possible LCC applications and saving potential.

The bridge investment is generated from an early planning that has been originated from an idea, followed by an initial study. A feasibility study will be carried out later on to analyze the benefits and the costs of the project. In this particular phase, decision-makers are considering whether or not to undertake the project. Whole-life costing (WLC) is a methodology for systematic economic consideration of all whole-life cost and benefits over a specified period of analysis as defined in the agreed scope (4). Therefore, WLC is the appropriate tool that can be used in this stage. In Sweden, usually, bridges are built at the same time of building an entire corridor which may consist of many bridges. In such cases, the feasibility study will be conducted to compare the life-cycle costs with the life-cycle benefits of the entire corridor, not only the corridor's bridges. Several alternative corridors might be proposed, and each of them may consist of various numbers of bridges with different bridge lengths and heights. Rough data will be available for the bridges in each corridor; numbers, width, preliminary length and height. Preliminary bridge LCCA that can be based on similar historical bridges data is of great importance in this phase to specify the most cost-effective corridor. From a network-level perspective, LCC has the largest saving potential in this phase.

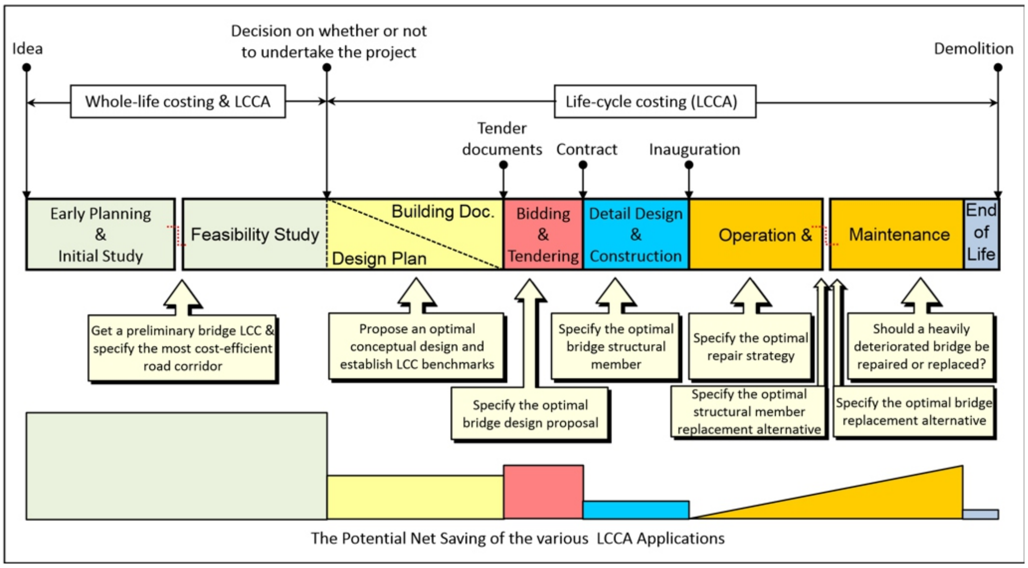

Figure 2. Bridge investment phases in Sweden, the possible LCC applications and their saving

If the decision to carry out the project is taken, several legal permissions have to be issued. Many parties with different interests and demands will be involved to assign the corridor final alignment. In doing so, more accurate data for the bridges in the chosen corridor will be available. For each bridge location, different bridge types might technically be feasible. However, each bridge type may have different initial costs, expected service life and life-cycle costs. LCC can effectively be implemented here to propose an optimal conceptual design.

Depending on the nature of the contract, the intensity and details of the tender documents may differ. When using a "design and build contract" as well as a "performance requirements contract," the tender documents will consist of brief outlines for the bridge together with intensive functional and performance requirements. The tender documents of

these forms are usually prepared in the design plan phase. In a "construction contract," the tender documents usually consist of more detailed drawings, and quantities. The tender documents of this contract-form are usually delivered to the interesting contractor after the building document phase. Using the first two contract forms, the horizon is broader for the contractor to propose an alternative design. Generally, a conceptual design for the bridge will be prepared and attached with the tender documents. However, the possibility of accepting an alternative design varies from one contract-form to another. The first two contract forms encourage the contractors not only to submit the least first cost, but also to integrate their staff knowledge and experience in proposing the optimal bridge design alternative. LCC can be used in these two investment phases to propose an optimal conceptual design.

During the tendering phase, which may be the shortest investment phase, the agency seeks to specify the most cost-effective design among all the proposed alternatives. The alternatives may differ in their static systems, types, structural members and construction materials. However, all of them provide the required function. Currently, the concept of the lowest bid is normally used when deciding a contractor. However, the lowest bid conventionally reflects the lowest first cost, not the lowest cost of ownership. The greatest saving potential for the project occurs in this particular phase. In case of alternative design, the contractors are required to attach general drawings for their proposal along with their cost estimate. Consequently, LCC can properly be implemented taking into account the available drawings.

Following the selection of the bridge proposal, the agency will sign the contract with the contractor and request that he begins the preparation of the detailed design. Once a rough detailed design is prepared, the construction will start. During the detail design and construction phase, LCC can be implemented by the agency and contractor to choose the most cost-effective bridge structural members or structural elements for the chosen proposal.

After the bridge inauguration, the operation phase commences. It might be the longest investment phase and will end when the agency demolishes the bridge. LCC has many useful applications during this phase. It can be implemented to choose the most cost-effective repair strategy for repairing an individual bridge structural member. It can also be implemented to choose whether to repair or to replace a specific bridge structural member. When the bridge grows old and heavily deteriorates, LCC can be implemented to decide whether to repair or to replace the bridge. LCC can also be used here to investigate the feasibility of installing advance monitoring system that might assist in elongating the bridge residual service life. When deciding to replace a bridge, several replacement options might be available. LCC can be used here to optimize between the available replacement options. Several demolition strategies with different impacts on the traffic might be available for a bridge replacement. LCC can also be used here to specify the most cost-effective bridge demolition strategy.

3. LCCA Tools

The time value of money is germane to LCC because the costs included in the analysis are incurred at varying points in time. For LCC, costs occasioned at different times must be converted to their value at a common point in time (15).

3.1. Net Present Value Method

The commonest method used to compare past, present and future cash flows with those of today is termed the Net Present Value method (NPV). Costs occur at different times, therefore it is necessary to use a discount rate in the calculations to reflect the "time value of money". This can be expressed as the NPV equation (15):

$$NPV = \sum_{n=0}^{L} \frac{C_n}{(1+r)^n} \qquad (1)$$

Where:

NPV is the life-cycle cost expressed as a present value,

n is the year considered,

C_n is the sum of all cash flows in year n,

r is the discount rate, and

L is the service life-span.

The net present value for a future cash flow C_o, expected to fall due every year during the service life-span L, e.g. annual operation cost, can be calculated by (*15*):

$$NPV = C_o \cdot \frac{1-(1+r)^{-L}}{r} \qquad (2)$$

3.2. Equivalent Annual Cost Technique

When comparing investment projects of unequal life-spans, it would be improper to simply compare the NPVs of the two projects unless neither project could be repeated to let all projects have the same analysis period.Equivalent Annual Cost (EAC) is often used as a decision support-tool in capital budgeting when comparing investment projects of unequal life-spans. In finance the EAC is the cost per year of owning and operating an asset over its entire life-span. The alternative associated with the lowest annuity cost is the most cost-effective choice. The EAC is calculated by multiplying the NPV by the annuity factor (15):

$$EAC = NPV \cdot A_{t,r} = NPV \cdot \frac{r}{1-(1+r)^{-L}} \qquad (3)$$

Where:

EAC is the equivalent annuity cost,

$A_{t,r}$ is the annuity factor,

3.3. Net Saving& Opportunity Loss

The Net Saving (NS) and the Opportunity Loss (OL) are two different techniques developed to highlight the feasibility of the LCCA results from different angles. The NS is the amount of money that could be saved by implementing the most cost-efficient alternative compared with the implementation of the other alternative, while the OL is the amount of money that could be lost by implementing the least cost-efficient alternative compared with the implementation of most cost-efficient one.

When comparing two alternatives having an equal life-span, the NPV could be employed to specify the most cost-efficient alternative. In this case, the NS will be equal to the OL and could be calculated by subtracting the NPV of both alternatives from each other. When comparing two alternatives having unequal life-span, the EAC could be employed to specify the most cost-efficient alternative.

$$NS = (EAC_A - EAC_B) \cdot \frac{1-(1+r)^{-L_B}}{r} \quad (4)$$

$$OL = (EAC_A - EAC_B) \cdot \frac{1-(1+r)^{-L_A}}{r} \quad (5)$$

Where:

EAC_X is the equivalent annuity cost associated with alternative (X),

L_X is the life-span of alternative (X).

3.4. Bridge User Cost

Bridge user costs can mainly be classified into two types; long-term user cost and work zone user cost (WZUC). The long-term user cost is due to permanent characteristics of the bridge. The WZUC are costs incurred by the users of the bridge as a result of deteriorating conditions of the bridge, such as a narrow width or low load capacity, which result from maintenance, repair and rehabilitation activities, leading to an increase in the vehicle trip time. By including the WZUC in the LCC analysis, the importance of avoiding traffic disruptions will be considered. The user costs during a work zone closure are usually evaluated with respect to the traffic delay costs, the additional vehicle operating costs, and the cost of the increased risk of accidents. The main challenge in the WZUC evaluation is in the estimation of the travel delay time to cross the bridge during a work zone condition. The time delay estimation considering the different traffic flow conditions was properly presented by (12). The structural engineering and bridges division at the Royal Institute of Technology, developed a bridge WZUC model adopted for the Swedish bridges similar to the model demonstrated by (12). This model was integrated within a stand-alone bridge LCC program named "BaTMan-LCC". Using this program, the bridge user cost will be estimated for thecase study in this paper.

4. Case Study

On some occasions during the bridge operation phase, the choice has to be made between two or more strategies to repair a specific structural member or structural element in a certain bridge. The choice is directed by numerous factors such the strategy initial cost, the bridge or the bridge structural member residual service life without action, the anticipated service life extension after the repair strategy, user cost, financial prerequisites, etc. Vårbyvägen Bridge in Sweden was constructed in 1969. The total bridge length is 102 m and the total bridge width is 21 m. The bridge is a Four-Lane Divided, situated in an interstate region and serves an average daily traffic of 9100 vehicles per day with a design speed limit of 90 km/h. The traffic growth rate in the bridge region is expected to be 1.1%. According to BaTMan, the Vårbyvägen Bridge has a number [1-813-1], which refers to [County number-Section/Junction number in the rout-Bridge number in the Section/Junction]. Figure 3 (a) and (b) show the bridge layout and the bridge cross-section, respectively.

4.1. Strategies Specifications

The surfacing of the bridge deck is deemed to be in such a condition that its residual service life is not more than 3 years if no action is taken (BaTMan CC 2). The bridge deck, which is the dominating structural member of the surfacing, is expected to last for at least another 50 years with normal maintenance (BaTMan Condition class 0). The choice now stands between immediately repairing the surfacing or utilizing its residual service life without action and then replacing the entire surfacing. It is estimated that it will cost 1,250 SEK/m2 to repair the bridge deck surfacing: mending the concrete, new waterproofing and paving of the deteriorated parts. Demolishing the old surfacing and placing with a new one, included paving, waterproofing and mending the bridge deck, would cost 2,900 SEK/m2. Table 2 presents the strategies specifications. Figure 4 and Figure 5 show the cash flow for strategy (A) and (B), respectively.

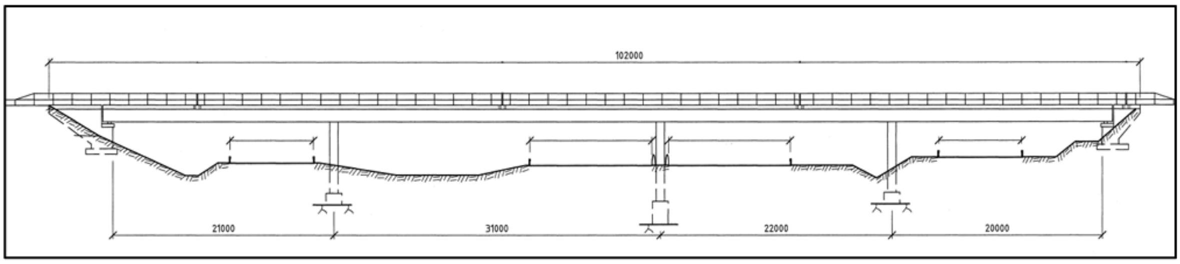

Figure 3 (a). the layout of the bridge, the dimensions are given in millimeters

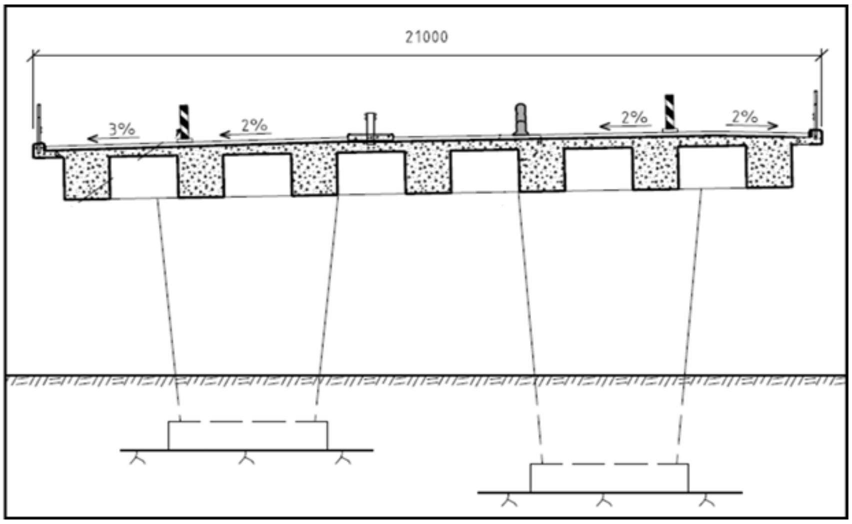

Figure 3 (b). cross-section of the bridge, the dimensions are given in millimeters

Table 2. Strategies specifications

Parameter	Strategy (A)	Strategy (B)
Strategy description	Immediate repair and then renew	Utilizing the residual service life without action and then renew
Dominating structural member's residual service life (years)	50	
Residual service life without action (years)	3	
Discount rate (%)	4	
Service life after a single action (year)	10	35
Initial cost (SEK/m^2)	1,250	2,900
Required installation time (hr/m^2)	0.75	2

