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ISSN 1934-7359 (Print)
ISSN 1934-7367 (Online)
DOI:10.17265/1934-7359

Journal of Civil Engineering and Architecture

Volume 11, Number 7, July 2017

David Publishing Company
www.davidpublisher.com

Journal of Civil Engineering and Architecture

Volume 11, Number 7, July 2017 (Serial Number 116)

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www.davidpublisher.com

Publication Information:

Journal of Civil Engineering and Architecture is published monthly in hard copy (ISSN 1934-7359) and online (ISSN 1934-7367) by David Publishing Company located at 616 Corporate Way, Suite 2-4876, Valley Cottage, NY 10989, USA.

Aims and Scope:

Journal of Civil Engineering and Architecture, a monthly professional academic journal, covers all sorts of researches on structural engineering, geotechnical engineering, underground engineering, engineering management, etc. as well as other issues.

Manuscripts can be submitted via Web Submission, or e-mailed to civil@davidpublishing.com or civil@davidpublishing.org. Submission guidelines and Web Submission System are available at http://www.davidpublisher.com.

Editorial Office:

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Abstracted/Indexed in:

Cambridge Science Abstracts (CSA)
Ulrich's Periodicals Directory
Chinese Database of CEPS, Airiti Inc. & OCLC
Summon Serials Solutions, USA
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Subscription Information:

$720/year (print)

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Journal of Civil Engineering and Architecture 11 (2017) 617-634
doi: 10.17265/1934-7359/2017.07.001

Optimization Design of Open Space Based on Microclimate and Behavior in China

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Abstract: Traditionally, microclimate, behavior and space design are characterized by a separation among climatologists, behavior researchers and designers. It is also unrealizable to apply the research results to the space design because of the gap created by the interdisciplinarity. In addition, although the relationships among space form, urban microclimate and people are intuitively understood, there are still not reasonable predictions on how a space affects the microclimate, and how the microclimate and space will affect people's sensation and behavior. By recording the microclimate and people's responses, this paper discusses the relationship between people's sensation and microclimate as well as people's behavior and open space in a busy downtown pedestrian street during hot summer. The research finds that shade plays a crucial role in outdoor comfort. All of the other objectively comfortable and acceptable microclimates differ significantly different shade situation. Simultaneously, space contradiction can be considered an essential factor for spatial utilization. This paper also provides proposal on canyon open space design based on this case study.

Key words: Activities, outdoor comfort, urban design, street canyon, northern city.

1. Introduction

As the urbanization continues, the urban forms are constantly changing due to city construction, which change the microclimate significantly. Bonan [1], Hart and Sailor [2], and Stone and Norman [3] have discussed the influence of the urban heat island effects on microclimates based on land use, urban density and urban structures. De Schiller and Evans [4], Evans and De Schiller [5] and Eliasson [6], have discussed the significance of the subtle impact of small-scale climate variations on the urban and regional scales. At the same time, a burgeoning number of studies have examined on the relationship between outdoor thermal comfort and outdoor activities from the perspectives of meteorology and behavioristic [7-14]. There have also been some demonstrations of the influence of microclimate on people's sensation from the view point of architectural design and landscape design [15-17]. Without addressing the microclimate, many studies have been conducted regarding different aspects of public open space and behavior [18-24]. Givoni [25] has discussed the relationships among building, design and the climate and introduced the design principles for different climate regions including the cold region. There are not so many details which were offered for outdoor thermal comfort and design.

Open spaces that accommodate the daily social activities of both pedestrians and stationary people play an important role in cities. The goals of open space design are gradually evolving toward attracting more people to stay outside door and enhancing the spatial utilization [26-29]. Street canyons can be considered one of the main types of urban open space. The term "street canyon" refers to narrow street with buildings running continuously along both sides [30]. The urban canyon is an important and basic part of urban climatology and urban design [31-33]. The urban canyon can be classified into three types based on the aspect ratio (W/H means width/height): regular canyon

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(an aspect ratio of approximately 1), avenue canyon (aspect ratio < 0.5) and deep canyon (an aspect ratio of approximately 2) [34]. In most cases, the commercial zones are planned in a central area, densely populated and convenient traffic area. These properties lead to its crucial status in the city. For field surveys, researching the commercial area always has more obvious applications and value [35].

For the open space design, microclimate and people's sensation and behavior in an urban open space have great references. However, research has seldom combined these viewpoints. Erell et al. [36] have discussed design and planning approaches for urban microclimates and presented two case studies at the street scale. From the viewpoint of microclimate, Erell has provided architects and urban designers a new perspective on the interaction between microclimate and each of the elements of urban landscape. However, people's behavior which can be realized as an objective standard of comfortable environment is not mentioned so much.

Using people's sensation and behavior as the standards to evaluate open space, this paper discusses the relationship between people's sensation and microclimate as well as between people's behavior and open space through a case study in a city central area in northern China. This study was discussed as follows:

(1) By analyzing the relationship between the different microclimates and people's sensations in urban canyon space in hot summer, comfortable microclimate levels and their change rules were estimated;

(2) From the viewpoint of microclimate and spatial behavior, the comfortable open space forms were discussed, and then proposals of regional open space optimizationdesign are proposed for the future sustainable urban construction or reconstruction.

2. Methods

2.1 Field Survey

The study case is a typical urban open space located in central area of Shenyang, China (41°48′01.11″ N, 123°27′49.33″ E, ASL (above sea level) = 55 m). This place can be realised as one of the commercial centres with multitudinous visitors every day. In this case, the pedestrian street canyon is between two large scale mixed-used buildings with shopping malls, subway station, super market, hotels and high rise apartments (Fig. 1). The densely-populated area can provide more samples and more accurate reference for the research. In the center of the research area, during the survey time, there was a temporary exhibition zone which leads to a more complicated behavior situation. This study excluded the exhibition zone from the behavior research.

Based on the history daily maximum temperature data from July to September in the period of 2009-2014 from the National Meteorological Information Center in China (Fig. 2) [37], this study selected July 28th to August 9th, 2015 (12 days) as the summer high temperature survey period.

2.2Microclimate and Sensation

As Fig. 3 shows, depending on the space situation, 11 types of spaces were considered. The positions, space styles, aspect ratios and facilities were used to define these spaces. Then, 15 measurement points were chosen according to the space types and the spatial distributions. These 15 points were separated in 3 groups with 5 points in each group. Microclimate data of each point were collected every 15 minutes during the daytime, including: air temperature (T_a), air velocity (V), relative humidity (RH), globe temperature (T_g) and shade situations. Table 1 shows the measurement factors of micrometeorological parameters.

Mean radiant temperature (T_{mrt}) is defined as the "uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in actual non-uniform enclosure" [38]. It is put forward based on the exchange of radiant energy between two objects by emitting and adsorbing heat. In this study, the T_{mrt} is

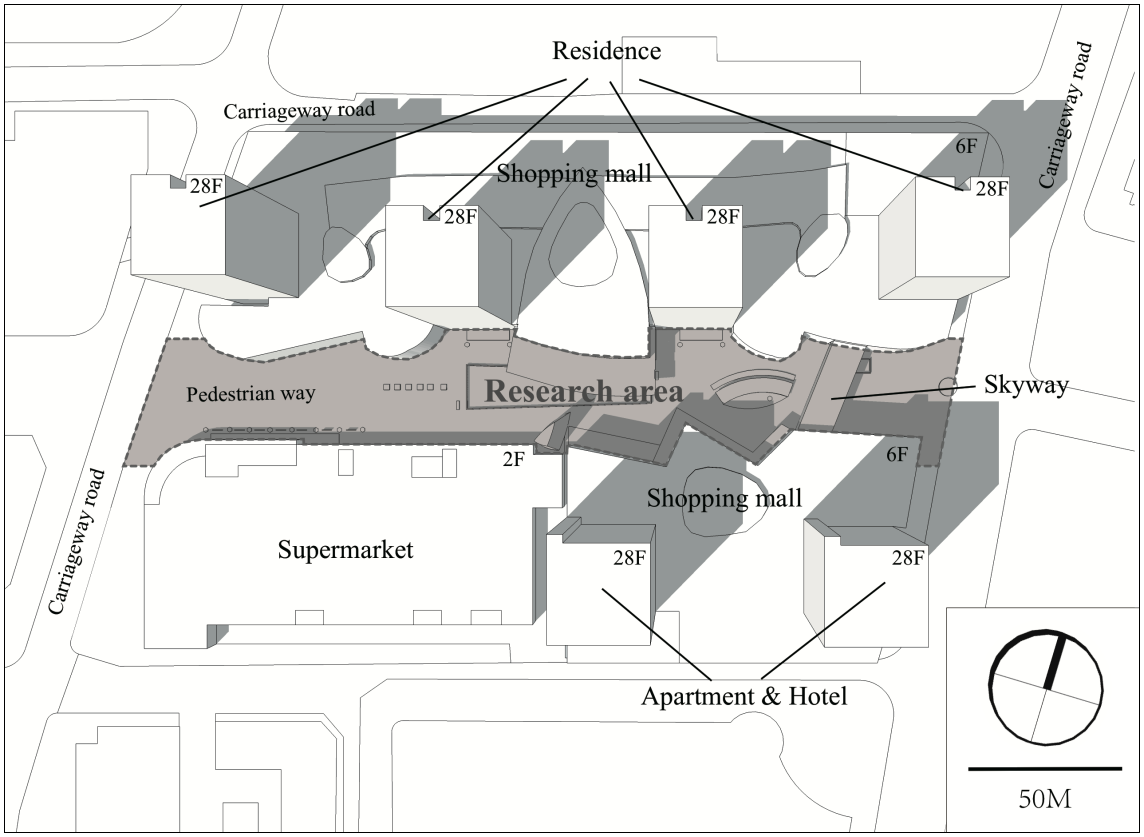


Fig. 1 Research area.