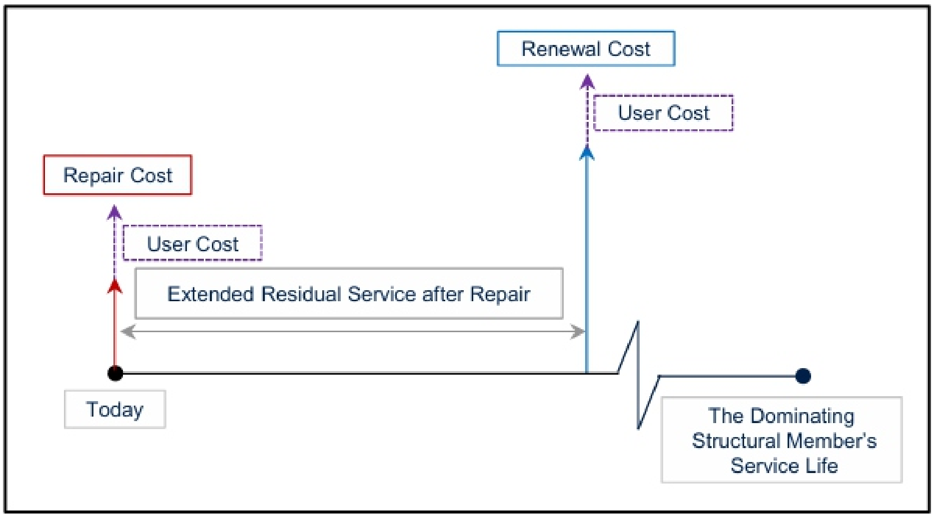

Figure 4. Strategy (A): Immediate repair and then renew

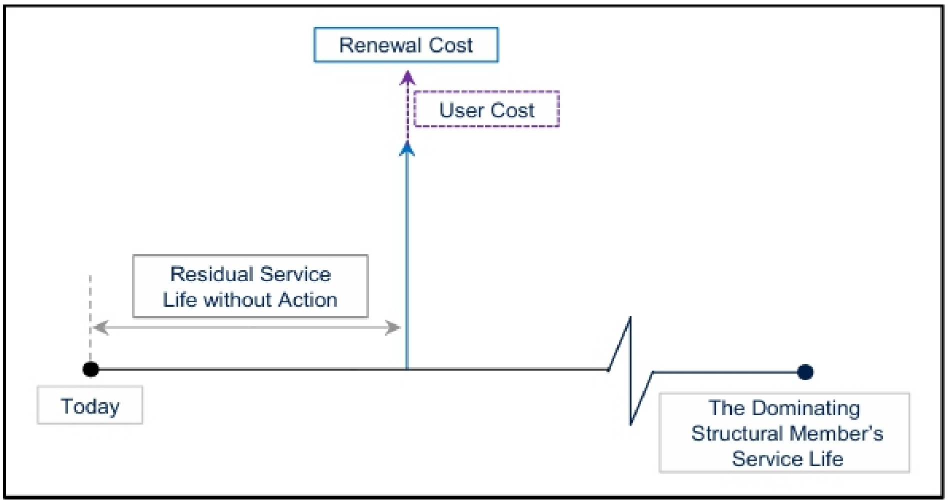

Figure 5. Strategy (B): Utilizing the residual service life without action and then renew

4.2. Analysis excluding the bridge user cost

Based on Table 2, the life-span for strategy (A) will be 45 years and 38 years for strategy (B). In this case both strategies have life-spans less than the residual life-span of dominating structural member which is 50 years. As shown in Table 3, strategy (B) is associated with a NPV less than strategy (A). However, this does not necessarily mean that strategy (B) is the most cost-effective, simply because the strategies have unequal life-span. Therefore, the EAC was calculated for each strategy, shown In Table 3. Using equation 4 and 5, the NS and the OL were calculated. The NS is equal to 912,691SEK/38 years or 47,124 SEK/year for a life span equals to 38 years. The OL is equal to 976,411SEK/45 years or 47,124 SEK/year for a life span equals to 45 years.

Table 3 LCC analysis results excluding the bridge user cost

Results	Strategy (A)	Strategy (B)
Net present value (SEK/m^2)	3,209	2,578
Equivalent annual cost (SEK/m^2)	155	133

By performing a sensitivity analysis to study the impact of varying the discount rate (r) from zero to 2r, as shown in Figure 6, strategy (B) remains the superior regardless the variation of r.

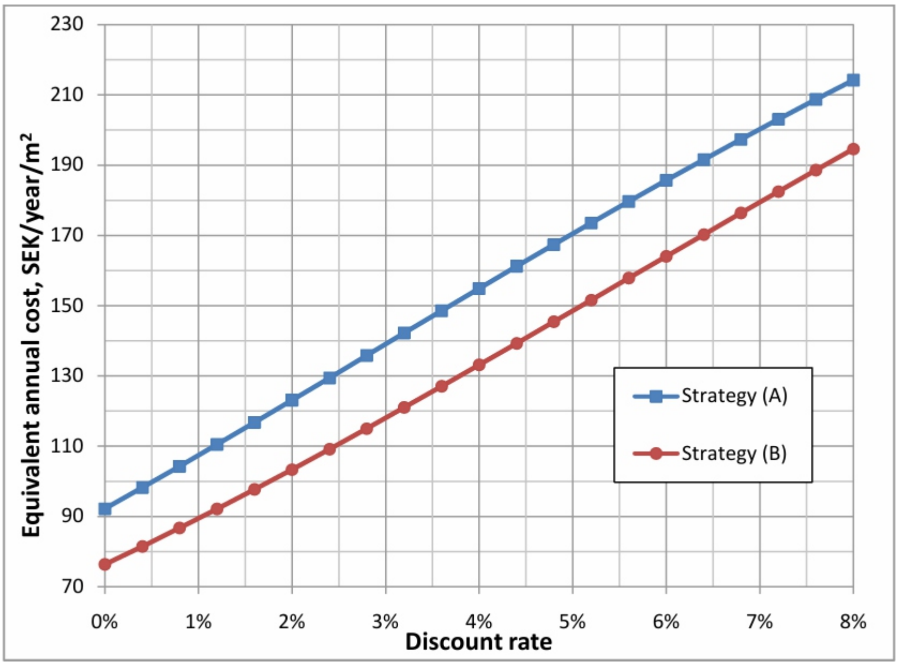

Figure 6. the impact of the discount rate variation on final decision

Keeping the same specification of strategy (B), Figure 7 presents the variation impact of the initial cost of the repair in strategy (A) on the final decision. If there is a possibility to negotiate the initial cost of the repair in strategy (A), it might be more beneficial to Trafikverket to choose strategy (A) as the most cost-effective solution when the repair's initial cost is less than 799 SEK/m2 instead of 1,250 SEK/m2, Figure 7.

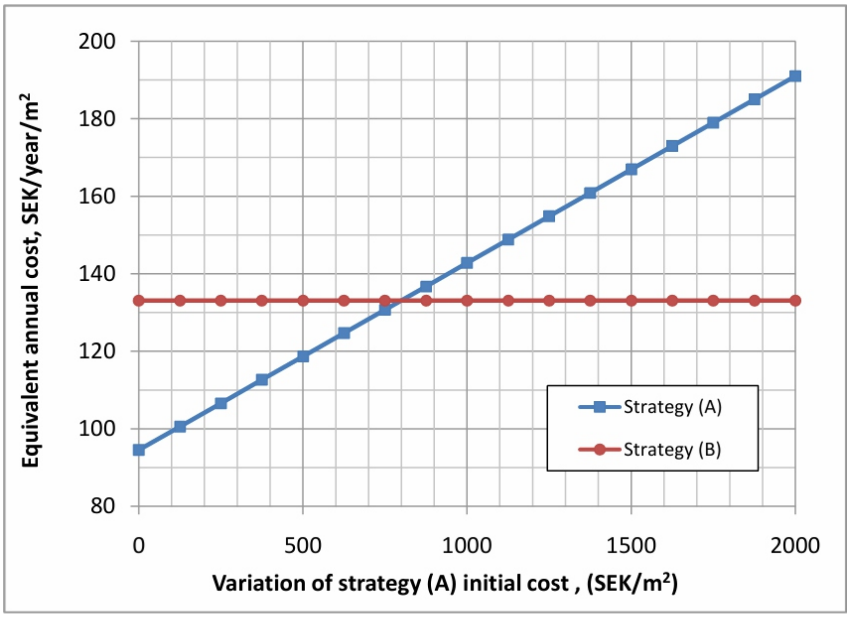

Figure 7. the variation impact of Strategy (A) initial cost on the final decision

7. Analysis Including the Bridge User Cost

The traffic data on BaTMan is automatically updated each year as BaTMan is directly connected to the Swedish National Road Database (NVDB). Furthermore, it is possible to get a map and online-view for the bridge itself as well as its surrounding network. For this bridge case, each strategies will have a special technique does not disturb the traffic under the bridge. Therefore, only traffic disturbance over the bridge is considered in this analysis. The bridge WZUC was calculated for the different strategies using the BaTMan-LCC program.In strategy (A) the WZUC will occur twice; once during the immediate repair and again during renewal 15 years later, while in strategy (B) the WZUC will occur only once during renewal works after 5 years. Figure 8 shows that strategy (B) is associated with less WZUC NPV than strategy (A).

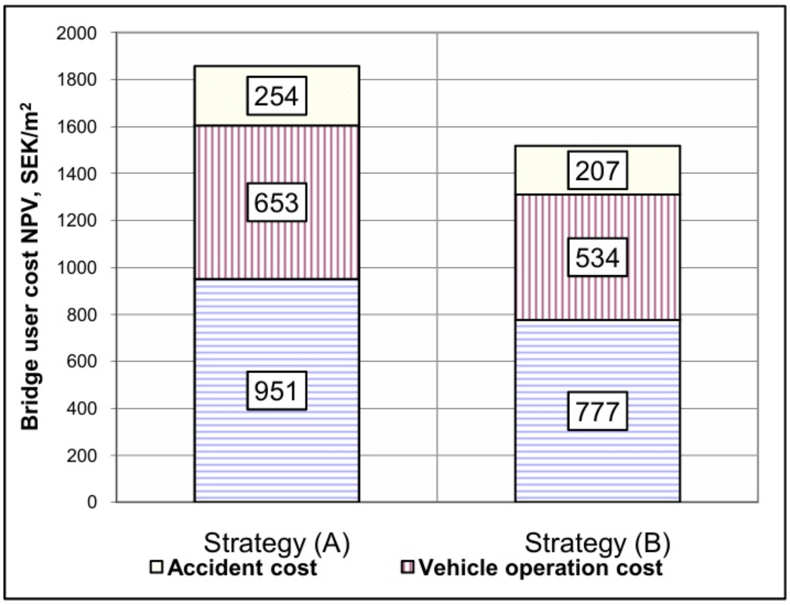

Figure 8. Bridge user cost results

By including the user cost in the analysis, as seen in Table 4, strategy (B) remains the most cost-effective choice. The NS is equal to 1,410,522SEK/38 years or 72,828 SEK/year for a life span equals to 38 years. The OL is equal to 1,508,999 SEK/45 years or 72,828 SEK/year for a life span equals to 45 years.It might be more beneficial to Trafikverket to choose strategy (A) as the most cost-effective solution when the repair initial cost become less than 565 SEK/m2 instead of 1,250 SEK/m2.

Table 4. analysis results included the bridge user cost

Results	Strategy (A)	Strategy (B)
Net present value (SEK/m^2)	5,067	4,096
Equivalent annual cost (SEK/m^2)	245	211

The residual service-life without action of the deck surfacing, presented in Table 2, is also subjected to uncertainty in the assessment. According to BaTMan's inspection manual (11), structural members with such deterioration have to be more frequently inspected. The next year inspection results might assign the deck surfacing CC2 also or CC3. A sensitivity analysis was conducted to study the impact of this uncertainty on the final decision. This sensitivity analysis shows that this uncertainty doesn't have significant impact on the final decision. Even if the three years in Table 2becomes zero (Cc3), strategy (B) remains the most-cost effective, Figure 9.

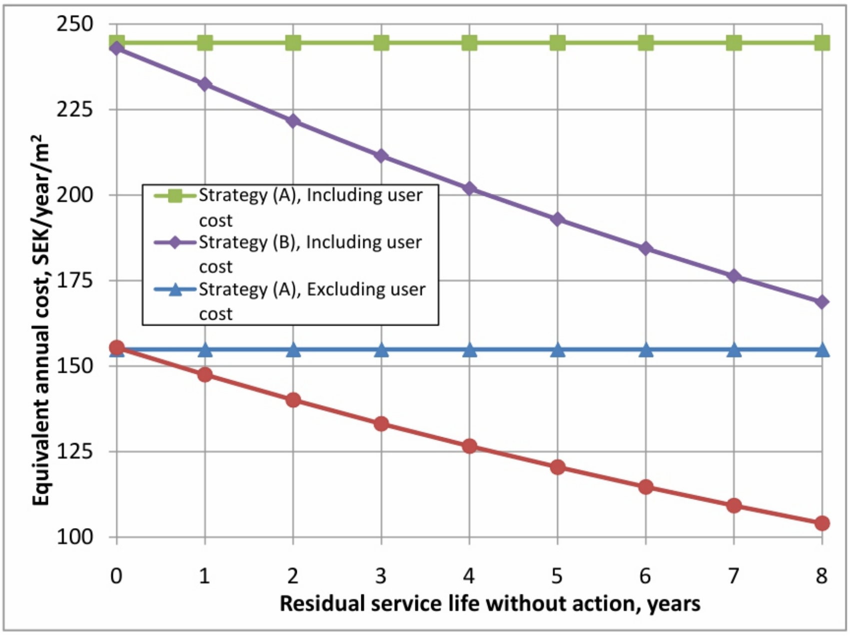

Figure 9. The variation impact of the surfcasting residual service life without action on the final decision

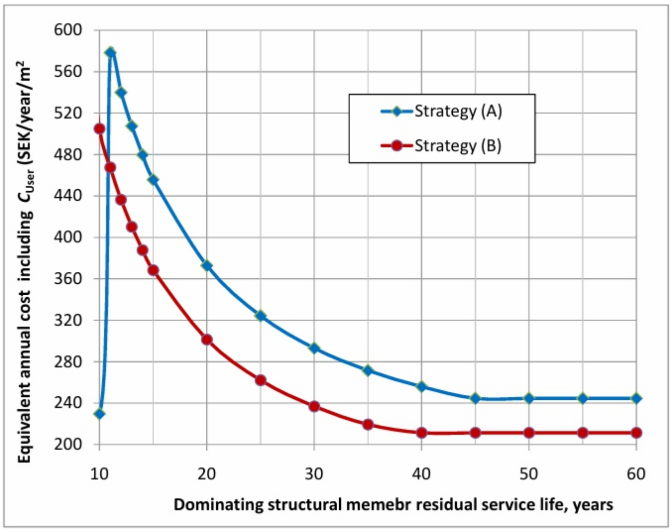

Figure 10. The variation impact of the bridge deck residual service life on the final decision

The service life extension of the structural element after implementing any of the repair strategies should not exceed the residual service life of the dominating structural member. When replacing a structural member, all of its structural will be replaced regardless if some of the elements are still functioning well. Therefore, the residual service life of dominating structural member is an important factor in the analysis. However, it is not an easy task to anticipate a long performance of the different bridge structural members. The impact of this uncertainty on the final decision was studied and presented in Figure 10. Strategy (B) remains the most cost-effective choice as long as the residual service life of the dominating structural member is longer than 10 years otherwise strategy (A) becomes the most cost-effective. In this figure, the EAC of strategy (A) sharply drops when the residual service life of dominating structural member is less than 10 years because at this point strategy (A) will comprise of an immediate repair without the later renewal.