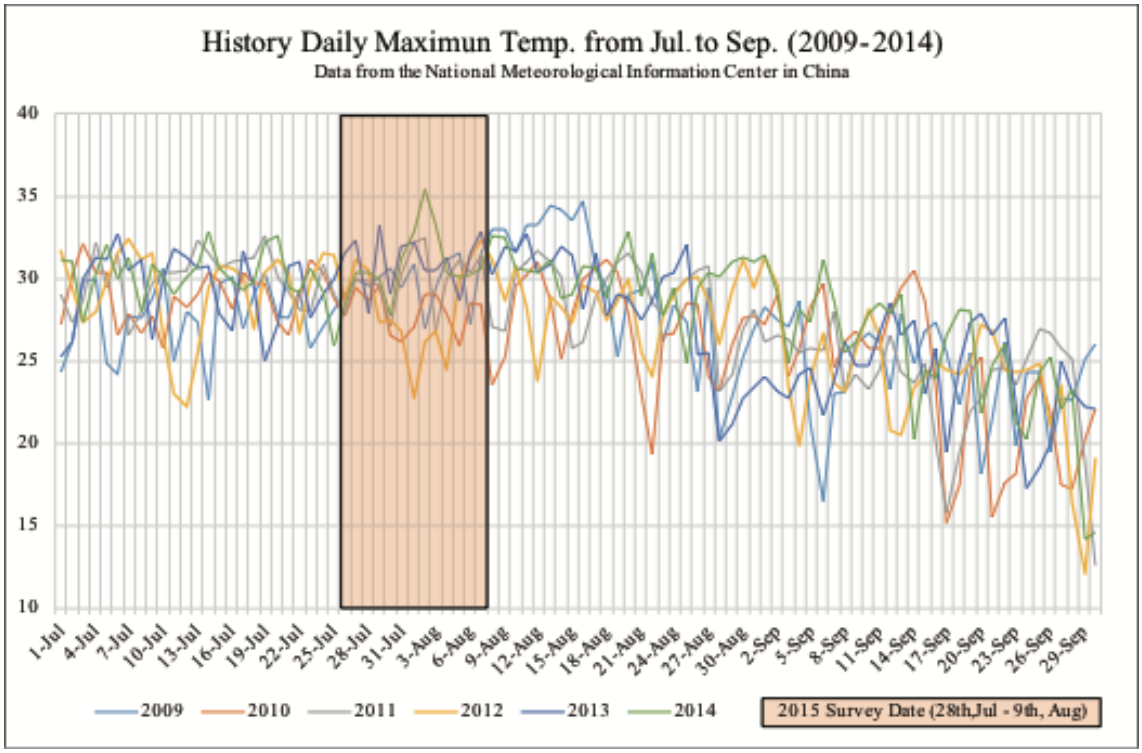


Fig. 2 History of daily maximum air temperature from July to September, 2009-2014.

Note: Weather station No.: 54342 coordinates: 41°44 N, 123°31 E, ASL = 49 m.

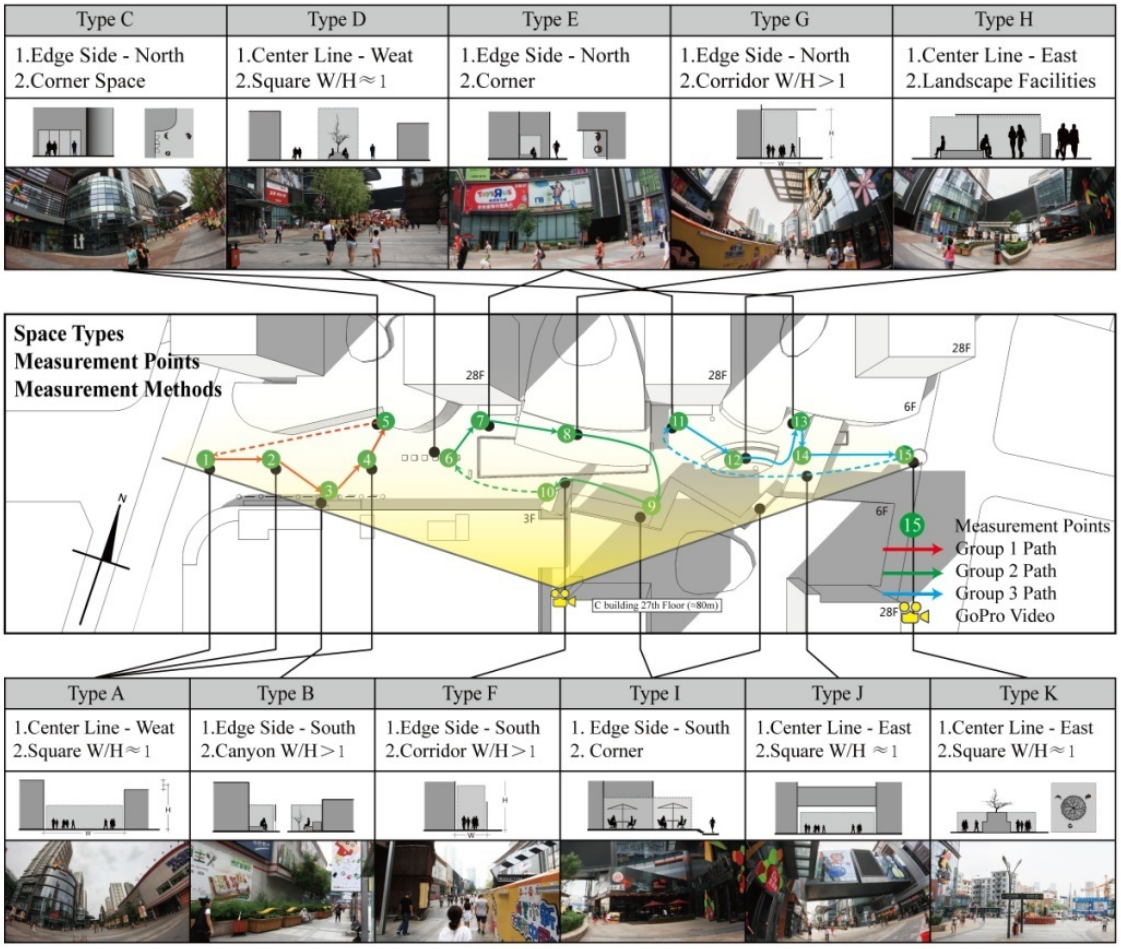


Fig. 3 Space types, position information and measurement methods.

Table 1 Measurement factors of microclimate parameters

Parameter	Accuracy	Resolution	Range	Setting
V	3%	0.1 m/s	0.6 to 40.0 m/s	Measurement Point No. 1 to No. 15, 1.5 m in height
T_a	0.5 °C	0.1 °C	-29.0 to 70.0 °C	
RH	3.0%	0.1%	5% to 95%	
T_g	0.6 °C	0.1 °C	0-80 °C	

estimated by the globe temperature method. Depending on the previous study, there are relatively small differences between the globe temperature methods and other complicated methods [39]. T_{mrt} is calculated based on the following equation [37]:

$$T_{mrt} = \left[\left(T_g + 273\right)^4 + \frac{1.10\times10^8 V^{0.6}}{\varepsilon D^{0.4}}\left(T_g\text{-}T_a\right)\right]^{\frac{1}{4}} - 273 \quad (1)$$

where, T_{mrt} is the mean radiant temperature (°C), T_g is the globe temperature (°C), T_a is air temperature, V is air velocity (m/s), D is globe diameter (m) (in this study D = 0.075 m), ε is emissivity (0.95 for black-colored globe).

Combined with the real-time microclimate data, a 7-point CSV (comfort sensation vote) [40] for the subjective responses of preferred change was used by the subjects to record their comfort levels. According to this scale, -3 is very uncomfortable, 0 is neutral and 3 is very comfortable; any recording higher than -1 is defined as acceptable. For the 15 points, during the survey days, in total, more than 2,400 groups of effective data were recorded. In the high position (27th floor in a high-rise building, approximately 80-m tall),

a Hi-Q video camera was used to record people's behavior during the survey. Panorama images were taken every 30 min at measurement points 1, 3, 10 and 14 simultaneously to record the positions of people.

Depending on the solar incident angle based on the CSWD (Chinese Standard Weather Data) [41] and the Chinese standard for Assessment Parameters of Sunlight on Building (GB/T50947- 2014) [42], this study used software to simulate the shadows in August 1st before sunset as a reference of the general shade situation.

2.3 Open Space and Behavior

This study analyzed the spatial behavior in August 1st and 4th as a comparison of sunny and overcast days. By analyzing the panorama images and the time lapse videos, the spatial behavior was analyzed including position maps and pedestrian routes. In the position maps, the study drew down people's position for every 30 min from 9:30 to 20:00, including the pedestrians and stationaries, and integrated them into one picture and counted the quantity of users, including the pedestrians and stationary people. In the pedestrian routes, the study used the time lapse video to draw down the moving path of the pedestrians with the same quantity (210 pedestrians in each day) during the lunch time (12:00-12:30) which can be realized as the busiest period during one day to analyze the different behaviors between different microclimate situations.

3. Results

3.1 Sensation with Microclimate

Over 2,400 groups of microclimate data and corresponding CSV were collected. The measured temperature range during the survey was 24.4-35.9 °C. The air velocity between 0-7.1 m/s was recorded. The measured relative humidity range was between 36% and 100%. The weather situations, e.g., clear days, overcast days, thunderstorm and partly cloudy days, were included during the survey.

Table 2 shows the correlation analysis between CSV and shade, T_{mrt}, T_a, T_g, V and RH by using the software IBM SPSS Statistics (Version 20.0.0). Bivariate correlation algorithms were used to analyze the correlation [43]. The Pearson correlation is a measure of the linear correlation between the two variables X and Y, giving a value between +1 and −1 inclusive, where 1 is total positive correlation, 0 is no correlation, and -1 is total negative correlation.

As the Pearson correlation shows, all the correlations are significant at the 0.01 level. That is, all the measured microclimate factors will affect the CSV, respectively. Among them, shade has the highest correlation (r = -0.464) with CSV, followed by RH (r = 0.449), T_a (r = -0.421). Consequently, the shade situation was the main factor to affect people's satisfaction of environment.

Measured air temperature and calculated mean radiant temperature (T_{mrt}) on clear and overcast days

Table 2 Correlations between CSV and measured microclimates (n = 2,489).

	CSV	Shade	T_a	V	*RH*	T_g
CSV	1					
Shade	-0.464**	1				
T_a	-0.421**	0.288**	1			
V	0.222**	-0.080**	-0.157**	1		
RH	0.449**	-0.287**	-0.685**	0.165**	1	
T_g	-0.354**	0.312**	0.415**	-0.078**	-0.438**	1

** Correlation is significant at the 0.01 level (2-tailed).

CSV—comfort sensation votes, T_a—air temperature, T_{mrt}—mean temperature radiant, V—air velocity, *RH*—relative humidity, T_g—globe temperature.