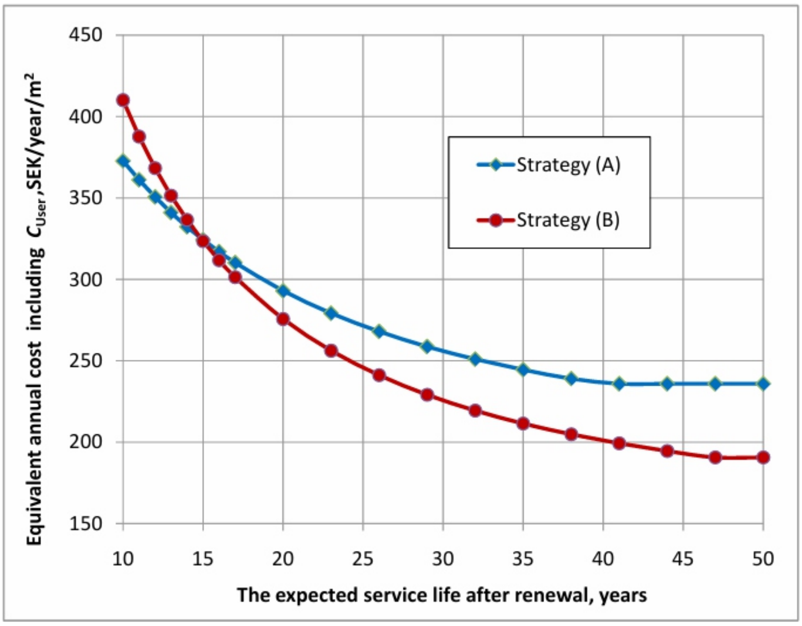

Figure 11. the variation impact of the renewal life-span on the final decision

The assessment of the service life extension after implementing strategies was assessed based on statistical treatment of an intensive historical data extracted from BaTMan related to similar actions performed on similar bridges. Therefore, the service life extension after implementing any of the strategies is subjected to uncertainties in the assessment. The impact of this uncertainty on the final decision was studied and presented in presented Figure 11 and Figure 12. Keeping the same expected service life after repair and varying the expected service life after renewal, Strategy (B) remains the most cost-effective where the renewals expected service life is higher than 15 years, Figure 11. Keeping the same expected service life after renewal and varying the expected service life after repair, Strategy (B) remains the most cost-effective as the repair's expected service life is less than 15 years, Figure 12.

Other way of formulating the repair strategies for this bridge is to consider only one single action in each strategy. In this case, strategy (A) will only comprise an immediate repair without considering the later renewal. From this point of view, strategy (A) will have a life span of 10 years instead of 45 years. Considering this short-term planning for strategy (A) and keeping the same specification of strategy (B), the analysis was performed. The EAC including the WZUC for strategy (A) and (B) are equal to 230 SEK/m2/year and 211 SEK/m2/year respectively. Consequently, strategy (B) remains the most cost-effective choice. The EAC of strategy (A) does not have that considerable variation in comparison with the long-term planning presented in Figure 4. Therefore, it is recommended to only consider one action in each strategy without complicating the analysis by considering long-term planning.

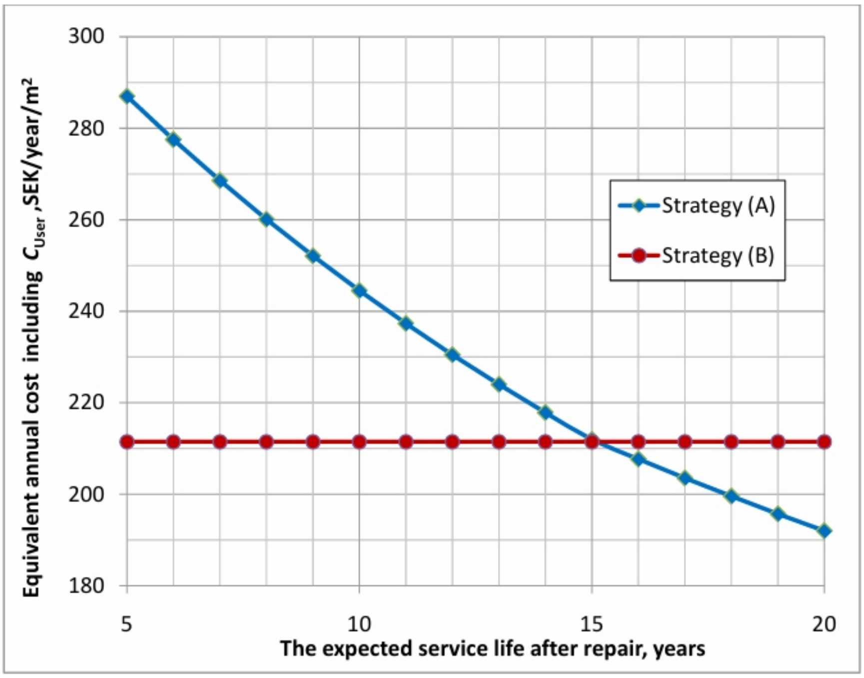

Figure 12. the variation impact of the repair life-span on the final decision

8. Conclusion and Discussion

This paper has discussed the need of a BMS withcradle-to-grave, integrated and comprehensive LCCA tools that can assist decision makers at all levels and within all phases in selecting the most cost-effective alternative. The paper has introduced the Swedish Bridge and Tunnel Management System (BaTMan). A comprehensive LCCA implementation scheme was illustrated, taking into account the bridge investment and management process in Sweden. A real case study was presented to demonstrate the recent improvement of BaTMan particularly in the function of specifying the most cost-effective repair strategy for a deteriorated bridge. The presented case study has clarified how the BaTMan inventory data could be expolited to support the LCCA on that function. Before this research study, the equivalent annual cost techniques, net saving (NS), and sensitivity analysis were not exist in that particular function in BaTMan. Moreover, the decision was used to be based on the net present value technique which is improper to compare alternatives that have unequal life-span.

It is not easy to draw a general conclusion from a LCCA process performed on a certain bridge case because the results are strongly dependent on the input. One of the key components of involved in LCCA is the incorporation of uncertainty into the analysis. Therefore, the sensitivity analysis is an important step in such analysis which can address the critical parameters for the final decision. The sensitivity analysis allows decision makers to evaluate their confidence in whether they have chosen the correct solution. It could be said that when the NS is a considerable amount, the variation of the included parameters will usually not have considerable impact on the final decision and vice versa. By using NS technique, decision makers will be able to estimate the consequences of their decisions, and it will promote forward thinking.

According to the analysis results, as well as the sensitivity analysis in the presented case study, the deck surfacing should not be repaired and should be replaced after utilizing its residual service life. Perhaps, the feasibility of the presented LCC analysis is not clear because it is only one single bridge. However, today, Trafikverket is responsible for 24,123 bridges with a total bridge area of 5,832 651 m2. Among of Trafikverket's bridges, there are 948 bridges have the same condition classes (bridge deck surfacing with Cc2) with a total area of 781,735m2. Considering the LCCA result presented in the case study in this paper, the OL excluding the WZUC is equal to22 SEK/year/m2. This loss will stand for 45 years. Consider that 50% of the Trafikverket's 948 bridges might be subjected to a wrong decision. This means that Trafikverket can save 8.6 million SEK/year. Moreover, it could mean that Trafikverket can save178 million SEK during the coming 45 years.

The LCCA in the presented case study was performed considering no budget limitations. The analysis was only considered the project-level regardless of the network-level considerations. These factors might significant direct the final decisions in other projects. These aspects are important to consider but are beyond the scope of this paper. In addition, further researches should be directed toward clarifying how to handle the same activity on a network-level, taking into account the NS from the project-level analysis.

List of Acronyms

LCC	Life-Cycle Cost
LCCA	Life-Cycle Cost Analysis
BMS	Bridge Management System
Trafikverket	The Swedish Transport Administration
BaTMan	The Swedish Bridge and Tunnel Management System
WebHybris	Software Navigation Tool can access BaTMan's database
CC	Condition Class
Pontis	A full-featured BMS used in more than 40 state departments of transportations in the United State of America
WLC	Whole-Life Costing
NPV	Net Present Value
EAC	Equivalent Annual Cost
NS	Net Saving
OL	Opportunity Loss
SEK	Swedish Kroner (approximately equals to 0.11 EUR in October 2013)
O&M	Operation and Maintenance
NVDB	The Swedish National Road Database
WZUC	Work Zone User Cost.

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A Geodesign Approach for Using Spatial Indicators in Land-use Planning

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ABSTRACT

This paper presents an original approach to Strategic Environmental Assessment (SEA) for supporting decision-making processes in Local Land-Use Planning (LLUP) which integrates a set of frameworks and methodologies into technologies based on the use of Geographic Information. The technologies embrace the domain of Planning Support Systems (PSS), whose architecture is based on the Geodesign framework. The structure of the Planning Support System includes spatial indicators frameworks rooted on the Driving Force-Pressure-State-Impact-Response (DPSIR) framework. The spatial DPSIR model allows dealing with common issues in spatial planning, such as collaborative and participative decision-making processes, informed alternative design, real-time impact assessment and environmental reporting. Furthermore, the planning support system may foster the widespread diffusion of innovations in the planning domain reeling on the availability of Spatial Data Infrastructures. The study aims at investigating the efficiency of this approach integrated into SEA-LLUP based on the results of a case study developed in Sardinia (Italy).

Keywords ***DPSIR, Planning Support System, Geodesign, Spatial Indicators, Environmental Assessment***

1.INTRODUCTION:

The sprawl of the cities and the urbanization processes have gobbled up a big amount of rural and natural areas, jeopardising the quality of environmental resources [1, 2]. Indeed, the evaluation process of the consumption of resources is a current challenge for environmental scientists and planners, who have to deal with the loss of natural capital and the general preservation of well-being for the future generations [3]. Urban development is usually related to the conversion of natural areas, whose ownership may be public or private. Often, the set of policies that regulate land-use and influences the rights of private landowners is oriented towards preserving natural areas and limiting the urbanization processes. By contrast, often landowners aim to achieve their advantage through specific actions, consuming local resources. The sum of these actions produces a range of cumulative effects on the environment that have to be considered in the decision-making stages, through specific plans, rules and policies. These phenomena led to producing several threats for the environment, from the local to the global scale, such as erosion and desertification, loss of biodiversity, climate changes and flooding [4].

The concept of sustainability concerns the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [5]. Indeed, sustainable development aims to ensure an adequate degree of quality of the resources, their accessibility and their availability for the future generations.

This general statement needs to be translated into policies and plans for supporting concrete applications. Jepson [6] pointed out that sustainability and planning are inextricably linked, in order to create a system to "protect the natural environment, meantime the economy has to be developed and the equity achieved".

In the last decades, the European Union has proposed a range of policies with the aim of integrating environmental considerations into projects, plans and programmes for protecting the environment. The Environmental Impact Assessment (EIA, Directive 85/337/EEC) and the SEA (Directive 2001/42/EC) directives are two of such policies that put into effect the European Union' objectives regarding the environmental preservation.

The SEA Directive, in particular, is oriented towards integrating environmental considerations into plans and programmes with the purpose of creating an informed process for supporting plan-making. In many European countries, SEA is a mandatory and an ongoing procedure applied at the national, the regional and the local levels [7].

The SEA has been implemented into the Italian Planning System through the Legislative Decree 152/2006 and it is intertwined with the plan-making processes.

In Sardinia, the SEA is a mandatory procedure for Municipal Master Plans (MMP). The MMP is the most important document for managing Local Land-Use Planning (LLUP), in order to ensure the sustainable development of the territory in compliance with the Regional Landscape Plan (RLP) of the Sardinia Region. Indeed, the RLP is based on a range of rules and principles of protecting the environment, limiting the fragmentation of landscape. These general environment-oriented conventions should be taken into account by the Municipal Master Plan, during the adjustment process to the RLP, through specific methods for supporting the land-use management. Despite the fact that the adjustment process of the MMP to the RLP has to be concluded within one year of approval of the RLP for all the municipalities, only a few MMPs have been revised until recently [35] and a range of difficulties are still presented [21].

In the light of the above premises, the paper is organized as follows. The first part introduces current pitfalls and weaknesses in spatial planning, focusing on the integration of the European Directives and innovations in planning practices. The second section illustrates a possible way of dealing with these issues, through innovative methodologies and technological innovations. The third part demonstrates how to operatively integrate this innovative approach to planning for filling the gap between research and practice, through a case study based on SEA-LLUP procedures in Sardinia (Italy). Finally, the conclusions highlight the results of the workshop and possible further research.

2. Current Barriers for Integrating Innovations in Spatial Planning

The intrinsic complexity of Land-Use Planning concerns a range of activities for managing the use of land in compliance with future planning objectives. The current innovation in computer-aided planning and accessibility to (geographic) data is fostering breakthroughs in decision-making [8]. Recently, the integration of European policies into the Italian National legal framework has promoted an environmental strategic approach to spatial planning. Despite these environment-oriented developments and the growth of the Information and Communication Technology (ICT) domain, a fruitful implementation in planning practices seems to be far from complete.

2.1. The INSPIRE Directive

The integration of the INSPIRE Directive (2007/2/EC) into the legal framework of European member states, promotes the creation and use of Spatial Data Infrastructures (SDIs) to assist in formulating and integrating Community environmental policies across Europe. The concept of SDI arose in 1993 by the U.S. National Research Council, in order to guarantee the accessibility to Geographic Information (GI) for potential users. The SDIs encompasses a range of key elements (e.g. metadata to catalogue spatial data through a range of thematic attributes and, spatial data themes and services) and implementation rules for guaranteeing the diffusion of GI in a transboundary context. Despite the wealth of interoperable services and the public access to GI, provided by the SDIs, is offering opportunities for professional users to innovate spatial planning practices [10], a fruitful integration into decision-making processes is still limited [9]. In Italy, several Regional Authorities have built their own INSPIRE-compliant SDI for supporting the management and planning of the territory. The Region of Sardinia developed the Sardinian Regional SDI (SRSDI) with the aim of sharing data and services to all web users, via download or network services. The SRSDI offers more than 300 spatial data and services which can be used for supporting Local Land-Use Planning activities.

Despite the importance of SDIs is evident at the Regional at the Local level, their efficiency in strategic planning and decision-making is still limited [11]. Indeed, the breakthroughs in the integration of SDIs into spatial planning processes, contrast with a range of pitfalls, such as incompatible and inconsistent spatial databases and limited accessibility to GI [36].

2.2. An Environment-oriented Planning Approach

The research on Strategic Environmental Assessment (SEA) effectiveness for evaluating the impacts of PPPs (Policies, Plans and Programmes) on the environment encompasses a wide range of scientific literature. SEA (Directive 2001/42/EC) and the Environmental Impact Assessment (EIA, Directive 85/337/EEC amended in 2014 by DIRECTIVE 2014/52/EU) have been developed as environmentally oriented approaches with the aim of integrating environmental concerns in decision-making processes [12]. SEA is a procedure inextricably linked with decision-making processes, which integrates the sustainable development principles into PPPs [13, 14]. Tetlow and Hanusch [15] pointed out that despite the benefits produced by the application of the SEA in planning processes [16, 17, 18] different pitfalls arose from the evaluation of its performance. One of these concerns the poor capacity of the SEA procedure to generate informed alternatives for supporting the decision-making process [18, 19]. In turn, the evaluation process of the alternatives' influence on the environment may be inadequate [16] to support the scenarios comparison for identifying the preferable planning solution. Further pitfalls concern the scarce influence and efficiency of monitoring programmes and public participation into plan-making phases [13, 20]. As a matter of fact, the efficiency of the SEA in informing decision-making processes and LLUP is still limited [6]. Emerging methodologies, such as the Geodesign framework and computer-aided innovations such as Planning Support Systems (PSSs), may contribute to filling the gap between current SEA goals and their fruitful integration in planning practices [21].

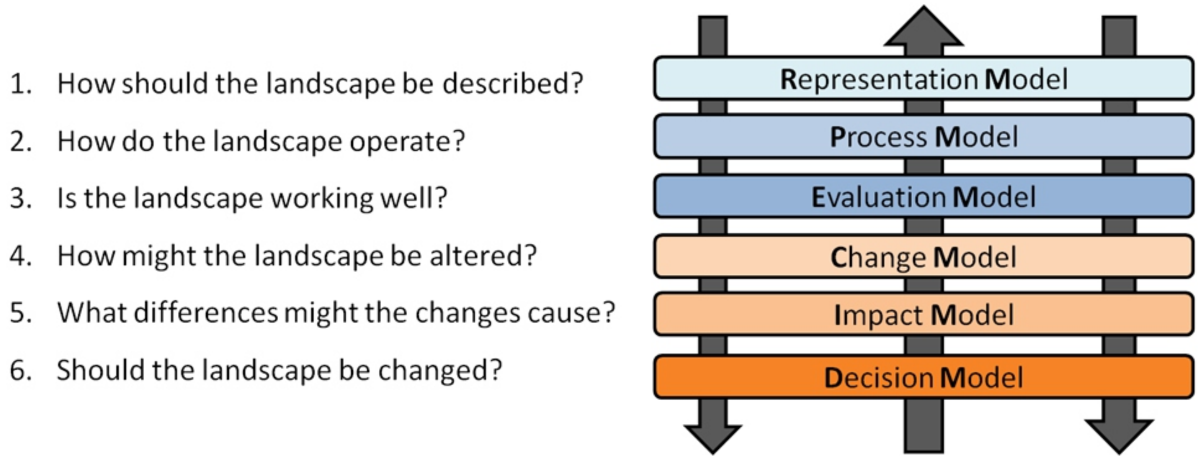


Figure 1. The Geodesign Models (Source: Author)

3.Innovations and Methodologies for Supporting LLUP

3.1. The Geodesign Methodology

Geodesign is an emerging methodological approach to planning and design that encompasses representation, analysis, design and impact assessment of the geographical space, through the participation of different stakeholders and professionals to decision-making. The Geodesign framework (GDF) may be able to bring innovation in spatial planning across different spatial scales [22], and address the current issues in the SEA procedures [10]. The GDF consists in six interactive models that operate for offering an innovative structure for dealing with planning processes (Fig. 1). The Representation Model (RM) describes the environmental system in an attempt to bring a fruitful comprehension of the geographic space on which the Geodesign team operates. In turn, the Process Model (PM) and the Evaluation Model (EM), generate information to investigate the dynamics of environmental phenomena and manage territorial weaknesses and strengths for addressing development strategies. The Change Model (CM), takes into account the knowledge base generated through the first three models to design scenarios, including solutions and alternatives. Finally, the influence of the design activities on the environment is evaluated through the Impact Model (IM) with the aim of producing information and supporting suitable decision processes (Decision Model – DM). The implementation of the GDF may occur in different ways which can be supported by Planning Support Systems. An early attempt to demonstrate the efficiency of Geodesign-based PSS architecture for supporting LLUP was carried out by Campagna and Matta [10]. An early approach to structured information flow integrated into LLUP procedures was carried out through a spatial indicators framework, claiming the need for further research.

3.2. The Planning Support System Architecture The term Planning Support System (PSS) is not new. It was coined by Harris in 1989 [23] for describing an architecture coupling a range of computer-based methods and models into an integrated system in order to support planning functions. This general definition was further developed, integrating more operatively the early definition of PSS as a system which couples Geographic Information System (GIS), and non-GIS data, spatial models and geo-tools for dealing with the complexity of planning procedures [24, 25]. The geo-tools nested in the PSS architecture concern the representation, management and analysis of spatial data across different spatial scale and time, through a user-friendly interface, providing planners support to deal with the complexity of planning procedures. These geo-tools include the Land Suitability Analysis (LSA), the sketch planning and the real impact assessment, the scenario comparison and the report production. The LSA is a GIS-application which allows analyzing the geographic space with the aim of locating predetermined uses of land according to specific parameters [26]. It provides the base on which to generate design activities for future territorial developments. Sketch planning can be considered part of the planning process and makes the planners able to

explore planning issues for producing alternatives and scenarios [27]. Sketch planning offers opportunities to enhance spatial modeling fostering participation and collaborative processes to decision-making steps. The real-time impact assessment concerns the influence of the alternatives on the environment through a set of spatial indicators, enclosed in a dynamic electronic dashboard. The indicators are able to support the communication of complex phenomena in a simple way [28, 29]. Indicators show the value of specific parameters used during the representation, analysis and decision procedures, fostering a collaborative and participative decision-making processes since the early plan-making phases. The PSS architecture makes available to users a range of indicators that realize the integration of spatial data into planning processes through structured frameworks. The production of predefined reports allows generating a transparent decision-making process, including maps, data, indicators and formulae, used during the plan-making phases. The role of spatial indicators in the PSS architecture is currently undefined. Although there are predefined indicators that show a set of parameters that influence the design and the impact assessment, there is a lack of relationship among them and a non-structured information flow across the geo-tools. For this reason, the fruitful integration of a structured spatial indicators framework into the PSS architecture can be considered far from being achieved.

3.3. A Spatial Indicators Framework

The role of indicators in planning processes concerns different phases and tasks. Indicators may show the current territorial situation and how specific environmental and urban parameters change during the design activities. In addition, they support the monitoring program for evaluating the influence of the design activities on the environment. According to the requirements of the regional planning regulations and the SEA-LLUP guidelines in Sardinia, a set of structured indicators have to be implemented in the Environmental Report (ER) for integrating impact assessment and monitoring program.

The most important indicators frameworks used at the international and the national level are based on the concept of causal chains, where the output of each component of the framework feeds the other in a loop [29]. An indicator framework based on the causal chain theory, may help to organize the cause-effect relationships among indicators, in order to provide reliable information about interdependencies between human societies and the natural environment [30].

The Driving-Force-Pressure-State-Impact-Response (DPSIR) is a casual-based indicators framework able to support the decision-making process [29]. The DPSIR is often used to stimulate the societal responses related to the environmental problems, in order to preserve the resources for the future generation, according to the sustainability of development principles [31]. The framework is based on five components that support the comprehension of phenomena and fills the gap between the real world and its representation. These components interact in a loop (Fig. 2): (i) Drivers (D), (ii) Pressures (P), (iii) States (S), (iv) Impacts (I) and (v) Responses (R). The first three components represent the "causes" that generate the "problems", encompassed in the fourth component. In turn, the fifth component deals with the problem putting the basis for the "solution(s)" [32].

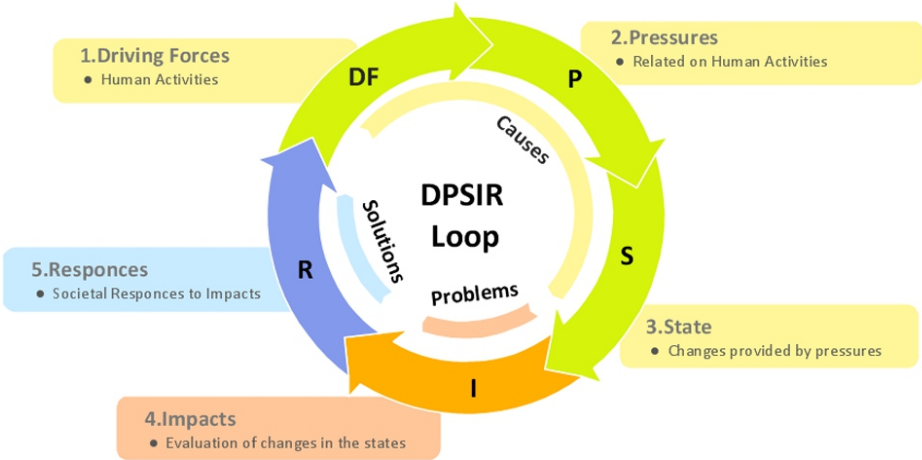


Figure 2. The DPSIR framework (Source: Author)

The Environmental Protection Agency (EPA), provides generic relationships among the DPSIR components for supporting the integration of the framework into spatial planning. These relationships drove the connections between the DPSIR framework with the GDF, as argued by Campagna and Matta [10] (Fig. 3). The iterations of the DPSIR loop are intertwined with the GDF models: the first loop concerns the analysis of the current territorial conditions (RM, PM and EM), such as the representation and analyses of current urban-environment phenomena and general proposals for producing future development strategies of the territory. The information and spatial data produced in this early phase can be considered the base on which operatively modelling the geographic space in compliance with the planning objectives and the sustainable resource consumption (CM, IM and DM) (Fig. 3). Nevertheless, the research on sDPSIR for supporting LLUP concerns just a few practical case studies [10, 33, 31].

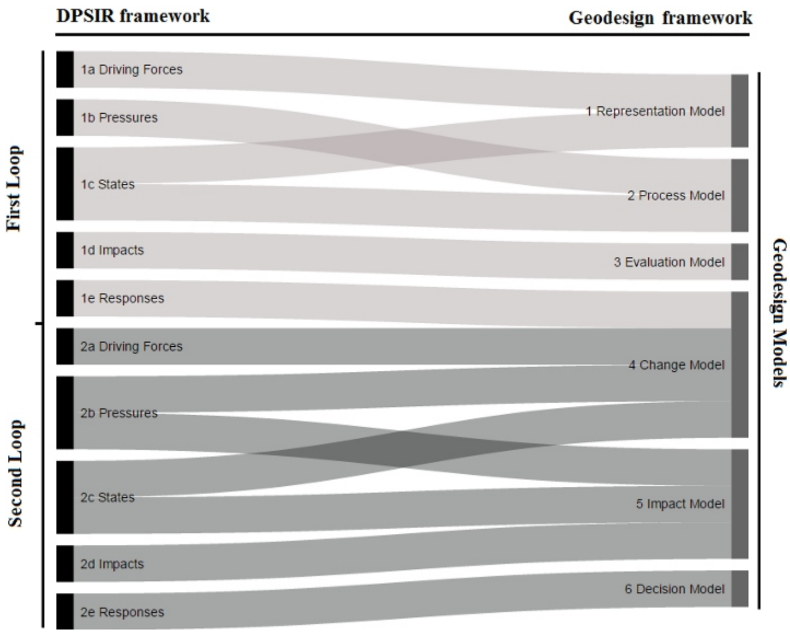


Figure 3. The relationships between DPSIR framework and GDF

The fig. 3 shows an early integration of the sDPSIR framework into SEA-LLUP, implemented in 2014 [10]. In order to extend the investigation into the role of spatial indicators in LLUP practices, a case study that concerns a practical workshop in the municipality of Gonnesa (Sardinia, ITALY) is proposed in the next paragraphs.

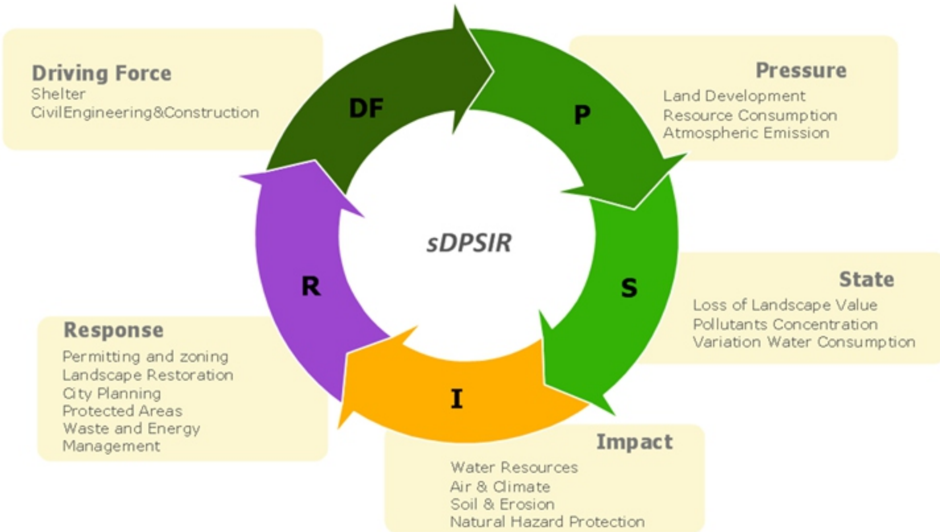


Figure 4. An early integration of the sDPSIR into SEA-LLUP

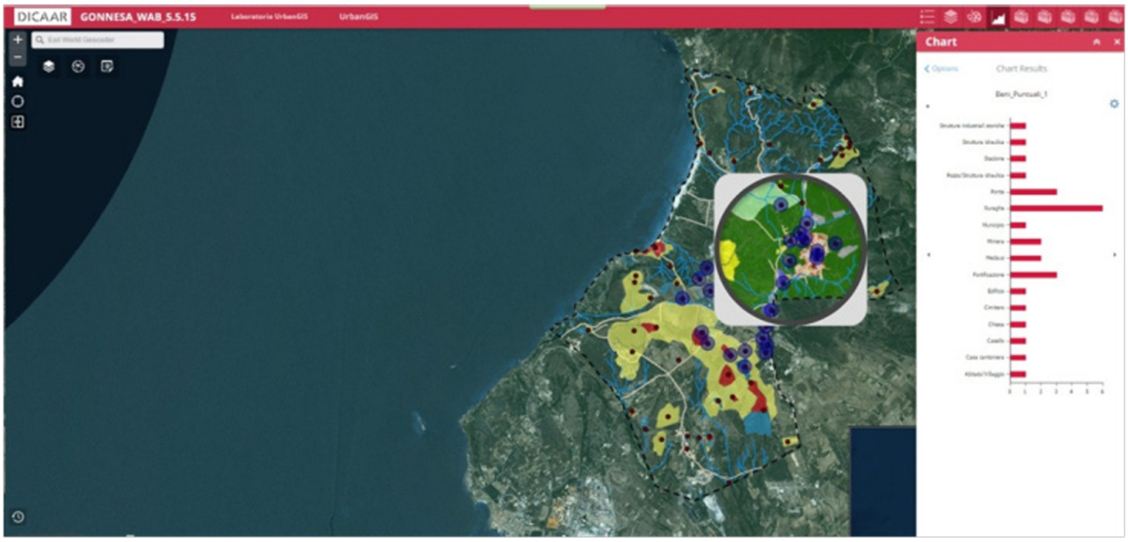


Figure 5. The Web-based PSS architecture for representing and analysing the DPS components

4. A SEA-LLUP Workshop for Integrating Innovations in Practices

4.1. The sDPSIR Integrated into a Geodesign-based PSS Architecture

The case study concerns a workshop on LLUP, realized by the UrbanGIS Lab of the University of Cagliari, in collaboration with the local authority of the municipality of Gonnesa. It was carried out in compliance with the COST TU 1002 guidelines for innovating spatial planning practices [37]. The group of participants to the workshop (Workshop Users - WUs) was composed by a range of professionals, researchers, and local administrators, with the aim of making value of their experiences for comparing current practices and the proposed methodologies and innovations.

The workshop aims to investigate how technological innovations and emerging methodologies may influence current planning practices. The goal was to analyse the process of location, design and evaluation of a new touristic area in the municipality area. This paper takes into account the influence of these innovations in spatial planning for demonstrating the role of GI and spatial indicators for supporting collaborative decision-making.

4.1.1. Representation and Process Models

The first phase of the workshop was oriented both to represent the municipal territory and to perform spatial analyses through the use of spatial data, made available by the Regional SDI (SRSDI) and the public administration. In a broad sense, the WUs were able to compare the current system for sharing and represent spatial and non-spatial data of the local administration with the innovative approach based on a Web-architecture. In this phase, a Web-Based PSS was used to generate information and integrate the Representation Model and the Process Model into practice (Fig. 5). The Web-based PSS is an architecture that makes available a range of thematic maps, such as the current land-uses, hydrogeological hazards and cultural and historical goods, and a range of nested geo-tools for performing spatial analyses (e.g. the number of historical sites in a specific portion of the area). The outputs of these analyses are shown through spatial indicators, representing the first three component of the sDPSIR: DF, P and S. Indeed, the values of the indicators represent the Driving Forces that dominate the urban phenomena (i.e. number of inhabitants, residential volumes and areas) and produce Pressures on the environment (i.e. soil consumption, costs).

In turn, the PM, through the geo-tools, provides the information for feeding the State component (i.e. loss of natural landscape, production of goods and services).