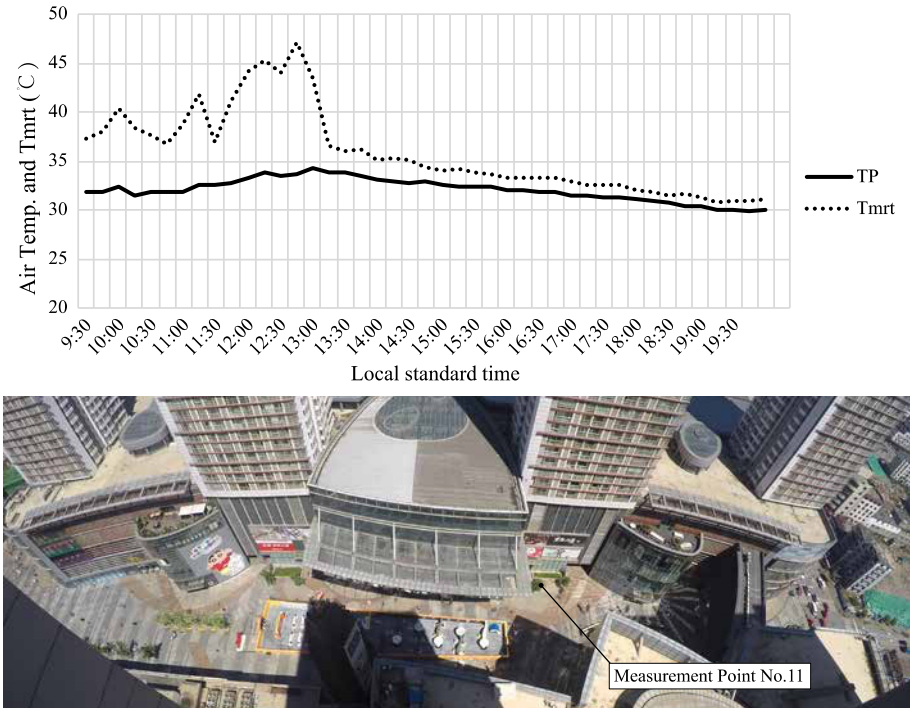


Fig. 4 Measured air temperature and calculated mean radiant temperature on a clear day (August 5th, 2015) and the photograph at 10:30.

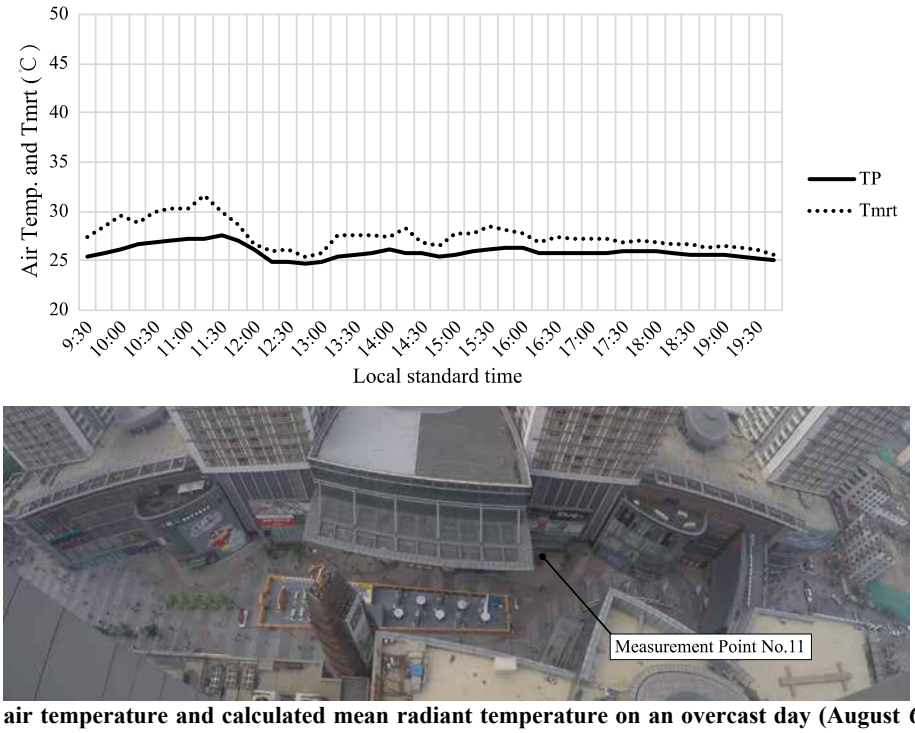


Fig. 5 Measured air temperature and calculated mean radiant temperature on an overcast day (August 6th, 2015) and the photograph at 10:30.

were shown in Figs. 4 and 5. The measurement point for this comparison was set on Point No. 11 where it can get sunlight before afternoon on clear day and change slightly on air velocity during whole day.

The difference of air temperature and mean radiant temperature between clear day and overcast day was

shown. The difference of mean air temperature between two days was 6.13 °C. During the clear day, higher temperature was recorded. The effect of shade on the magnitude of T_{mrt} was also clearly shown. Depending on Figs. 4 and 5, on the clear day, when the measurement point was exposed in sunlight before 13:00, T_{mrt} is significantly higher than the air temperature. When the building shade fell over the measurement point, slightly higher T_{mrt} than air temperature was recorded. The same result was also found in overcast day.

It should note that, however, the results in specific days may be subject to several errors. Nevertheless, combining with the above correlation results, and several previous studies, shade will play an important role on people's comfort [44-47]. It can be considered as higher priority to separate the other factors on analyzingthe outdoor situation.

The general relationships between CSV, and mean microclimate in each period in different shade situations were analyzed. As shown in Fig. 6, the following results were obtained: First, the CSV tendency of "not in the shade" is significantly lower than "in the shade". When subjects are in the shade, they are comfortable with a CSV of 0 to 1 all day. However, when they are out of the shade, all the measured CSV belong to the uncomfortable level. Second, the temperature and humidity indicate the general variation of the CSV. Higher temperature and lower humidity in the noon decrease the CSV. Third, the ruler guides of Nos. 1-8 indicated the extremums of CSV. It can be found that, instantaneous variations of the CSV are related to the wind speed. Higher wind speed made the CSV lower, lower wind speed made the CSV higher.

By using microclimate data and mean CSV (n = 2,520), the detailed relationships between CSV and microclimate in the shade are plotted in Fig. 7. In

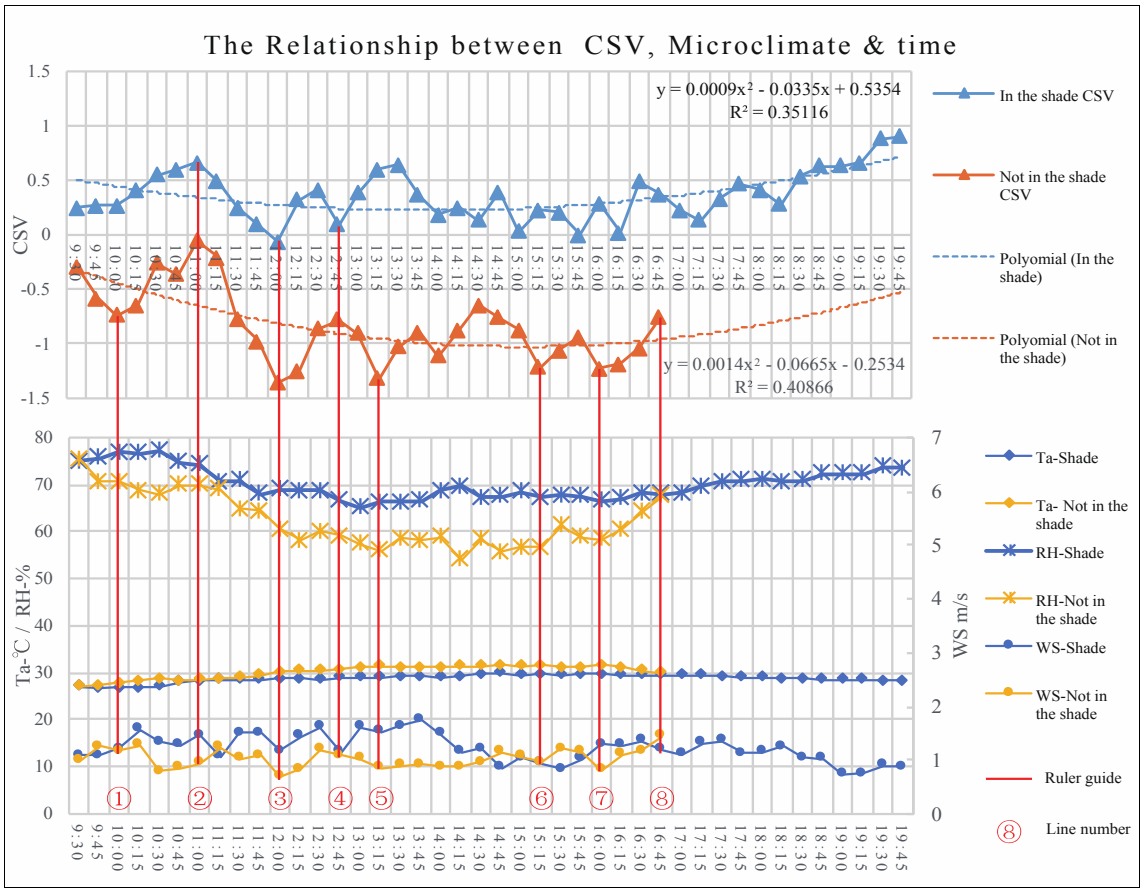
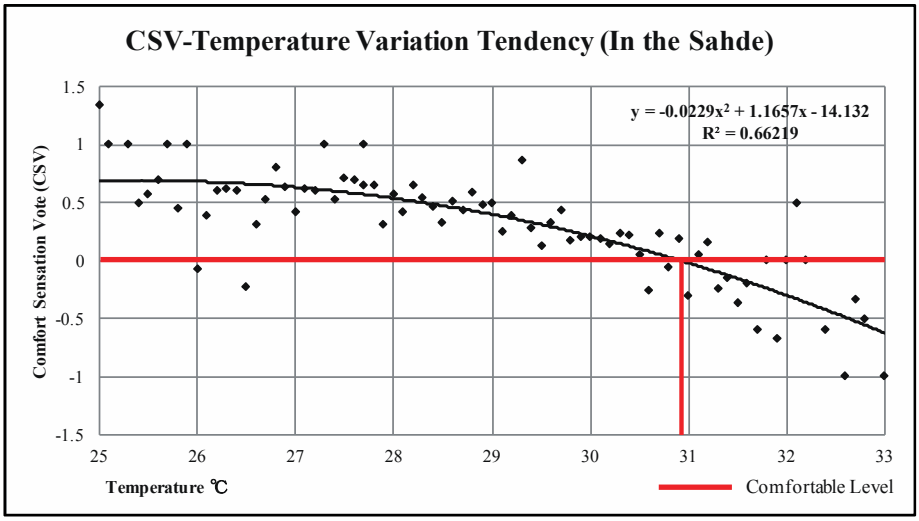
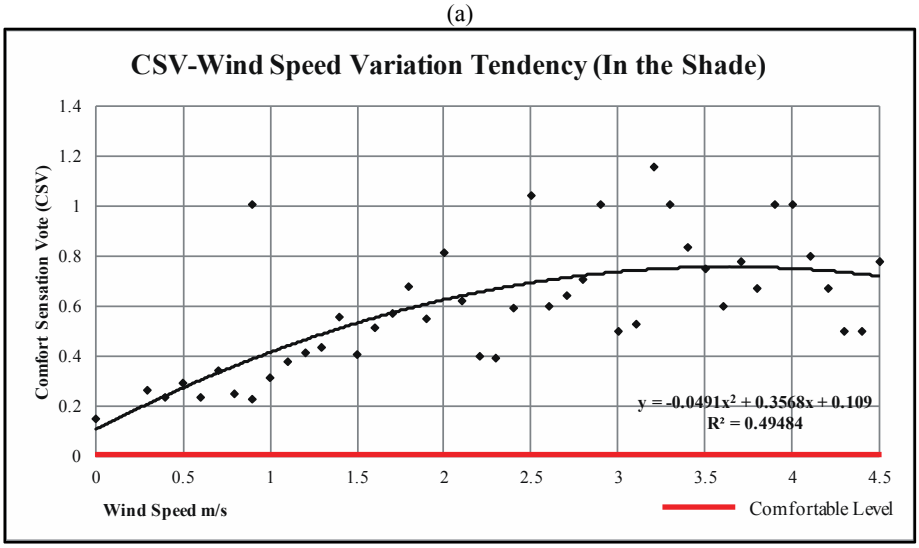


Fig. 6 The general relationships between CSV and mean microclimate in each period in different shade situations (n = 2,520).



(a)



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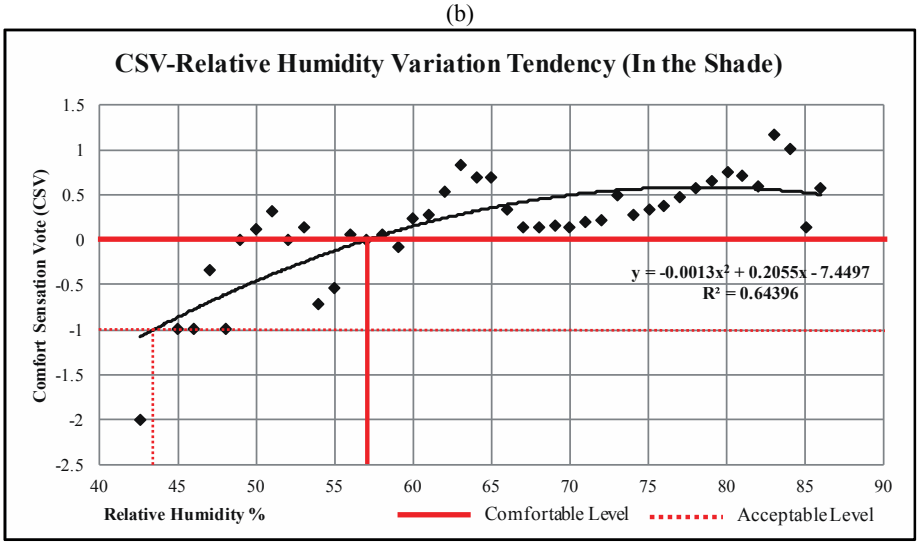


(c)

Fig. 7 CSV: (a) mean T_a (in the shade); (b) mean V (in the shade); (c) mean RH variation tendency (in the shade).

the shade, CSV will decrease with increasing temperature and belong to the comfortable range of -1 to 1. As the equations binomial curve fitting shows, a temperature of ≤ 30.9 °C can be considered comfortable. The CSV increases with increasing wind speed, and all the measured wind speeds belong to the comfortable level of 0 to 1 in the shade. However, when the wind speed is in the range of 0~3.5 m/s, the comfortable level increases. When the wind speed is over 3.5 m/s, the comfortable level decreases. The CSV increases with increasing relative humidity. A relative humidity that is higher than 57% can be considered comfortable. However, when it is lower than 43%, it is not considered acceptable.

Meanwhile, the detailed relationships between CSV and microclimate out of the shade are plotted in Fig. 8. It can be found that all the measured elements cannot meet the comfort requirements except for the relative humidity. Parts of each microclimate element belong to the acceptable range ($CSV > -1$). The CSV increases with increasing wind speed and relative humidity and will decrease with the increasing temperature. When the temperature is lower than 30.7 °C, the comfortable level in acceptable. When the temperature is higher than 27 °C, the comfortable level decreases significantly. When the wind speed is faster than 1.25 m/s, the comfort is within the acceptable range. When the wind speed is close to 3 m/s, it is possible to obtain a comfortable level. For relative humidity, the situation can be considered comfortable when the relative humidity is higher than 78%. When the relative humidity is lower than 64.5%, the comfort is in an unacceptable range.

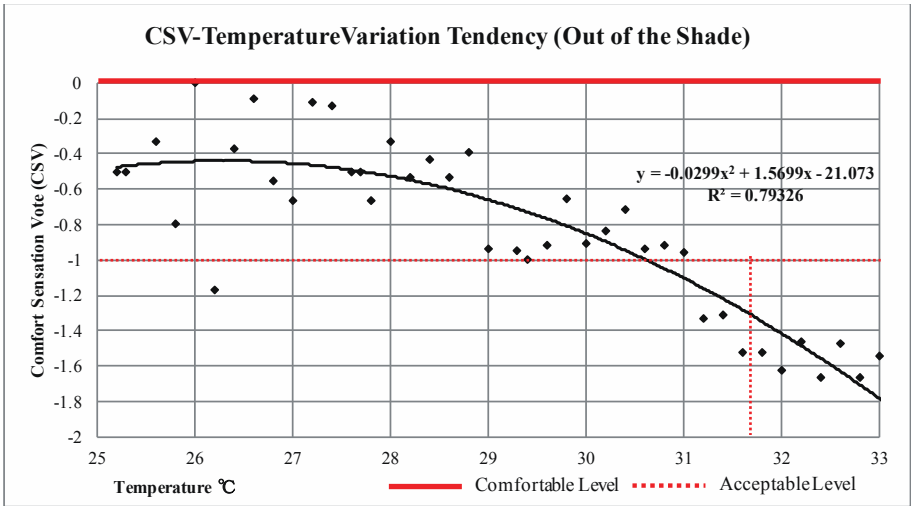
Additionally, the shade period before sunset at each measurement point is analyzed. Different colors represent different sunshine duration. Depending on the spatial arrangement, the positions are separated into the center line and edges. The center line is composed of east and west parts, in which the edge sides are composed of south and north parts. As shown in Fig. 9, the east side has more shade than the west side and the edge side has more shade than the center. Meanwhile, the south edge side has more shade than the north side. The corner (Nos. 7, 9, 11 and 13) and the under-roof locations (Nos. 8 and 12) also can provide more shade than the wide-open spaces such as Nos. 1, 2, 4, 6 and 15.

Based on the above results, the mean microclimate including T_a, WS and RH in different positions are also analyzed with the mean CSV. There are only slight differences in the mean temperature and humidity among the 15 points. However, the wind speeds vary for each point. As Fig. 10 shows, the center line has higher wind speed than the edges, especially at location Nos. 4, 6, 12 and 14, which are in the broad square and do not have any obstacles in the prevailing wind direction (east-west). Nevertheless, both ends of the center line (Nos. 1 and 15) have lower wind speeds than the other locations. Hence, uneven space edges, especially on the south side, can provide relatively favorable shade situations without higher wind speeds. The center line position can provide a favorable wind environment, but the broad square cannot provide a long period of shade. As shown by the mean CSV in each point, the comfortable position sequence from high to low is as follows: east center, south edge, north edge and west center. That is, the differences in shade and wind speed significantly influence the comfortable level.

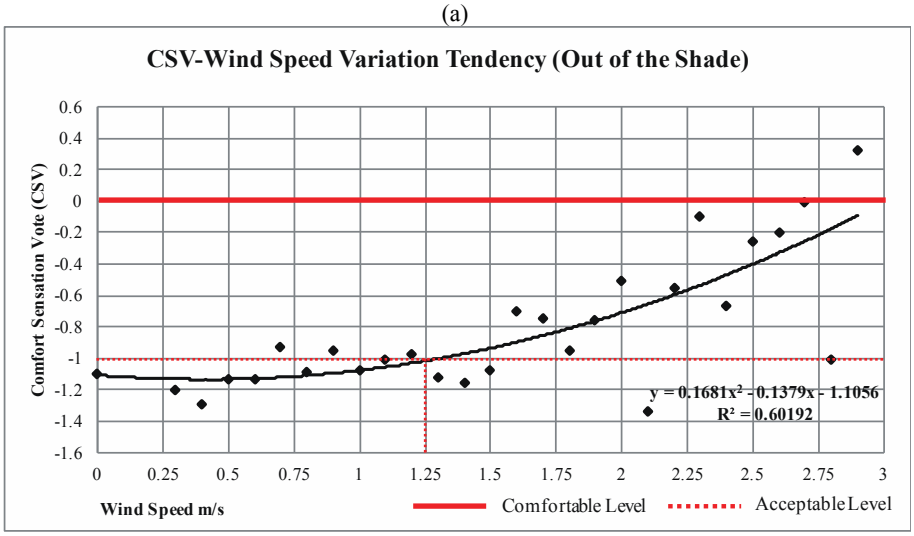
3.2 Behavior in Open Space

By using the panoramas, the position maps were analyzed in August 1st and 4th as a comparison of sunny and overcast day. As Fig. 11 shows, the study drew down the people's position for every 30 mins from 9:30 to 20:00, including the pedestrians and stationaries, and integrated them into one figure and counted the quantity of users (Fig. 12) by the separation of shade situation and behavior.