4.1.2. Evaluation Model

The third phase of the workshop is based on the management and the analyses of the knowledge generated through the RM and PM. Indeed, the first three components of the sDPSIR depict the “causes” of the “problem” that in turn, generate the Impacts on the environment. This information flow allows establishing both the environmental questions and the development goals for the territory. These issues can be dealt with a range of proposals that may arise from different groups of stakeholders, related to their own purposes, such as environmental and socio-economic questions. Nevertheless, if not adequately supported by methodologies and analysis tools, the process of combination and analyses of different planning goals may be too complex. For this reason, the EM supports the process of evaluation of these purposes, driving the design of future suitable alternatives.

The EM may enclose both mitigation actions for reducing the environmental impact of current urban phenomena and suitable proposals for new design and developments. This planning task is supported by the Land Suitability Analysis (LSA) tool with the aim of generating a range of suitability maps [26] and fostering the negotiation among stakeholders, concerning different plan solutions.

The CM encloses the transformation of the geographical space due to the results by the design setting. The causes of

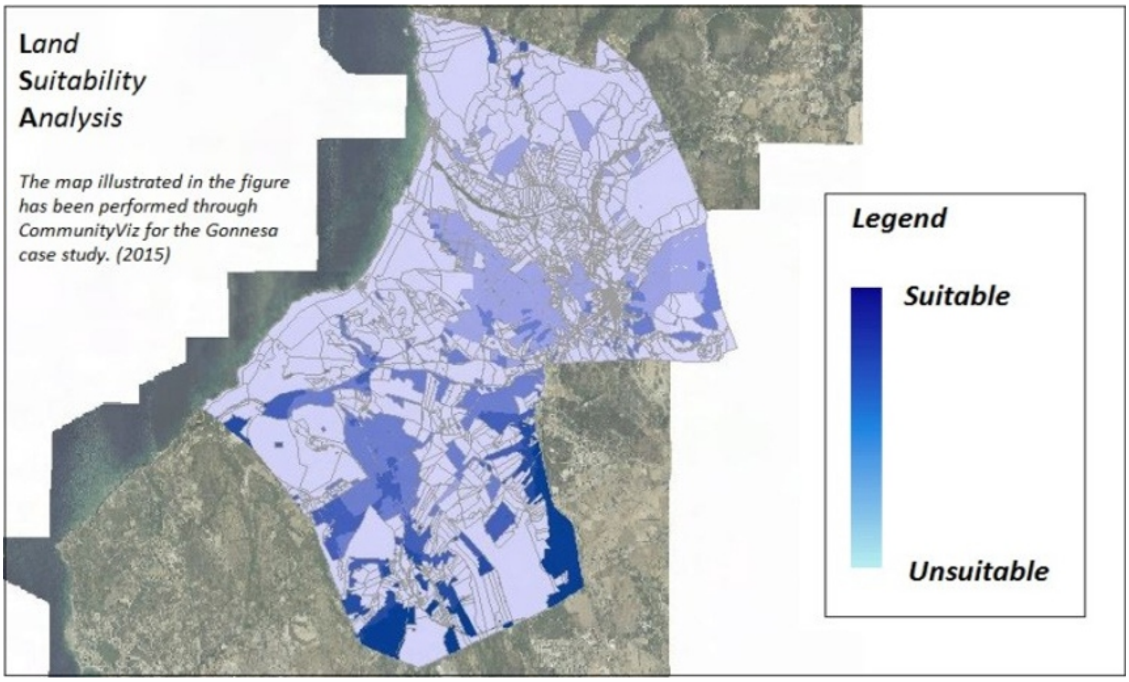


Figure 6. An Evaluation map for supporting the development of future strategies

The LSA tool allows combining a wide range of spatial data for producing maps that represent the result of a range of spatial analyses. The maps, namely suitability maps, concern specific urban and environmental phenomena that should be analyzed for defining the alternatives in the CM. The spatial data are combined through different spatial operations, such as weighted selections, that generate a range of criteria, which value can be changed during the negotiation phase. These variations produce real-time changes in the suitability maps, offering different planning solutions. The maps may represent, with a different colour ramp, for instance, the suitability rate of adequate sites for the planning purposes. The lightest colours represent the lowest suitability rate, where the combination of selected criteria defines the non-adequate areas. The darkest colours concern the highest suitability rate, representing the adequate areas for the proposed planning goal (Fig. 6).

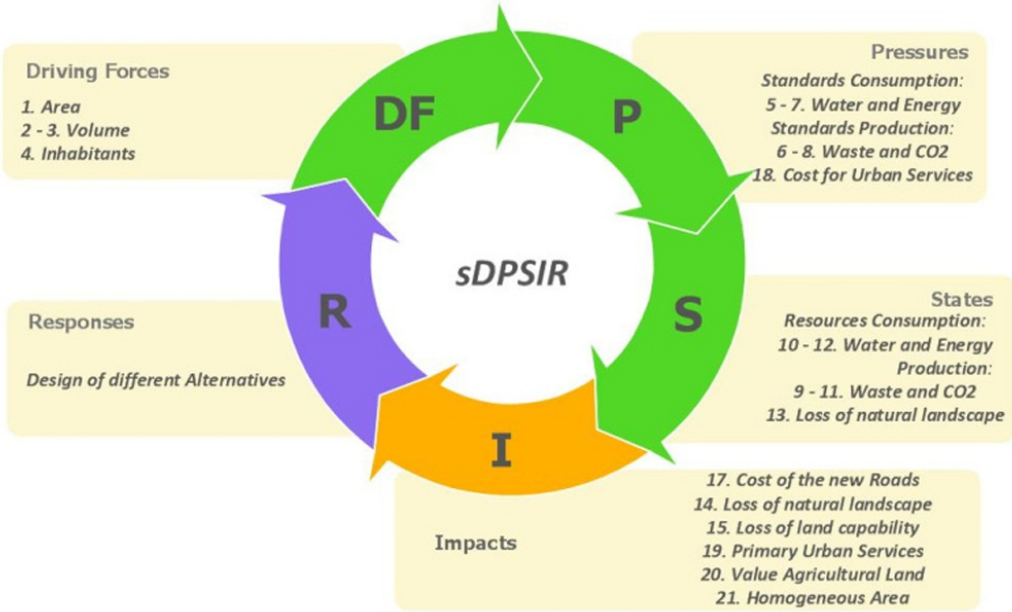
The WUs were able to produce real-time map variations, thanks to a set of dynamic weighted attributes (e.i. proximity to the main roads), informing the discussion regard their own purposes for future territorial developments (Fig. 6).

The evaluation maps represent the location of suitability areas on the territory for a specific planning goal, in order to deal with the “causes of the problems”, depicted through the Impact component of the DPSIR framework. The group of spatial indicators related to the Impact, show the influence of the design activities on the environment, through a dynamic dashboard enclosed in the PSS architecture. It can be argued that the impact component embraces the base-knowledge of the territory both for supporting planners in design activities and for driving suitable planning solutions, in compliance with participative and collaborative planning procedures.

4.1.3. Change and Impact Model

The CM encloses the transformation of the geographical space due to the results by the design setting. The causes of the territorial metamorphosis may have different drivers, represented through the DPSI components. In order to support planners for dealing with this task, the CM is supported by the PSS architecture through the sketch planning tool that makes the users able to design a range of alternatives. The sketch planning is a GIS-based planning tool that allows putting into effect abstract concepts for evaluating their effect on the environment referring to a specific planning objective [34]. The WUs were able to negotiate a range of alternatives based on the evaluation maps, for generating different scenarios. Each design solution is related to a real-time variation of the spatial indicators that foster the comprehension of the design influence on different domains (e.g. environmental, social and economic).
On the one hand, the sketch planning activities may support the design of mitigation actions that arose from the evaluation of the territorial phenomena originated in the preliminary analysis phases (e.g. environmental problem). On the other hand, the design concerns proposals for the municipal territory in order to support development strategies (e.g. a new touristic area). For this reason, the CM operates for dealing with the “Responses” that arise from the DPSI components, feeding back the framework with new

Drivers and Pressures. It can be argued that, the CM both complete the first loop of the sDPSIR framework and put the basis for the second one (Fig. 3). Indeed, the spatial indicators are able to show how the Driving Forces may create new Pressures on the environment leading to changes in the State. For this reason, the Impacts change, in compliance with the new information generated during the design activities.



The CM and the IM operate at the same time, representing how changes in the geographical space are instantly related to a variation of different parameters. The DPSIR framework nested in the PSS architecture is able to support the communication of information to stakeholders in a simple way, improving the comprehension of how these alternatives influence the environment and providing a structure for organising complex information flow along the decision-making procedures.

4.1.4. Decision Model

The different scenarios and the relative environmental impacts show how the decision-making process may influence the environment and the citizen' well-being. In order to generate a suitable response to the planning goal, the scenarios should be compared and analyzed. The process of comparison may lead to operating further design activities for enhancing the final design solution. This process contributed to the production of the final alternatives is in compliance with both the planning goal and the stakeholder' purposes. The "responses" generate a negotiation among stakeholders with the aim of merging the requests of sustainable resource consumption from the SEA and the purposes of economic and urban growth from the local administration. The final scenario represents both how the information flow supports the decision-making process since the early phases, starting from the analysis of the current situation to the scenarios comparison, and how the sDPSIR contributes to the management of this information (Fig. 7). The DM depicts the future developments of the municipal territory in an attempt to communicate in a simple way the intrinsic complexity on which the decision-making process is based.

5. Conclusions

Land-Use planning encompasses a wide range of methodologies, technologies and groups of people, such as politicians, citizens and stakeholders, in order to orchestrate the uses of lands in compliance with sustainable development goals [38]

In this context, the paper presents an innovative approach to Strategic Environmental Assessment of a Local Land-Use Planning Support System implemented for the municipality of Gonnesa (Sardinia, Italy). The case study shows how structured GI frameworks, integrated into SEA-LLUP procedures, fulfil an important role in supporting decision-making processes.

The PSS architecture allow the integration of the GI in the Sardinian planning context, and may contribute to dealing with the complexity of planning activities in all the plan-making phases, such as the creation of the base-knowledge for generating an informed design of alternatives and for supporting the negotiation among stakeholders.

The sDPSIR framework nested in the PSS architecture provides a structure for developing the cause-effect relationships on which the planning goals are built. This causal chain supports a collaborative and transparent planning process since the early plan-making phases. Indeed, it allows generating a shared comprehension of the territorial context making available dynamic data that change thanks to a continuous integration of information from stakeholders. In addition, this base-knowledge becomes the source for addressing informed alternatives' design and supporting the monitoring of their influence on the environment. For this reason, this innovative approach may allow emphasising the role of the GI technologies across the plan-making phases in the Sardinia planning context.

The workshop was enriched by a range of questionnaires for assessing the WUs' opinions on this innovative approach to SEA-LLUP. The participants pointed out that the PSS architecture, and in particular the management of the information flow across the decision-making, may be considered a reliable plan-making support. Moreover, the PSS architecture allows not only of dealing with the request of the SEA-LLUP procedures both for integrating informed environment-oriented procedures into practice and monitoring their impact, but also of fostering a transparent and collaborative decision-making process, from the early plan-making phases until the final decision, supporting a shared comprehension of the planning processes among stakeholders and decision-makers.

In conclusion, this PSS can be considered an innovative approach that contributes to the integration of the Geodesign framework into planning activities, such as in the representation and analysis of the current territorial context, in the design of plan alternatives, in the support of the participation processes and in the evaluation of the most suitable development scenario. The sDPSIR framework may contribute to putting into effect the GDF models in practice, supporting the planning process through an informed design of alternatives and a real-time impact evaluation across the decision-making phases.

However, the results illustrated in the paper concern an early approach to planning practices, for this reason, further case studies may contribute to ameliorating the architecture for dealing with the complexity of the plan-making activities.

Acknowledgements

The work presented in this paper was developed in the framework of the International PhD in Environmental Science and Engineering at the University of Cagliari. We would like to thank Matteo Serra for his efforts on organizing the workshop and the Web-based PSS architecture.

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Standard Practices for an Effective Competitive Tendering Process for Public Works Procurement

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ABSTRACT

This paper is a desktop study that targets the identification of standard practices for an effective competitive tendering process for public works procurement in developing countries. After defining the process and detailed activities involved, it was divided into five following phases: tender planning, tender documentation, tender solicitation, tender evaluation and tender pre-award. Then, an intensive analysis of different public procurement laws and related documents of seven developing countries was performed. As results, 38 standard practices were identified. Using the frequencies and relative frequencies, 33 were found implemented in the seven developing countries and only 20 representing 52.64 % attracted frequencies above 5/8. The study found that following practices are the most frequent: develop a realistic procurement plan, accurate budget, get approvals and publish it, appoint suitable design team, obtain a complete project design, select appropriate tendering option; secure project design quality, use standard documents, review and approve tender documents before publication; advertisement of tender proposals, proper handling of requests for clarification, etc. The study concludes that when these practices are fully implemented, they will surely produce the predicted results.

***Keywords** Standard Practices, Competitive Tendering, Works Procurement, Developing Countries*

1.INTRODUCTION

In public works procurement, Competitive Tendering (CT) is widely recognized as an attractive procurement mechanism due to its widespread benefits. These include promoting competition and hampering corruption [1], reducing cost by broadly 20% [2], and providing the enabling environment for effective utilization of scarce resources in the economy [3]. Consequently, CT is strongly advocated by international organizations like World Bank (WB), European Union (EU), African Development Bank (AfBD), and the Organization for Economic Co-operation and Development (OECD). As a result, the majority of developing countries prescribed it as the prime method of public works procurement. Although CT appears to be the most acceptable method of selecting contractors [4], and the most beneficial to local construction industries [5], its implementation has been the most difficult in developing countries [3]. For instance, despite the reforms of Public Procurement Acts, Regulations and Procedures that consecrated the standardization of tender documents in the majority of developing countries, the implementation of CT remains challenged by excessive delay imputable to a lengthy process; and fraudulent and corrupt practices do persist. Furthermore, losses of time and cost due to long process are estimated between 20 to 30% of grant-in-aid according to OECD-DAC (Development

Assistance Committee) [6].

This situation has led to Paris Declaration on the Aid Effectiveness for partner countries; which declaration stressed the urgent need for improvement of effectiveness in Public Procurement practices [6]. Therefore, the present study aims at identifying the key activities that can be standardized in order to improve the effectiveness of Competitive Tendering Process (CTP) in public works procurement in developing countries. Two specific objectives are set: define the main phases of the process at pre-contract stage and identify the most frequent practices for standardization. A part from introduction and conclusion, the paper is structured into three sections. The first section briefly presents literature review followed by the method employed while the third section presents the main findings including results discussion.

2. Literature Review

Standard practice refers to widely accepted and core activity, technique, principle, method or process that is regarded as effective to achieve certain goals in a sector or sphere of business [7], [8], [9]. In addition, it is a best practice that has shown through experience to consistently lead to the desired result and when executed effectively leads to superior project performance. Not only that, standardization is a way of prompting the process by a limited number of key practices [10]. Therefore, the standardization aims at gathering and harmonizing a limited number of key practices that can enable a process to be effective and easy to implement and to generalize.

Based on these assertions, seven Public Procurement Acts of developing countries were thoroughly reviewed. Though the competitive tendering process may vary from one country to another despite the reforms undertaken in 2000s, a typical process can be divided into five following main phases: Tender planning, Tender documentation, Tender solicitation, Tender evaluation and Tender award. Concerning the practices, Patrice [11] has identified 47 steps or activities from tender planning up to the award of contract in Chad Republic. Another recent study of Douh [12] has identified 49 activities ranging from needs assessment up to works commissioning.

Undoubtedly, such process is not only very long and laborious but it is responsible of excessive delays in project delivery. Besides, the compilation of consulted sources has found about 38 most frequent activities distributed along the five phases of the competitive tendering process at pre-contract stage. Therefore, there is obviously a need for shortening the process by a way of standardization. The complete list of these activities is tabulated in the third section.