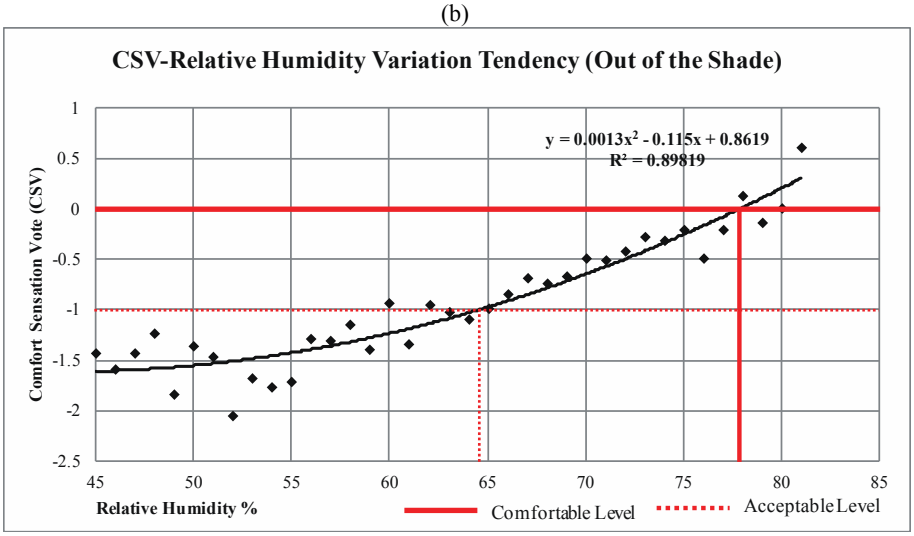
As shown in Fig. 11, on an overcast day, outdoor space can attract more people than clear day. On a clear day, the east side with long periods of shade, abundant



(a)



(b)



(c)

Fig. 8 CSV: (a) mean T_a (out of the shade); (b) mean V (out of the shade); (c) mean RH variation tendency (out of the shade).

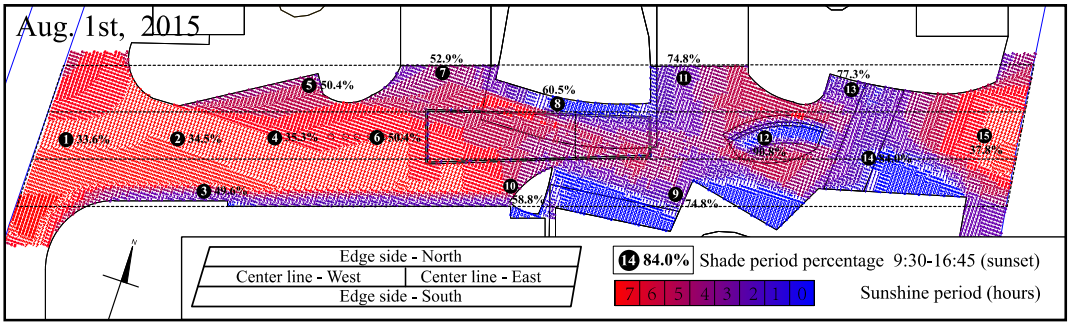


Fig. 9 Shadow situation before sunset.

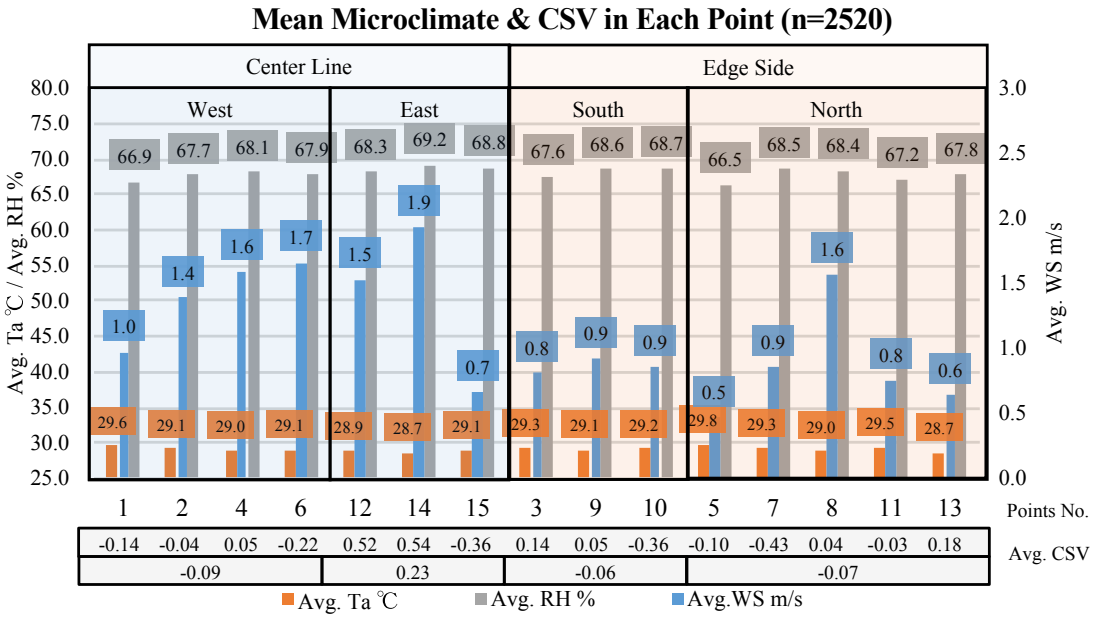


Fig. 10 Mean microclimate factors in each point with CSV.

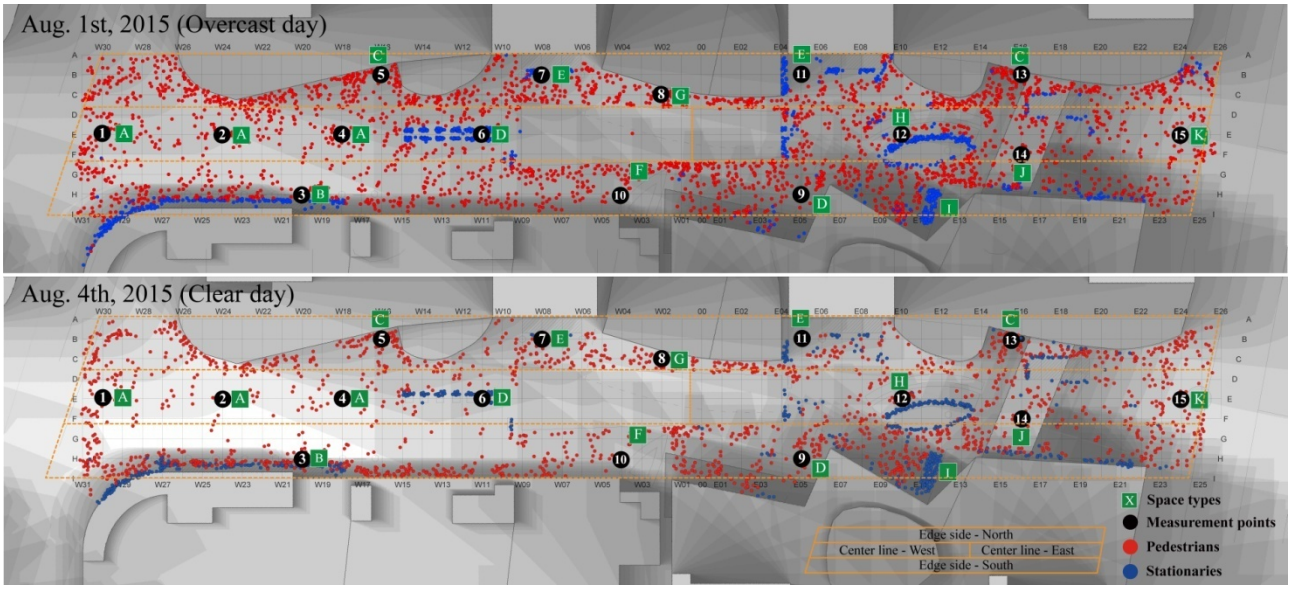


Fig. 11 The position relationship between clear day (August 1st) and overcast day (August 4th).

seats and other facilities (Nos. 9/Space Types I, 11/E, 12/H, 13/C and 14/J) can gather more people than the west side (Nos. 1, 2 and 4). The south side has more shade and can therefore gather more people than the north side, especially the area on the south side with seats or places to stay (e.g., Nos. 3/B and 9/I).

In these 2 days, the square type space A (Nos. 1, 2 and 4) and their south side square show low usage rates. People neither prefer to stay in or pass by the too-wide space that lacks any structures norspends long periods here. The activities tend to be irregular and fill the area on anovercast day. Many stationary people will choose to stay near the building edges (e.g., No. 3/B). Also, most of the pedestrians prefer to pass by the edge space (e.g., Nos. 5/C, 9/D, I and 13/C). The building corner (e.g., No. 9/I and 11/E) with seats and shade is suitable for long time stays. It can provide independent and quiet spaces that do not interfere with pedestrians. Space Type I can also provide a height difference to isolate two different types of space. Also, the under-roof space, such as Space Type H can provide thick shade all day. With the facilities such as seats, shrubs and fences, it is suitable for long stays.

Fig. 12 shows the number of people in these 2 days. The total number in overcast day before sunset is more than clear day in each measured time except 9:30. Both on an overcast day and a clear day, there are about 20%-30% of stationary people in the outdoor space. Before sunset, especially in overcast day, the number of the stationaries remained stable. During the survey, the static space is always full of people. To some degree, it can reflect the capacity of the static space. On a clear day, before sunset, about 60% of the people will stay in the shade. Combine with the former result, shade is an important element on the outdoor comfort.

The study also picked up the lunch time during these 2 days to draw down the pedestrian routes. The characteristicsof pedestrians were analyzed with the same quantity between different microclimate situations. As shown in Fig. 13, when the number of analyzed people is equal, the general routes are in the east-west direction (left-right direction). All the

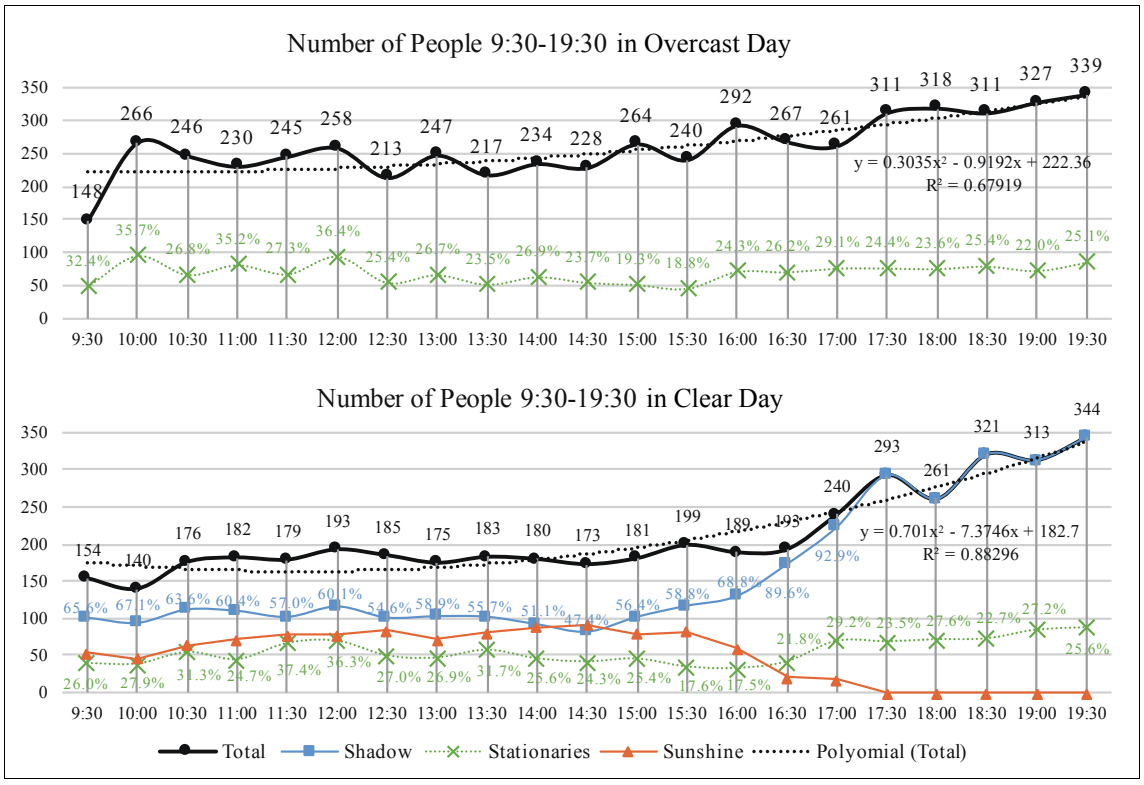


Fig. 12 Number of people comparison between clear day (August 1st) and overcast day (August 4th).

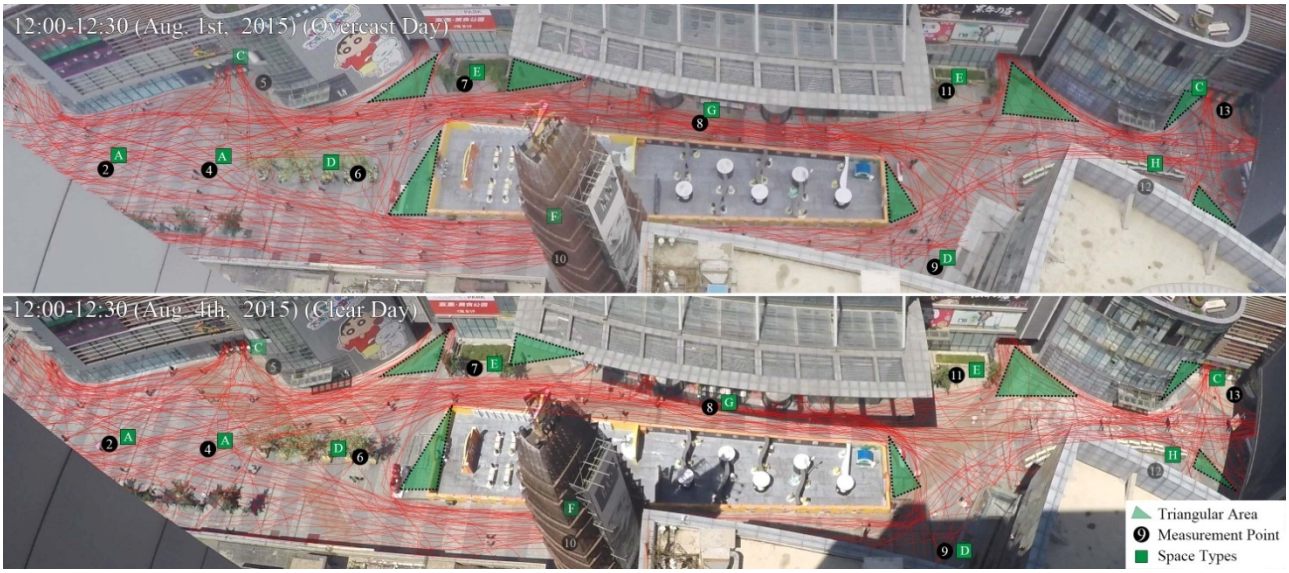


Fig. 13 Pedestrian routes comparison between clear day (August 1st) and overcast day (August 4th).

pedestrian routes are curved with almost no straight lines. In both cases, the pedestrian routes tend to be thicker at the edge of the buildings and the narrow spaces (Space Types F and G). When the space becomes wider, the routes tend to be laxer. Narrow canyon type spaces and the cross-flow are the space disadvantages for pedestrians. Pedestrians can choose any path in this case. It will create interferences between the pedestrians and stationary people, such as Space Types D (No. 6) and E (No. 7), because there are almost no boundaries or separations between the static space and dynamic space. However, a static place that has sufficient space in front does not cause as much interference with pedestrians, such as Space Types I and E (No. 11). Also, some triangular blank areas are formed by angular space edges and curved pedestrian routes. Both pedestrians and stationary people do not tend to choose this type of space that has the potential for interference.

4. Conclusion

This research focused on the relationship among open space design, people and microclimate. Through a field survey in a commercial open space, the study analyzed the microclimate elements that have a remarkable influence on behavior and feeling during the hottest summer in a northern China. The analyses and results led to the following conclusions:

4.1 Microclimate and Sensation

(1) In summer, shade plays a crucial role in the outdoor comfort. All the other objectively comfortable and acceptable microclimates show significant differences in different shade situations;

(2) In the shade, the comfortable temperature is ≤ 30.9 °C, the comfortable relative humidity is ≥ 57% and all the measured wind speeds (0-4.5 m/s) belong to the comfortable level. Meanwhile, a higher wind speed can increase the comfortable sensation. When the wind speed is in the range of 0~3.5 m/s, the comfortable level can expand. When the wind speed is over 3.5 m/s, the comfortable level decreases. When not in the shade, no measured temperature or wind speed can satisfy the comfortable requirements. The comfortable relative humidity is ≤ 78%. The acceptable temperature is ≤ 30.7 °C, humidity is ≥ 64.5%, and the wind speed is ≥ 1.25 m/s;

(3) In this canyon space, the mean temperature and humidity at each point are approximately the same; however, the wind speeds and shade that change CSV are distributed unevenly. The shade period sequence from long to short is as follows: south edge, north edge,

east center and west center. The wind speed in the center line is higher than on the edges. The CSV position sequence from high to low is as follows: east center, south edge, north edge and west center. That is, the difference in shade and wind speed significantly influences the comfort level.

4.2 Open Space and Behavior

(1) Shade can encourage more people to use the space;

(2) People prefer to choose the place with higher wind speed, and thick shade for either staying or passing by;

(3) Seats, space edges, corner spaces, under the roof spaces, the space with abundant landscape facilities and the spaces with height differences are popular for stationary people, especially when the location can meet the comfortable conditions. Too-wide square spaces, narrow aisles and spaces without abundant facilities are unpopular;

(4) Curved pedestrian routes without boundaries and angular static spaces create interference between pedestrians and stationary people and create triangular blank areas that are wastes of traffic space.

5. Discussion and Design Optimization

For this case, shade is an essential requirement for the people who want to be active outside and should be given priority in design. Additionally, using the naturally longer shade on the east side, more static space can be designed. At the west side, more landscape structures should be designed to enlarge the shading area and increase the comfort level here.

Dynamic spaces and static spaces should be clearly separated to avoid the space use conflicts to improve space utilization. Avoiding too-wide spaces without facilities and too narrow space and creating more comfortable static spaces with enough facilities can improve the quality of a space. Reducing rectilinear spaces and making more rounded spaces without angular edges can provide a flowing space for pedestrians and can also decrease the interference between dynamic and static spaces.

For stationary people, corner spaces, building edges and the center line area with higher wind speed should be thoughtfully considered to attract more people to stay for longer times. Creating landscape structures that are open to the direction of the prevailing summer wind and providing shade, seats and spatial separations among the above-mentioned places are necessary for a high-quality static space.

Based on the above results and conclusions, designing a canyon open space as a sandwich structure can be realized as a solution for the comfortable sensation and spatial utilization. As Fig. 14 shows, the static space should be arranged in the middle side and at the edge of the buildings. The traffic space is placed between these two static spaces. This design can not only improve the space utilization and decrease interference between stationary people and pedestrians but also offer possibilities for creating a favorable microclimate environment. Because the wind environment

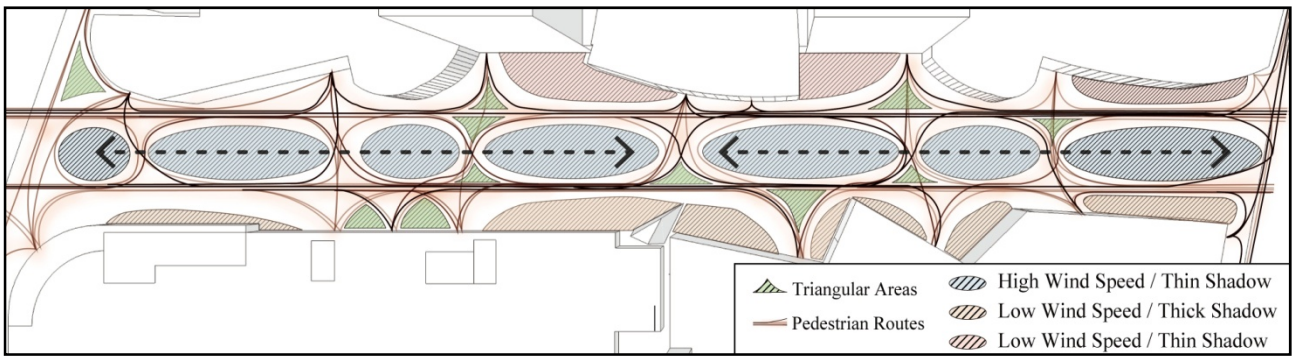


Fig. 14 Optimization design of canyon open space.

in the middle is better than that on the edges, designing the shading structures and humidifiers that are open to the wind direction can create a favorable environment based on the above-mentioned principle of a comfortable microclimate.

To create a suitable and high-quality open space that is comfortable for both pedestrians and stationary people, the following proposals should be considered:

(1) At the beginning of the open space design, understand the general microclimate situation and the comfortable threshold in the hottest day. Among all the microclimate elements, shade plays a crucial role and should be considered first. Roofs and plants, etc., that can provide thick enough shade. Based on theseparameters, different design methods will be separated by different microclimate situation (Fig. 15).