2. Method

The study adopted a mixed method with desk study using secondary data and descriptive statistic. Principal sources are Public Procurement Acts or Laws, regulations and associated manuals of procedures, procurement bulletins, periodic reports, and casual study reports. Using non-probability sampling technique, a judgmental sample of eight (8) Public Procurement Acts including seven developing countries is purposively selected. These countries are Ghana, Chad, Cameroun, Uganda, Rwanda, Senegal, and Kenya and United Nations Commission on International Trade Law (UNICITRAL) which is used for benchmarking [13, 14, 15, 16, 17, 18, 19].

Then, a methodology involving three steps is used for data analysis. First, an intensive literature review has resulted in a list of 38 core practices. Second, the identified practices were checked against the articles of the Acts including those of UNICITRAL [20]. Third, using frequencies of occurrence, every identified practice is assessed. Thus, a variable that has occurred 5 times over the 8 sources will score 5/8 (i.e. 62.5%) and is considered as very common and therefore qualified for standardization.

4. Results and Discussion

As introduced above, the literature review has revealed a list of 38 core practices which is displayed in Table 1 below with their respective sources. Based on this list, the above method was used to analyze and establish the most common practices that can be adopted as standard practices in developing countries.

Baseline Standard/Best practices	Chad	Ghana	Kenya	Rwanda	Senegal	Cameroun	Uganda	UNCITRAL	Others
A. Tender Planning Phase									
1. Needs assessment and formulation of project initial brief	Art 14	S 21			Art 5	Art 6	Art 58		
2. Publication of approved Annual Procurement Plan	Art 14	S 21		Art 6	Art 6, 56	Art 6	Art 54,58	Art 6	
3. Provision of an adopted accurate estimate in the national budget	Art 15				Art 8	Art 6	Art 58	Art 12	
4. Selection of an appropriate Tendering Option	Art 36						Art 63	Art 26	
5. Appointment of an Independent and Free Tender Committee	Art 22	S 17	Art 28		Art 36		Art 26, 38		
6. Development of detailed project design by competent professionals	Art 15				Art 5		Art 31		
B. Tender Document Development Phase									
7. Provision of complete project design documentation						Art 6	Art 59		
8. Setting of Non-discriminatory Eligibility/Participation conditions	Art 15	S 22			Art 46	Art 17	Art 43, 63	Art 8	
9. Use of Standard Tender Documents		S 50	Art 52		Art 10		Art 56	Art 39	
10. Use of neutral & standard Technical specifications	Art 15	S 49	Art 34	Art 25	Art 7		Art 61	Art 10	
11. Pre-disclosure of Evaluation criteria and expected terms of contract	Art 29						Art 71		
12. Pre-disclosure of Tender Award criteria							Art 66	Art 11	
13. Alignment with primary & secondary objectives	Art 7		Art 39						
14. Requirement of approval of Tender documents or No-objection	Art15, 23,30				Art 58				
C. Solicitation of Tenders Phase									
15. Pre-Tender meeting									Papyrus
16. Allocation of sufficient time to Advertisement of tender proposals	Art 30	S 44	Art 54	Art 28	Art 63	Art 20		Art 33	
17. Use of multiple and/or dedicated media for Tender Advertisement	Art 30	S 44	Art 54	Art 29	Art 63	Art 20		Art 33	
18. Grant of enough time for preparation of Tender Bids			Art 55	Art 29	Art 63		Art 64	Art 33	
19. Sale of Tender document at a minimum price					Art 58				
20. Reception and response to Requests for Clarifications	Art 38	S 51			Art 66		Art 65	Art 15	
21. Submission/ Reception/of Tenders and Public Opening of Bids	Art 51	S 56	Art 58, 60	Art 32,34	Art 67	Art 25	Art 68	Art 40,42	
D. Evaluation of Bids Phase									
22. Constitution of qualified and ethical Tender Evaluation Panel	Art 52	S 63	Art 44, 139	Art 15-17	Art 38,40			Art 26	
23. Appointment of an Independent Observer to monitor the process	Art 22	S 19				Art 96	Art 37		
24. Evaluation of tenders using Points system of scoring		S 58	Art 66	Art 39	Art 68-70	Art 27		Art 43	

25.	Requiring of necessary clarification of bids	Art 52	S 57	Art 62	Art 38			Art 73	Art 16	
26.	Requiring of tender security covering the Validity Period	Art 66	S 54, 55	Art 57, 61	Art 31,35	Art 113	Art 23		Art 17, 41	
27.	Appropriate use of Margin of Preference	Art 13	S 60		Art 41	Art 50	Art 31			
28.	Risk analysis (Construction Industry Data Base)									CIDB
29.	Production and Signature of Tender Evaluation Report	Art 52				Art 83				
E.	**Pre-Award Phase**									
30.	Provision of Complete recordkeeping of procurement proceedings		S 27, 28	Art 45	Art 8	Art 83		Art 41,55	Art 25	
31.	Pre-Award meeting and Review of Tender evaluation report						Art 31		Art 22	
32.	Requirement of the No-objection of Tender Evaluation Report	Art 55				Art 83				
33.	Commit and secure necessary funds (Attestation of Availability)									
34.	Publication of tender results including successful & Unsuccessful			Art 46, 67	Art 43	Art 85-87	Art 33	Art 54	Art 23	
35.	Debriefing meeting with successful and Unsuccessful tenderers									
36.	Right to challenge and appeal tender procedures (complain/ dispute			Art 93		Art 88	Art 95		Art 64	
37.	Provisional award of contract	Art 55		Art 67	Art 43	Art 84	Art 33			
38.	Pre-Contract Audit (Government of Jamaica)									GOJ

From the Table 1, out of the identified 38 practices, 33 were found implemented in developing countries but only 20 representing 52.64 % attracted frequencies varying above 5/8. Among the 20 most common practices presented in Table 2 below, only 16 have been identified as very common in developing countries representing 42 %. The rest four practices are provided by UNICITRAL and are: Selection of an appropriate Tendering Option, Pre-disclosure of tender Award criteria, Pre-Award meeting to Adopt Tender evaluation report, and Right to challenge and appeal tender procedures. Even though these last practices are not formally prescribed in Public Procurement Acts of developing countries, they are implemented for major projects in Chad and Ghana as best practices in the area of procurement.

Table 2. Core practices and Frequencies

	Relevant Standard practices	Mark (> 8)
A.	**Tender Planning Phase**	
1.	Publication of approved Annual Procurement Plan	7
2.	Needs assessment and formulation of project initial brief	5
3.	Provision of an adopted accurate estimate in the national budget	5
4.	Appointment of an Independent and Free Tender Committee	5
B.	**Tender Document Development Phase**	
5.	Use of neutral & standard Technical specifications	7
6.	Setting of Non-discriminatory Eligibility/Participation conditions	6
7.	Use of Standard Tender Documents	5
C.	**Solicitation of Tenders Phase**	
8.	Reception/Submission of Tenders and Public Opening of Bids	8
9.	Allocation of sufficient time to Advertisement of tender proposals	7
10.	Use of multiple and/or dedicated media for Tender Advertisement	7
11.	Grant of enough time for preparation of Tender Bids	5
12.	Reception and response to Requests for Clarifications	5
D.	**Evaluation of Bids Phase**	
13.	Requiring of tender security covering the Validity Period	7
14.	Constitution of qualified and ethical Tender Evaluation Panel	6
15.	Evaluation of tenders using Points system of scoring	6
16.	Requiring of necessary clarification of bids	6
17.	Appropriate use of Margin of Preference	5
E.	**Pre-Award Phase**	
18.	Provision of Complete recordkeeping of procurement proceedings	6
19.	Publication of tender results including successful & Unsuccessful	6
20.	Provisional award of contract	5

Table 3. Frequencies and Relative Frequencies

Classes	Frequencies	Relative frequencies
0	5	13.16 %
1	1	02.63 %
2	8	21.05 %
3	2	05.26 %
4	2	05.26 %
5	8	21.05 %
6	6	15.79 %
7	5	13.16 %
8	1	02.64 %
Total =	**38**	**100.00 %**

4.1. At Tender Planning Phase

Under this phase, four practices have scored above or equal to 5/8 frequencies. The first common practice is Wide, earlier and timely publication of a realistic annual procurement plan with 7/8. This high score confirms the fact that procurement plan is a key element which provides contracting authority with project brief that has to comply with national or local goals and both primary and secondary objectives of development [19, 13, 21]. Not only that, timely published procurement plan allows the private sector to respond more effectively to the project requirements and specifications. Furthermore, Thai [22] states that Procurement Plan is a core document from which all tendering activities shall flow. The second practice is Ascertain the accuracy of the allocated budget with 5/8. In effect, cost has been a determinant factor in planning stage of every construction project. Most often, Governments do conduct feasibility study, prior to the budget planning, to improve the estimate accuracy. The third practice is the Appointment of an Independent and Free Tender Committee (with 5/8), for the project design and coordination team quality is a determinant success factor in construction project asserted Watermeyer [21]. The last practice at this phase is the Appropriate assessment of needs (with 5/8). Ideally, a public construction project has to meet beneficiaries' expectations and needs. Often, many Government projects fail to meet the actual needs of people when political considerations are involved. From what precedes, the most common practices that can contribute in increasing the effectiveness of CTP at planning phase can be summarized as follows: develop a realistic procurement plan based on an appropriate needs assessment including an accurate budget, widely published and managed by a suitable project team.

4.2. At Tender Documentation Phase

Out of the eight practices identified under this phase, only three have scored above or equal to 5/8. The first is Use of neutral and standard Technical specifications with 7/8 which is in line with the recommendation of OECD/MAPS (Methodology for Assessing Procurement Systems) [23] because it limits collusive practices. The second practice with 6/7 is Setting of Non-discriminatory

Eligibility/Participation conditions that are able to ensure some fairness and equity to all bidders; for it is observed that eligibility conditions are designed such a way that favors some participants to the detriment of others. The last is Use of Standard Tender Documents with 5/8. Indeed, since the reforms of PPA in 2000s, there is a worldwide agreement on the mandatory use of standard tender documents in both international and national tendering transactions. Ideally, tender documentation must be complete, précised and clear in an applicable language as well including neutral specifications and non-discriminatory eligibility conditions.

4.3. At Tender Solicitation Phase

Five out of the six identified practices are found relevant. The first practice is the Submission or Reception of Tenders and Public Opening of Bids with 8/8. In fact, it is recommended to register all the bids received on receipt before storing them in the designated box in a prominent place and kept locked until the opening session. Then, tender opining commences immediately and must take place on the date, time, and venue advertised. A tender opening panel shall comprise at least three persons including a member of the entity's tender committee. For purpose of transparency, it is not allowed for a tender opening session to be halted or postponed once the process has begun. Following recommendations are made to guarantee the effectiveness of the process: ensure that opening session is public and minutes of proceedings are duly written and signed as well as the attendance list; and original copies of bids are secured at all times. In case of rejection, the bid must be returned unopened.

The two following practices have attracted 7/8 each: Allocation of sufficient time for Advertisement of tender proposals and Use of multiple and/or dedicated media for Tender Advertisement. Solicitation of tenders begins with tender announcements and obviously, tender announcements' channels play a vital role as well as advertisement duration. A tender proposal should be advertised in a way to attract a wide pool of potential bidders by using several media and allocate sufficient time for preparation [24]. That is why regulations impose at least two national newspapers of wide

circulation (Chad), a dedicated procurement gazette (Uganda, Rwanda and Kenya), Public Procurement Authority Electronic Bulletin or a website (Ghana, Senegal), or international newspapers or radio for large projects. The two last practices are Grant of enough time for preparation of Tender Bids with 5/8 and Reception and response to Requests for Clarifications with 5/8. Indeed, requests for clarifications, in all cases, have to be answered and copies placed in the procurement record file. So, any response to a tenderer must be communicated to all tenderers without identifying the author of the request. It will be noted that when a response to request for clarifications generates substantial modifications in the project, it is recommended to extend the submission date accordingly.

4.4. At Tender Evaluation Phase

Out of the six practices identified, five are found relevant. This has made evaluation of bids a very sensitive step in tendering process [25]. Following practices have to be considered carefully. First is the Request of tender security covering the Validity Period with 7/8. Secondly, comes the Constitution of qualified and ethical Tender Evaluation Panel with a score of 6/8. In constituting the panel, the highest ethical standards shall be applied to ensure fairness, transparency and trust. To comply with international practices, an evaluation team should be selected among the specialists in the area and comprising at least three to six people. Lloyd [26], recommends the involvement of an independent observer on the evaluation panel because his presence helps ensure that competing bids are impartially evaluated and provides reassurance to participants as to the integrity of the evaluation process. Furthermore, no meetings or consultations between the Procurement Entity and tenderers are permitted during this phase.

The third position goes to Evaluation of tenders using Points system of scoring which has gained 6/8 indicating clearly that this system is perceived as more objective and straight forward. Requiring of necessary clarification of bids has attracted 6/8 occupying the fourth position. During the evaluation, only criteria listed in the bidding documents will be applied. And when clarification is needed, it must be required without hindering fairness and equity. The last practice is Appropriate use of Margin of Preference with a score of 5/8, what is a relevant practice to accomplish some secondary objectives. Therefore, according to Appiah and Adam [27], the role of tender evaluation phase is of paramount relevance in CTP and all endeavors are to be directed towards an irreproachable evaluation process to meet the foreseen expectations and maintaining trust.

4.5. At Tender Pre-award Phase

Provision of Complete record keeping of procurement proceedings through an evaluation report and Publication of tender results including successful and unsuccessful are the two first practices that have the identic score of 6/8. Usually, a period of 10 to 14 days is allocated for eventual complaints, because bidders have the right to protest the results as opined Lloyd [26] as well as the procurement acts. When there is a formal founded protest, the award process is suspended till the settlement of the case. If no formal complaint is registered after the prescribed period, a provisional notification is issued to the winner who should be required to confirm in writing acceptance of the tender award and submit the appropriate performance security; after what the final notification is issued. The third practice is Provisional award of contract with 5/8. After evaluation report approval, the procuring entity should send a provisional notification to both successful and unsuccessful tenderers. A debriefing is to be organized with all tenderers to publicly release tender results. Failure to do that may constitute grounds for the annulment of the award. In that event, the Procurement Entity may award the contract to the next lowest evaluated bidder, whose offer is substantially responsive and qualified to perform the contract satisfactorily. Generally, a pre-award meeting is held to review and adopt the tender evaluation report. Prior to the meeting, a formal commitment of the required funds must be done in the form of 'Funds Availability Attestation'.

Before concluding, it is worthy to add that three following practices were revealed by the study: Pre-Tender meeting applied in Papyrus, Risk analysis at pre-award phase by Construction Industry Development Board (CIDB) [28] in

South Africa, and Pre-Contract Audit by Government of Jamaica. Actually, the practice of Pre-tender meeting, suggested by Papyrus, prior the preparation of bids is relevant because it helps bidders understand the project objectives and client expectations. Risk analysis prior to the award of contract, as proposed by CIDB [28], is also a best practice for its implementation can mitigate some risks associated. Furthermore, the Pre-Contract Audit is very popular in Jamaica as well as in USA where its implementation saves up to 10% of the bid amount.