(2) Curved pedestrian routes should be planned with rounded space edges to enhance spatial utilization. The triangular blank area formed by a curved route and an angular boundary can be used for some functional landscape structures such as streamline leading or symbols (Fig. 16);

(3) Avoid too-wide square spaces without any facilities and too-narrow spaces. Provide abundant street facilities which can offer shade, resting areas and spatial separations at suitable places without spatial contradiction. By controlling the width of the traffic space with streamline leading structures, traffic efficiency can be improved by design. Additionally, depending on the shade distribution, setting landscape structures and plants that are open to the prevailing wind direction is necessary to ensure the spatial utilization (Fig. 17);

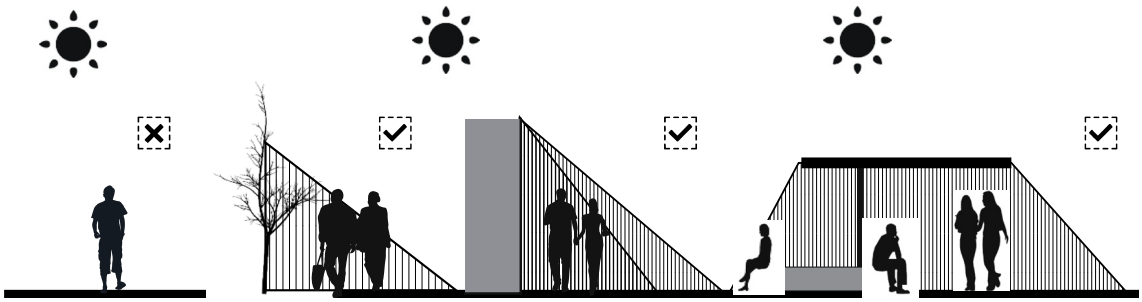


Fig. 15 Comfortable microclimate creation.

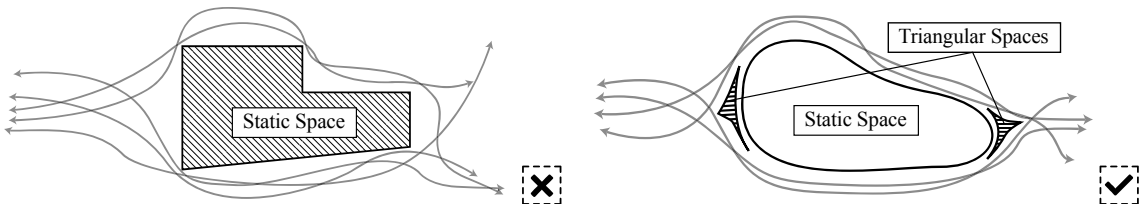


Fig. 16 Flowing route and curve space.

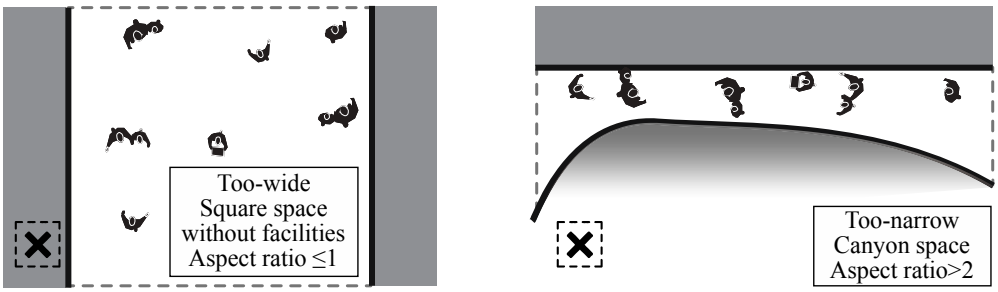


Fig. 17 Spatial scale.

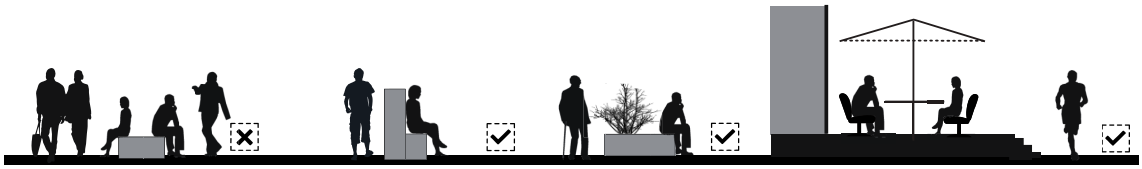


Fig. 18 Space interference.

(4) By creating independent static spaces in the centerline area, edge side area and corners, interference between pedestrians and stationary people can be avoided. Meanwhile, spatial separations, such as fences, billboards, shrubs, height differences, are necessary in areas that could create conflicts. Providing sufficient functional facilities and structures are required to create an attractive place (Fig. 18).

6. Future Study

The microclimate in a northern city varies greatly between summer and winter. In Shenyang, China, the average annual temperature ranges from 1981 to 2010 is 35.8 °C [48]. Based on the summer study, the future research will focus on the cold winter situation. By analyzing both summer and winter, comprehensive and integrated proposals will be provided for the urban design of open space for northern cities with large temperature differences.

Acknowledgments

This work was supported by JSPS KAKENHI Grant Number JP25249082. The first author is supported by the Chinese Scholarship Council (CSC) scholarship (File No. 201406080003). The authors would like to express their appreciation to the students from JangHo Architecture Collage in Northeastern University, China who helped authors to finish the Shenyang survey during July 28th to August 9th, 2015. They are Rundong LI, Guangyu MA, Weisi HUANG, Jiaxin LV, Fan XU and Peiyang SUN.

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Journal of Civil Engineering and Architecture 11 (2017) 635-652
doi: 10.17265/1934-7359/2017.07.002

Risk Management Concepts in Dam Safety Evaluation: Mosul Dam as a Case Study

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Abstract: Gradual shift has been observed lately of dam safety procedures from the conventional technical based towards a wider scope of risk management procedure based on risk analysis. The new approach considers the likelihood level of occurrence of a multitude of hazards and the magnitude of the resulting possible consequences in case of failure using rational cause and effect arguments. Most dam owners are shifting towards the use of the new risk based procedures; and even governments themselves are moving towards formalizing the new trend. Legislations in the United States were promulgated [1] after serious dam failures and the adoption of stringent levels of scrutiny led such federal dam owners to pioneer in this field and in developing the concepts and methods required. The corner stone in risk analysis is the definition of the potential modes that may lead to failure and assessment of the likelihood levels of their occurrence and possible category of the consequences which, after thorough evaluation, will shape the decision making. This type of analysis was applied to Mosul Dam as a case study and resulted in definite recommendations.

Key words: Risk analysis, risk management, Mosul Dam, Iraq.

1. Introduction

Due to changing values of society in the last few decades and specially so in respect to dam safety, it has become necessary to provide and develop tools to look into the worth of new dams in order to facilitate their acceptance by the various groups active in forming public opinion and by financing agencies looking for best returns in the fragile world's economies of today. New values have been adopted by various elements which include such groups as environmentalists, welfare societies, health organizations and insurance companies in their outlook towards dams. Nobody can; however, ignore the fact that most countries continue to build new dams to generate and store clean energy even with the development of nuclear, wind and solar forms of power. Highly developed countries and, to lesser degree, the lesser developed ones are burdened with a legacy of thousands of aging dams which need regular re-evaluation in the light of their safety concerns and their potential hazards in addition to their diminishing benefits. These old dams may need basic repairs and upgrading measures, which require very large investments. In many cases, the decision maker could face at certain point the situation where a drastic decision of closing a facility might have to be made. The possibility of decommissioning the dam has to be checked especially if it poses a grave safety hazard or has expired due to sedimentation or malfunctioning and does not meet the requirements of today's safety standards or operation requirements.

In the past, the subject of dam safety was treated on a purely technical basis as related to floods, seismicity, foundation conditions and dam design, and questions of human errors of operation were to be avoided by compiling detailed operation and maintenance manuals have been avoided. The development of the new line of thoughts, however, requires new decision concepts, which infuse the new social and economic values and the limitation of resources in the decision-making

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processes. Much work has been done during the past four decades on this field which has resulted in what is known now as risk management as an evaluation and optimization tool in this field.

2. Traditional Dam Safety Procedures and Risk Management

In the context of dam safety evaluation, a clear shift of public opinion and management policies is observed from the old and traditional dam safety procedures which normally deal with the impacts of a given hazard such as an extreme flood, seismic event or a certain deficiency towards a wider framework of decision making processes known as risk assessment. This framework, while it embraces the old procedures and principles, adds other elements into the process. They aim towards improving the understanding of dam behavior, assisting in finding new ways to satisfy investigation and surveillance needs. They also assist in identifying measures for risk reduction and contributing to the optimization process of resource allocation in addressing the needs of one dam or group of dams. Risk analysis drives towards more accurate estimates of hazards frequencies and expected damage. In such approach, the uncertainties are partly related to the natural randomness of hazards, and partly because of our incomplete understanding and measurement of the hazards exposure and vulnerability to be considered. In a statement made in the proceedings of the third United Nations Conference on Disaster Risk Reduction [2], it states: "Historical losses can explain the past but they do not necessarily provide a good guide to the future. In a pessimist view, the worst disasters that could happen have not happened yet".

A probabilistic risk assessment might simulate those future disasters, which based on scientific evidence, are likely to occur. In this assessment, the probabilistic model augments historical records by reproducing the physics of the phenomena and recreating the intensity of a large number of synthetic events. In contrast, a deterministic model treats the probability of an event as finite and it is done in five steps:

(1) Surveillance and thorough inspections, instrumenting and monitoring, and data collection;

(2) Emergency preparedness planning, which includes documenting in details required actions in case of emergency and the preparation of responsible person names lists and telephone numbers to be contacted in such case, the definition of emergency actions and annual or semiannual drills on them. All these actions may be outlined and detailed in what is known to be an EAP (emergency action plan);

(3) Comprehensive periodic review of the dam components and marking their functioning and any deviation from previous reviews. Such reviews may be carried out every 5 or 10 years [3];

(4) Deficiency investigation in case any such deficiency is confirmed in the reviewing process, so to assess remediation options and their priority, finally;

(5) Once a deficiency is defined and a treatment option is determined then rehabilitation action will be started.

In the more oriented risk management policy, these five steps are incorporated in the framework of the whole risk management process and communicated to stakeholders; as suggested in Fig. 1.