2. Conclusions

The study has fully defined the concept of Competitive Tendering Process and a typical process is divided into five following main phases: Tender planning, Tender documentation, Tender solicitation, Tender evaluation and Tender pre-award. Briefly, the study identified the following practices as common standard practices that can lead to an effective CTP: Develop a realistic procurement plan including an accurate budget, get the required approvals, publish it, appoint a suitable project design team, obtain a complete project design, and select an appropriate tendering option; secure project design quality, use standard documents, and review and approve tender documents before publication; wide and long advertisement of tender proposals, proper handling of requests for clarification, and publicly opening session; appoint a suitable evaluation panel team, use of points scoring system, drafting the report on time using standard format, and include a clear recommendation for the award; review and adoption of tenders evaluation report, publication of tender results, resolution of eventual complaints / disputes before final award.

It is often recommended to hold a pre-award meeting for adopting the evaluation report before the publication of the results. Lastly, giving a right to tenderers to challenge the procedures seems be a good practice that enhance equity and fairness.

Lastly, as a matter of fact, by reducing the CTP at only 20 key activities, the study has the merit of shortening the process. Not only that, when these practices are fully implemented as proposed, they would produce undoubtedly the predicted results. These advantages could be savings in time and cost by broadly 20% of total cost incurred as it is USA and Cyprus. However, it is still observed that although CT is the most employed method and the most beneficial to construction industries, yet its implementation remains ineffective due to the lack political will to fully enforce laws and regulations as prescribed. This can be traced to the lack of performance assessment culture in one hand and the resistance to changes in the other hand. Therefore, the study recommends a change of mind to use the standard practices in order to improve the effectiveness.

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Shear Strength of Normal and Light Weight Reinforced Concrete Slender Beams without Web Reinforcement

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ABSTRACT

There is no general consensus or accepted theory for evaluating the ultimate shear capacity of reinforced concrete beams without web reinforcement as a result the requirements in most of Codes of practice are provided in the form of empirical equations for predicting the shear capacity of reinforced concrete beams. In this paper, a study is conducted to evaluate the predictive accuracy of 6 empirical equations used in different Code of practice to predict the shear capacity of reinforced concrete slender beams. Empirical equations used in some Codes are identified to be superior to other equations. In addition, a study was also conducted to assess predictive accuracy of 17 empirical equations proposed in the literature by several researchers to predict the shear capacity of reinforced concrete slender beams. Among these 17 empirical equations some equations are identified to be superior to the other proposed equations. On the basis of experimental results of reinforced concrete beams having shear span to depth ratio a/d ≥2.5, empirical equations are proposed which include basic parameters i.e. concrete compressive strength, shear span to depth ratio and ratio of longitudinal reinforcement. The coefficient of correlation (COR) for proposed empirical equation for predicting the shear capacity of reinforced concrete beams having depth d < 300mm and d ≥ 300mm without web reinforcement comes out to be 0.869 and 0.953 respectively.

Keywords Empirical Equations, Shear Strength, Slender Beams, Concrete Compressive Strength

1.INTRODUCTION

Extensive research over the years on the combined effects of flexure and shear on the resistance capacity of the structure has not yielded a generalized theory of combined flexure shear for computing the resistance capacity of reinforced concrete members [1], [2]. As a result, the design for shear is uncoupled with respect to the flexural design.

Most of the code of practices uses empirical equations to estimate the shear capacity of reinforced concrete beams. In addition to the equations in the Codes, there are number of empirical equations proposed in the literature by different researchers. Empirical equations developed from experimental results for calculating Vc involves different influencing parameters based on the variable considered in the experimental program by the researcher. Each researcher has selected different influencing parameters as there is no general consensus or accepted theory for evaluating the ultimate shear capacity of reinforced concrete beams without web reinforcement.

In this paper, Design equations used in six (6) Design Codes of practice were evaluated using the experimental data contained in ACCESS shear database [3].Predictive accuracy of 17empirical equations proposed in the literature for predicting the shear capacity of reinforced concrete slender beams a/d> 2.5, were studied using the experimental data contained in ACCESS shear database [3]. On the basis of results, for slender reinforced concrete beams, empirical equations used in some Codes are identified to be superior to others. Among the proposed empirical equations in the literature, equations that use the use (f'c)⅓ function and include depth factor are found to be superior to others.

On the basis of experimental results of reinforced concrete beams [3] having shear span to depth ratio a/d≥ 2.5, empirical equations are proposed which include basic parameters i.e. concrete compressive strength f'c, shear span to depth ratio a/d and ratio of longitudinal reinforcement ρ. The coefficient of correlation (COR) for proposed empirical equation for predicting the shear capacity of reinforced concrete beams having depth d < 300mm and d ≥ 300mm without web reinforcement comes out to be 0.869 and 0.953 respectively.

2. Evaluation of Design Equations

Equations 1 to 6 shows empirical equations in different Codes of practice along with their limits of applicability used to predict the shear capacity of reinforced concrete slender beams. For the study of predictive accuracy of the Code equations, experimental data for slender beams from the shear database [3] was used.

It can be seen that to reflect the effect of concrete compressive strength f'c on the shear capacity of reinforced concrete beams, ACI Code [4] Eq. 1, Canadian Code [5] Eq.2 and New Zealand Code [6] Eq. 3 use function (f'c)½, whereas the Euro code EC2 [7] Eq.4 , Espanish Code EHE-99 [8] Eq. 5 and CEB-FIP Model Code [9] Eq.6 use function (f'c)⅓. The influence of size effect on the shear capacity is not included in the equations of ACI Code [4] Eq. 1, and New Zealand Code [6] Eq. 3, whereas the equations of the other Codes have terms that accommodate the influence of size effect.

$$\vartheta_{cr} = 0.16\sqrt{f'_c} + 17.2\rho\frac{Vd}{M} \qquad \text{for a/d} \geq 2.5 \qquad (1)$$

$$\vartheta_{cr} = 0.2\sqrt{f'_c} \qquad \text{for d} \leq 300\text{mm} \qquad (2)$$

$$\vartheta_{cr} = \left(\frac{260}{1000+d}\right)\sqrt{f'_c} \geq 0.1\sqrt{f'_c} \qquad \text{for d>300mm}$$

$$\vartheta_{cr} = (0.07 + 10\rho)\sqrt{f'_c} \qquad \text{for a/d >2.0} \qquad (3)$$

$$\vartheta_c = \frac{0.18}{\gamma_c}K(100\rho_l f_{ck})^{1/3} + 0.15\sigma_{cp} \qquad (4)$$

$$\vartheta_c \min = 0.035k^{3/2} f_{ck}^{\ 1/2}$$

where

$f_{ck} \leq 100\ MPa$

$$k = 1 + \sqrt{\frac{200}{d}} \leq 2,$$

where d is in mm

$$\rho_l = \frac{A_s}{b_w d} \leq 0.02$$

$$\vartheta_c = 0.12\xi(\rho_s f_{ck})^{1/3} - 0.15\sigma_{cd} \quad (5)$$

where

$$\xi = 1 + \sqrt{\frac{200}{d}}$$

$$\vartheta_c = 0.12\left(1 + \sqrt{\frac{200}{d}}\right)\left(\frac{3d}{a_s}\right)^{1/3}(\rho_s f_{ck})^{1/3} - 0.15\sigma_{cd} \quad (6)$$

where

N_d = Factored Axial Force

Ac = Area of concrete

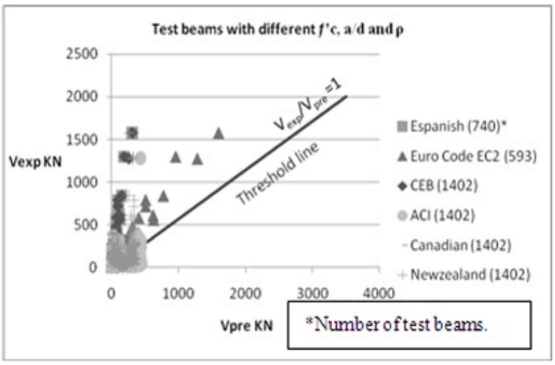

Figure1. Comparison of prediction of Code equations with experimental results.

Fig. 1 shows the plot of the experimental (measured) ultimate shear force (Vexp) and predicted ultimate shear force (Vpre), for all the 6 code equations, along with the threshold line (Vexp/Vpre = 1). It can be seen from Fig. 1, the (Vexp/ Vpre) of CEB-FIP Model Code [9] Eq. 6 and Espanish EHE-99 Code [8] Eq. 5 are much greater than 1, which shows that these two codes significantly underestimate the shear capacity of reinforced concrete slender beams, as compared to ACI Code [4] Eq. 1, Euro Code EC2 [7] Eq. 4, New Zealand Code [6] Eq. 3 and Canadian Code [5] Eq. 2.

Table 1. Summary of results for the Average Margin of Safety (Vexp/Vpre)avg of empirical equations used in different Codes for predicting the shear capacity of normal strength and high strength reinforced concrete slender beams.

Code	No. of Beams used for Evaluation	*Average Margin of Safety (Vexp/Vpre)avg
CEB-FIP Model	1402	7.214
Espanish EHE-99	740	6.539
ACI	1402	1.314
Eurocode EC2	593	1.273
NewZealand Code	1402	1.207
Canadian Code	1402	1.209

Table 1 shows the summary of results in terms of the comparison of the average Margin of Safety (Vexp/Vpre)avg of design equations used in different Codes of practice for predicting the shear capacity of reinforced concrete slender beams. The number of beams, whose data was used, varies for each case, because of the relative constraints or the limits in the respective empirical equations of the Codes. From Table 1 it can be seen that the average Margin of Safety (Vexp/Vpre)avg for CEB-FIP Model Code [9]Eq. 6 and Espanish EHE-99 Code [8] Eq. 5 is 7.214 and 6.539 respectively which is much higher than (Vexp/Vpre)avg values, when using the ACI Code [4] Eq. 1, Euro Code EC2 [7] Eq. 4, New Zealand Code [6] Eq. 3 and Canadian Code [5] Eq. 2.which are 1.325, 1.273, 1.207 and 1.209 respectively. Thus the CEB-FIP Model Code [9] Eq. 6 and Espanish EHE-99 Code [8] Eq. 5 estimations are significantly more conservative (order of 6 or higher) as compared to other codes and are not considered in the further evaluation.

2.1. Effect of Influencing Factors

Two major factors are studied, the concrete compressive strength and the size effect. Table 2 shows the summary of results showing the Average Margin of Safety (Vexp/Vpre)avg with coefficient of correlation (COR) for Normal Strength Concrete (NSC) having $f'c < 40$MPa and High Strength Concrete (HSC) having $f'c \geq 40$MPa reinforced slender beams. It can be seen from Table 2 that in case of NSC beams, COR for Euro code EC2 Code [7] Eq. 4 is 0.974, which is higher as compared to New Zealand Code [6] Eq. 3 , Canadian Code [5] Eq. 2 and ACI Code [4] Eq. 1, which are 0.855, 0.932 and 0.899 respectively.

In case of HSC beams, COR for Euro code EC2 [7] Eq. 4 is 0.974 which is higher as compared to New Zealand Code [6] Eq. 3 , Canadian Code [5] Eq. 2 and ACI Code [4] Eq. 1 which are 0.882, 0.932 and 0.90 respectively. It should be noted that Euro code EC2 [7] Eq. 4 equation uses cubic root function $(f'c)^{1/3}$ rather than the square root function $(f'c)^{1/2}$ used by ACI Code [4] Eq. 1, Canadian Code [5] Eq. 2 and Newzealand Code [6] Eq. 3 to reflect the effect of the concrete compressive strength $f'c$ on the shear capacity of reinforced concrete beams. This implies that $(f'c)^{1/2}$ function used in the ACI Code [4] Eq. 1, Canadian Code [5] Eq. 2 and Newzealand Code [6] may not be adequate to reflect the effect of the $f'c$ on the shear capacity of high strength reinforced concrete beams.

Table 2. Summary of results showing the Average Margin of Safety with coefficient of correlation for NSC and HSC reinforced slender beams.

Code	Strength of Concrete			
	No. of Beams used for evaluation	NSC / HSC	Average Margin of Safety	COR
Eurocode EC2	593	370	1.60	0.974
		223	1.14	0.974
New Zealand Code	1402	951	1.25	0.855
		451	1.12	0.882
Canadian Code	1402	951	1.28	0.932
		451	1.04	0.932
ACI Code	1402	951	1.38	0.899
		451	1.16	0.907

Table 3 shows the summary of results showing the Average Margin of Safety (Vexp/Vpre)avg with COR for NSC and HSC reinforced slender beams including the size effect. It can be also seen from Table 3 that in case of beams with effective depth d < 300mm the COR for Euro code Ec2 (2002) Code [7] Eq. 4 is 0.985, which is higher as compared to Canadian Code [5] Eq. 2 (1994), ACI Code [4] Eq. 1 (2008) and New Zealand Code [6] Eq. 3 (1995) which are 0.932, 0.90 and 0.674 respectively. In case of beams with effective depth d ≥ 300mm the COR or Euro code EC2 [7] Eq. 4 is 0.975, which is higher as compared to Canadian Code [5] Eq. 2 , ACI Code [4] Eq. 1 and New Zealand Code [6] Eq. 3 which are 0.938, 0.90 and0.899 respectively. It should be noted that the Euro code EC2 [7] Eq. 4 and Canadian code [5] Eq. 2 equations that are identified to have higher values of coefficient of correlation COR use depth factor in their respective expressions, whereas ACI Code [4] Eq. 1 and New Zealand Code [6] Eq. 3 equations do not use depth factor in their relative expressions. Although the COR of Euro code EC2 Code [7] Eq. 4 is higher, however the applicability over the number of beams is limited, due to constraints or the limits in the empirical equation as compared New Zealand Code [6] Eq. 3, Canadian Code [5] Eq. 2 and ACI Code [4] Eq. 1 for which a larger number of test beams were used to assess the predictive accuracy.

3. Evaluation of Empirical Equations Proposed in the Literature

Number of empirical equations has been proposed in the literature for predicting the shear capacity of NSC and HSC beams without web reinforcement. Equations 7 to 23 shows empirical equations

7 to 23 shows empirical equations proposed by Karim et al [11] Eq. 7, Daejoong Kim et al [13] Eq. 8, K.N.Smith [19] Eq. 9 and Eq.10 , ASCE-ACI – Committee 426 [1] Eq.11, Crist [21] Eq. 12, Daiz De Cossio et al [22] Eq. 13, Jin-Keun Kim et al [14] Eq. 14, Eq. 15 and Eq. 16, Shuaib et al [17] Eq. 18, Zsutty's [20] Eq. 18 ,Mphonde et al [18] Eq. 19 ,Gastebled et al [10] Eq. 20, Kaiss et al [15] Eq.21 , S. Sarkar et al [12] Eq. 22 and Okamura [16] Eq. 23 , along with their limits of applicability.

Table 3. Summary of results showing the Average Margin of Safety with coefficient of correlation for NSC and HSC reinforced slender beams including the size effect.

Code	Size Effect			
	No. of Beams used for evaluation	d<300mm / d≥300mm	Average Margin of Safety	COR
Eurocode EC2	593	292	1.35	0.985
		301	1.20	0.975
New Zealand Code	1402	1046	1.19	0.674
		356	1.23	0.899
Canadian Code	1402	1046	1.31	0.932
		356	0.90	0.938
ACI Code	1402	1046	1.44	0.884
		356	0.92	0.916

It can be seen that effect of $f'c$ on the shear capacity of reinforced concrete beams is accommodated through use of $(f'c)^{1/2}$ function in the equations proposed by Karim et al [11] Eq. 7, Daejoong Kim et al [13] Eq. 8, K.N.Smith [19] Eq. 9 and Eq.10 , ASCE-ACI – Committee 426 [1] Eq.11, Crist [21] Eq. 12 and Daiz De Cossio et al [22] Eq. 13, through use of $(f'c)^{1/3}$ function in the equations proposed by Jin-Keun Kim et al [14] Eq. 14, Eq. 15 and Eq. 16, Shuaib et al [17] Eq. 18, Zsutty's [20] Eq. 18 and Mphonde et al [18] Eq. 19 and through the use of $f'c0.35$, $f'c0.38$, $f'c0.55$ and $f'c$ functions in the equations proposed by Gastebled et al [10] Eq. 20, Kaiss et al [15] Eq.21 , S. Sarkar et al [12] Eq. 22 and Okamura [16] Eq. 23 respectively. It can be seen that that the issue of size effect is addressed only in equations proposed by Okamura et al [16] Eq. 23, Shuaib et al [17] Eq. 18, Jin-Kuen-Kim et al [14] Eq. 14, Eq. 15 and Eq. 16 and Gastebled et al [10] Eq. 20.

$$\vartheta_c = 0.4 + \sqrt{f'_c \rho \frac{d}{a}(10 - 3\,A_d)}$$ For $\frac{a}{d} \geq 2.5,\ A_d = 2.5$ (7)

$$\vartheta_u = 0.2\left(1 - \sqrt{\rho}\right)\left(\frac{d}{a}\right)^r \left[\sqrt{f'_c} + 1020\rho^{0.9}\left(\frac{d}{a}\right)^{0.6}\right]$$ Where $r = \left(\frac{d}{a}\right)^{0.6} \rho^{-.01}$ (8)

r= internal moment arm length index

$$\vartheta_{cr} = 2.6\sqrt{f'_c} + 3409\frac{Vd\rho}{M}$$ (9)

$$\vartheta_{cr} = 1.74\sqrt{f'_c} + 4550\frac{Vd\rho}{M}$$ (10)

$$\vartheta_c = (0.8 + 100\rho)\frac{\sqrt{f'_c}}{12}$$ $\leq 0.179\sqrt{f'_c}\mathrm{MPa}$ (11)

$$\vartheta_{cr} = 2.27\sqrt{f'_c} + 2905\frac{Vd\rho}{M}$$ (12)

$$\vartheta_{cr} = 2.14\sqrt{f'_c} + 4600\frac{Vd\rho}{M}$$ (13)

$$\vartheta_u = 15.5 f'_c{}^{\propto/3}\rho^{3/8}\left(0.4 + \frac{d}{a}\right)\left(\frac{1}{\sqrt{d}} + 0.07\right)$$ For d $\geq 250\,mm\ (9.84\,in)$ (14)

For $\frac{a}{d} \geq 3, \propto = 1$

$$\vartheta_u = 3.5\, f'_c{}^{1/3}\rho^{3/8}\left(0.4 + \frac{d}{a}\right)\lambda(d)$$ $\frac{a}{d} \geq 3$ (15)

Where, $\lambda(d) = \frac{1}{\sqrt{1+0.008d}} + 0.18$

$$\vartheta_u = 19.4\, f'_c{}^{\propto/3}\rho^{3/8}\left(0.4 + \frac{d}{a}\right)\left(\frac{1}{\sqrt{d}} + 0.07\right)$$ For d $\geq 250\,mm\ (9.84\,in)$ (16)

For $\frac{a}{d} \geq 3, \propto = 1$

$$\vartheta_u = \eta\left[1.8\left(f'_c \rho \frac{d}{a}\right)^{0.333}\right]$$ For $3 \leq \frac{a}{d} \leq 6$, (17)

$$\eta = 1 - 0.00265\left[\frac{(d - 135.9)^{0.85}}{\left(\frac{a}{d}\right)^{0.63}}\right]$$

For $\frac{a}{d} \leq 3$

$$\eta = 1 - 0.03985\left[\frac{(d-135.9)^{0.8}}{\left(\frac{a}{d}\right)^{2.84}}\right]$$

$$\vartheta_u = 2.3(f'_c\rho\frac{d}{a})^{0.333} \qquad \frac{a}{d} \geq 2.5 \qquad (18)$$

$$\vartheta_u = 0.366\sqrt[3]{f'_c} + 0.49 \qquad \frac{a}{d} = 3.5 \qquad (19)$$

$$\vartheta_c = 0.15\left(\frac{37.41}{\sqrt{d}}\right)\left(\frac{3d}{a_s}\right)^{1/3}(100\rho_s)^{1/6}(1-\sqrt{\rho_s})^{2/3}f'^{\,0.35}_c \qquad (20)$$

$$\vartheta_{cr} = 1.8\left(f'_c\rho\frac{V_u d}{M_u}\right)^{0.38} \qquad \text{For } \frac{a}{d} \geq 2 \qquad (21)$$

$$\vartheta_n = 3.05\left(f'_c\rho\frac{d}{a}\right)^{0.55} \qquad For\,\frac{a}{d} > 2,\; 40 < f'_c < 110\text{ MPa} \qquad (22)$$

$$\vartheta_c = 0.20\frac{\rho^{1/3}}{d^{1/4}}f'_c\left[0.75 + \frac{1.40}{a/d}\right] \qquad (23)$$

Table 4. Summary of results for the Average Margin of Safety of empirical equations proposed in literature for predicting the shear capacity of concrete in normal and high beams.

Authors of the proposed empirical equations, published in the literature	No. of Beams used for Evaluation	** Average Margin of Safety $(\mathbf{V_{exp}/V_{pre}})_{avg}$
Okamura et al	1402	2.677
Shuaib H et al	1401	1.470
Kaiss F. Sarsam et al	1402	1.460
K.N.Smith et al (B)	1402	1.317
Jin-Keun Kim et al (A)	897	1.306
Gastebled et al	1402	1.194
S. Sarkar et al	1402	1.180
Crist	1402	1.117
Daizet al	1402	1.107
Jin-Keun Kim et al(C)	897	1.106
Zsutty	1402	1.050
Jin-Keun Kim et al(B)	897	1.044
ASCE-ACI Committee 426	1402	1.004
K.N.Smith et al (A)	1402	0.973
Karim et al	1402	0.921
Daejoong Kim et al	1402	0.746
Mphonde et al	19	0.696

** listed in the order of descending order of Average Margin of Safety

Table 4 shows the summary of results in terms of the comparison of the average Margin of Safety's(Vexp/Vpre)avg of different proposed equations for predicting the shear capacity of reinforced concrete slender beams (a/d> 2.5). From Table 4, it can be seen that the average Margin of Safety's (Vexp/Vpre)avg for the empirical equation proposed by Mphonde et al [18] Eq. 19 is 0.67 which is the least among all the empirical equations, with its applicability on only 19 test beams due to its limits. It can be also seen from Table 4 that although the empirical equations proposed by Jin-Keun Kim et al [14] Eq. 14, Eq. 15 and Eq. 16, have relatively low values of the average Margin of Safety's (Vexp/Vpre)avg as compared to other proposed empirical equations but its applicability is limited to only 897 test beams as compared to 1402 test beams used for other proposed empirical equations. Therefore in the further evaluation, the empirical equations proposed by Mphonde et al [18] and Jin-Keun Kim et al [14] are not considered.

Table 5 shows the summary of results for the Average Margin of Safety (Vexp/Vpre)avg and the size effect with respective Coefficient of correlation (COR), using the empirical equations of empirical equations proposed in literature for both normal strength concrete (NSC) and high strength reinforced concrete (NSC) slender beams.In case of NSC reinforced slender beams,, the equations proposed by Gastebled et al [10] Eq. 20, Shuaib et al [17] Eq. 18 and Kaiss et al [15] Eq.21, have higher values of coefficient of correlation (COR) which are 0.959,and 0.938 respectively as compared to other proposed equations (Table 5). In case of HSC reinforced concrete slender beams, the empirical equations proposed by Shuaib et al [17] Eq. 18, Gastebled et al [10] Eq. 20 and Daejoong Kim et al [13] Eq. 8 have higher values of coefficient of correlation (COR) which are 0.967, 0.950 and 0.948 respectively as compared to other proposed equations (Table 5).

Table 5. Summary of results for the Average Margin of Safety and the size effect with respective Coefficient of correlation (COR), using the empirical equations of empirical equations proposed in literature for both normal and high strength reinforced concrete slender beams.

Author	Strength of concrete			
	No. of Beams used for Evaluation	(NSC) / (HSC)	Average Margin of Safety	COR
Gastebled , May	1402	951	1.24	0.959
		451	1.08	0.950
Shuaib et al	1401	950	1.51	0.938
		451	1.37	0.967
Kaiss et al	1402	951	1.52	0.938
		451	1.33	0.942
Daejoong Kim et al	1402	951	0.74	0.936
		451	0.76	0.948
Sarkar et al	1402	951	1.27	0.947
		451	0.97	0.938
Zsutty's	1402	951	1.08	0.933
		451	0.98	0.941
ASCE-ACI -426	1402	951	1.05	0.930
		451	0.9	0.929
Karim et al	1402	951	0.96	0.930
		451	0.85	0.943
K.N.Smith et al(B)	1402	951	1.38	0.906
		451	1.18	0.913
K.N.Smith et al(A)	1402	951	1.025	0.899
		451	0.86	0.907
Crist	1402	951	1.17	0.899
		451	0.98	0.907
Daiz De Cossio, Seiss	1402	951	1.16	0.904
		451	0.99	0.911
Okamura et al	1402	951	3.15	0.966
		451	1.68	0.919

In Table 5, generally the equations which uses cubic power or power lesser than square root on $f'c$ to reflect the effect of the concrete compressive strength $f'c$ on the shear capacity of reinforced concrete slender beams have higher values of COR as compared to the equations which use power equal to or higher than square on $f'c$ to reflect the effect of the concrete compressive strength $f'c$ on the shear capacity of reinforced concrete beams. Exception in the proposed equation of Daejoong Kim et al [13] Eq. 8 which uses square power on $f'c$ and has a COR value of 0.948.

Table 6 also shows the summary of results Average Margin of Safety (Vexp/Vpre)avg with respective COR's for reinforced concrete slender beams with effective depth d < 300mm and with effective depth d ≥ 300mm. For reinforced concrete slender beams with effective depth d < 300mm, empirical equations proposed by Zsutty's [20] Eq. 18, Kaiss et al [15] Eq.21, Karim et al [11] Eq. 7 and Shuaib et al [17] Eq. 18 have higher values of COR's, which are 0.901, 0.896 and 0.896 respectively as compared to other proposed equations (Table 6).

For 355 reinforced concrete slender beams with an effective depth d ≥ 300mm, empirical equation proposed by Shuaib et al (1986) and Gastebled et al have the higher values of COR's, which are 0.967 and 0.965 respectively as compared to other proposed equations (Table 6). It is important to note that empirical equations proposed by Shuaib et al [17] Eq. 18 and Gastebled et al [10] Eq. 20 use the size effect and depth factor variable in their expressions to reflect the shear capacity of reinforced concrete slender beams.

Table 6. Summary of results for the Average Margin of Safety and the size effect with respective Coefficient of correlation (COR), using the empirical equations of empirical equations proposed in literature for both normal and high strength reinforced concrete slender beams.

Author	Size Effect			
	No. of Beams used for Evaluation	d<300mm / d≥300mm	Average Margin of Safety $\left(\frac{v_{exp}}{v_{pre}}\right)$	COR
Gastebled , May	1402	1046	1.21	0.869
		356	1.15	0.965
Shuaib et al	1401	1046	1.51	0.896
		355	1.35	0.967
Kaiss et al	1402	1046	1.55	0.896
		356	1.17	0.948
Daejoong Kim et al	1402	1046	0.77	0.868
		356	0.65	0.949
Sarkar et al	1402	1046	1.24	0.857
		356	0.98	0.948
Zsutty's	1402	1046	1.12	0.901
		356	0.84	0.863
ASCE-ACI -426	1402	1046	1.03	0.760
		356	0.91	0.951
Karim et al	1402	1046	0.98	0.896
		356	0.74	0.947
K.N.Smith et al(B)	1402	1046	1.43	0.892
		356	0.95	0.922
K.N.Smith et al(A)	1402	1046	1.07	0.884
		356	0.68	0.916
Crist	1402	1046	1.23	0.884
		356	0.78	0.916
Daiz De Cossio, Seiss	1402	1046	1.21	0.890
		356	0.79	0.890
Okamura et al	1402	1046	2.83	0.790
		356	2.22	0.879

4. Proposed Empirical Equation

On the basis of shear data base of the experimental test results [3], an empirical equation is developed for predicting the shear capacity of reinforced concrete beams having shear span to depth ratio a/d≥ 2.5.

For d < 300 mm and $\frac{a}{d} \geq 2.5$

$$\vartheta = 0.35 \left(\frac{a}{d}\, f'c\right)^{0.33} \rho^{0.1} \tag{24}$$

For d ≥ 300 mm and a/d ≥2.5

$$\vartheta = \xi\, 0.35 \left(\frac{a}{d}\, f'c\right)^{0.33} \rho^{0.1} \tag{25}$$

where

$$\xi = \frac{17.32}{\sqrt{d}}$$

The proposed empirical equations (Eq. 24 and Eq. 25), contains basic parameters i.e. concrete compressive strength $f'c$, shear span to depth ratio a/d and ratio of longitudinal reinforcement ρ. In addition to these basic parameters, proposed equation also uses depth factor ξ to account the effect of size effect on the shear capacity of reinforced concrete beams without web reinforcement. In order to assess the predictive accuracy of proposed empirical equations (Eq. 24 and Eq. 25), test results of 1085 reinforced concrete beams without web reinforcement from ACCESS shear database (Rafeeqi et al 2011) were used. The COR for Eq. 24 comes out to be 0.869. For the predictive accuracy of Eq. 25 test results of 393 reinforced concrete beams without web reinforcement from ACCESS shear database [3] were used. The COR for Eq. 25 comes out to be 0.953. Although the COR of the proposed empirical equation is less as compared to equations of Shuaib et al [17] Eq. 18 and Gastebled et al [10] Eq. 20, the applicability of the proposed equation is over a larger number of beams (393) as opposed to 355 beams for equations proposed by Shuaib et al [17] Eq. 18 and Gastebled et al [10] Eq. 20.

5. Summary and Conclusions

From the evaluation study of design equations used in different codes of practice to predict the shear capacity of reinforced concrete slender beams, the following conclusions can be drawn;

1) The predictions of CEB-FIP Model Code and Espanish EHE-99 are much more conservative as compared to ACI Code, Euro code EC2, New Zealand Code and Canadian Code.

2) For NSC and HSC beams, the predictive accuracy of Euro code EC2, ACI Code, Canadian Code and New Zealand Code is comparable.

3) The $(f'c)^{1/2}$ function used in the ACI Code, Canadian Code and New Zealand Code seems to be inadequate to reflect the effect of the $f'c$ on the shear capacity for higher strength concrete.

4) The $(f'c)^{1/3}$ function used in Euro code EC2 seems to be better in reflecting the effect of the $f'c$ on the shear capacity.

5) The issue of size effect is addressed in equations of Euro code EC2 and Canadian Code. The equations used by, Euro code EC2 and Canadian Code have higher values of coefficient of correlation (COR) for beams with effective depth $d \geq 300$mm as compared to ACI Code and New Zealand Code equations which do not have a depth factor in their respective expressions.

From the evaluation study of proposed empirical equations published in the literature following conclusions can be drawn;

1) the shear capacity of reinforced concrete slender beams, considering all beams (NSC as well as HSC beams) with $d < 300$ mm as well as with $d < 300$ mm, overall the empirical equation proposed by Shuaib et al provides the highest COR and thus is considered to be the superior to the other equations.

2) An empirical equation is developed that is applicable to test data of 393 beams. For beams with effective depth $d < 300$ mm, the COR for the proposed equation is 0.869 and for beams having effective

depth d < 300 mm, the COR for the proposed equation is 0.869 and for beams having effective depth d ≥ 300 mm, the COR for the proposed equation is 0.953.

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