In a follow-up to performing these actions, the decision-making stage should begin trying to make the best use of all the previous findings by incorporating them in an iterative process to reach the final optimum decision hoped for and conclude the risk management as a whole. An example of such integration was proposed by British Columbia Hydro (BS Hydro), Canada, as explained in Fig. 2.

In Fig. 2, the shaded areas represent deficiency investigation components while the diamond areas are actually (risk management points) where a decision of Yes or No should be made in order to proceed in the overall risk management.

In each risk management point, three major actions would have to be taken; these are risk analysis, risk evaluation and risk assessment.

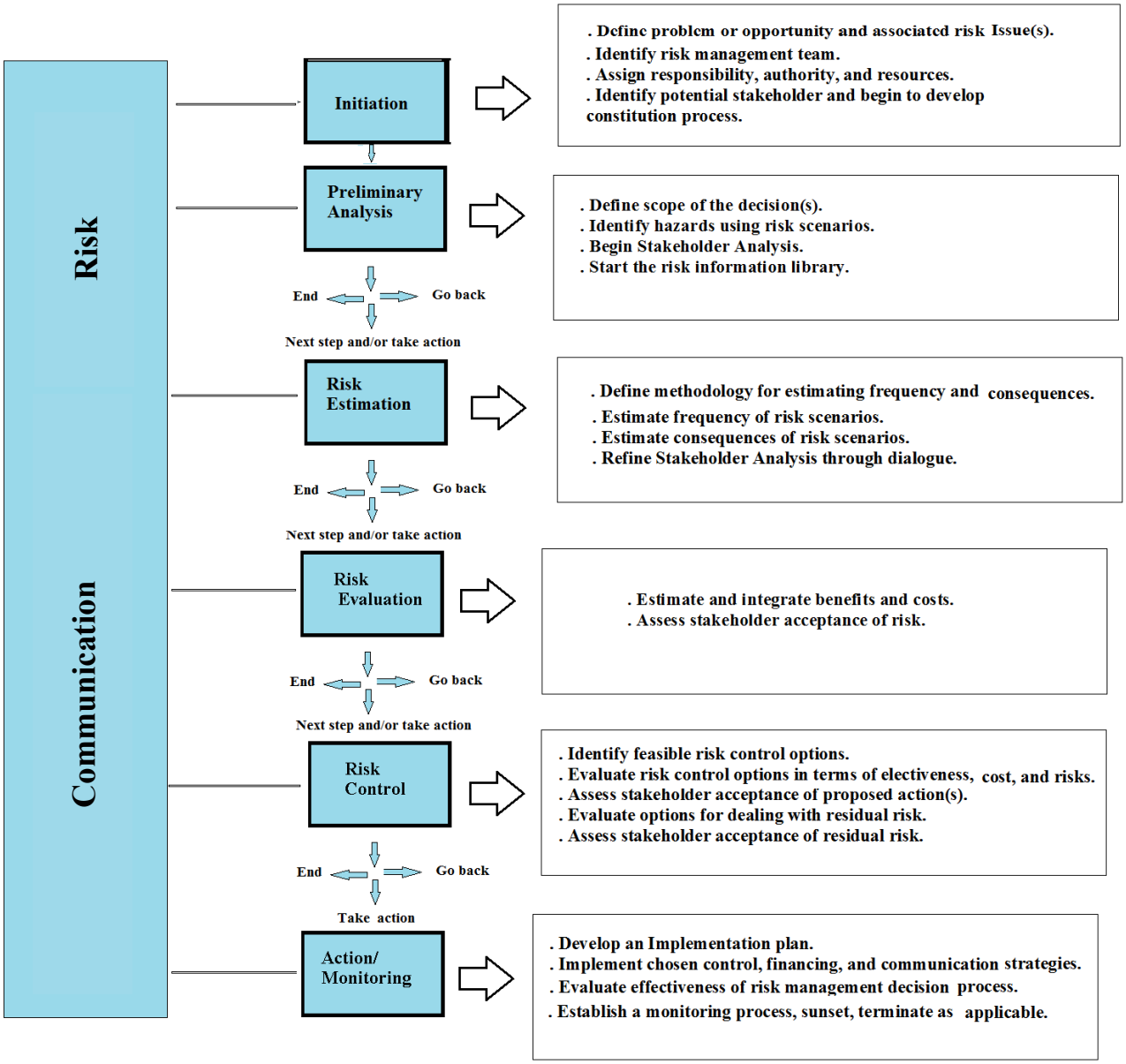

Fig. 1 Steps in risk management decision-making [4].

3. Main Concepts in Dams Risk Management

Risks may be considered as the intentional interaction with uncertainties. In the overall framework of dam safety, it can be defined as "the measure of the likelihood of occurrence of an adverse condition and the severity of consequence of such a condition". The risk for a particular mode of failure is the probability of occurrence of a loading scenario PL (static, seismic, hydrologic, geologic, mechanical, etc.) multiplied by the response of some component of the structure PF (probability of failure of this component) times the consequence of such load CL (uncontrolled release of reservoir). This may be expressed by the following equation:

$$\text{Risk} = \text{PL} \times \text{PF} \times \text{CL}$$

Risk analysis is the calculation of dam safety and risks for certain condition(s) typically resulting in failure (uncontrolled release of the reservoir). The procedures adopted by some dam owners and authorities

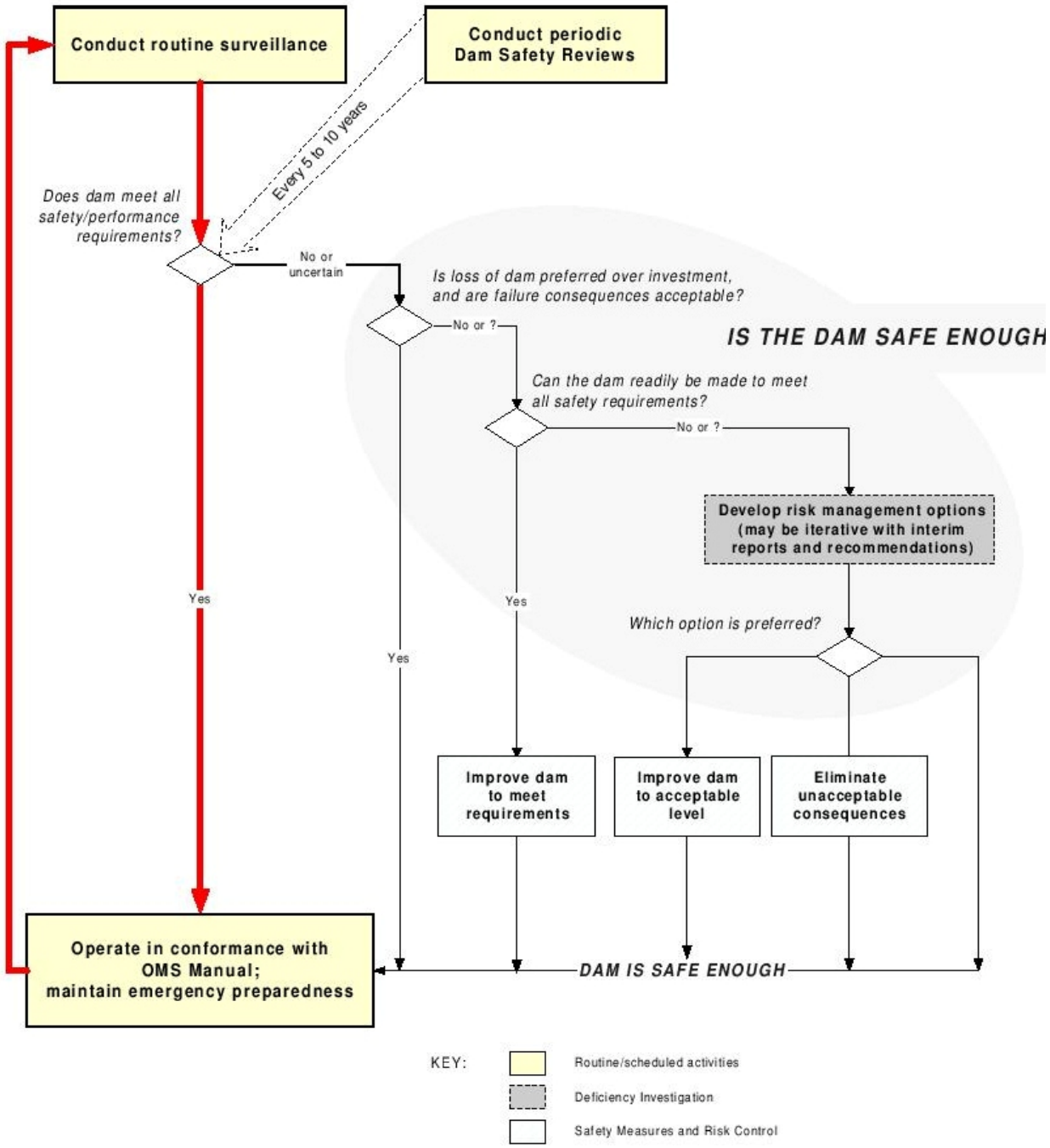

Fig. 2 BC hydro's proposal for integrated risk management processes.

can be made visible by using a ranking system for the likelihood of failure estimates and magnitude of consequences such as FMECA (failure mode and effect analysis, or can be quantitative risk analysis.

Risk assessment is the process of considering the quantitative or qualitative estimate of risk together with all related social, environmental, temporal, and other factors in order to determine a recommended course of action to mitigate or accept the risk. Such analysis must necessarily be carried out by experts in various fields; such as geologists, geotechnical engineers, hydrologists, hydraulic and structural engineers, and mechanical and electrical engineers.

Risk evaluation is the process by which risks are

examined in terms of costs and benefits and evaluated in terms of acceptability of risk considering the needs, issues, and concerns of stakeholders. Risk management is the systematic application of management policies, procedures, and practices to the tasks of analyzing, evaluating, controlling, and communicating about risk issues. In another word, it is the total of the previous operations just outlined, and so its final goal is to enhance the decision-making process. It takes in due course the stakeholder's perception of their needs and concerns through the communication process. A graphic representation of a typical FMECA for dam safety procedure is shown in Fig. 3. This procedure was established by the United State Federal Emergency Management Agency (FEMA) [5] in their guidelines known as "Federal Guidelines for Dam Safety Risk Management" [5]. The framework of activities shown in Fig. 1 is, in fact, nothing more than performing the same activities indicated in the flow chart shown in Fig. 2. Fig. 3, however, shows the interrelationship of these activities. It also shows that the performance of PFMA (potential failure modes analysis) is the first step in the whole process of risk analysis leading to the decision making stage of risk management.

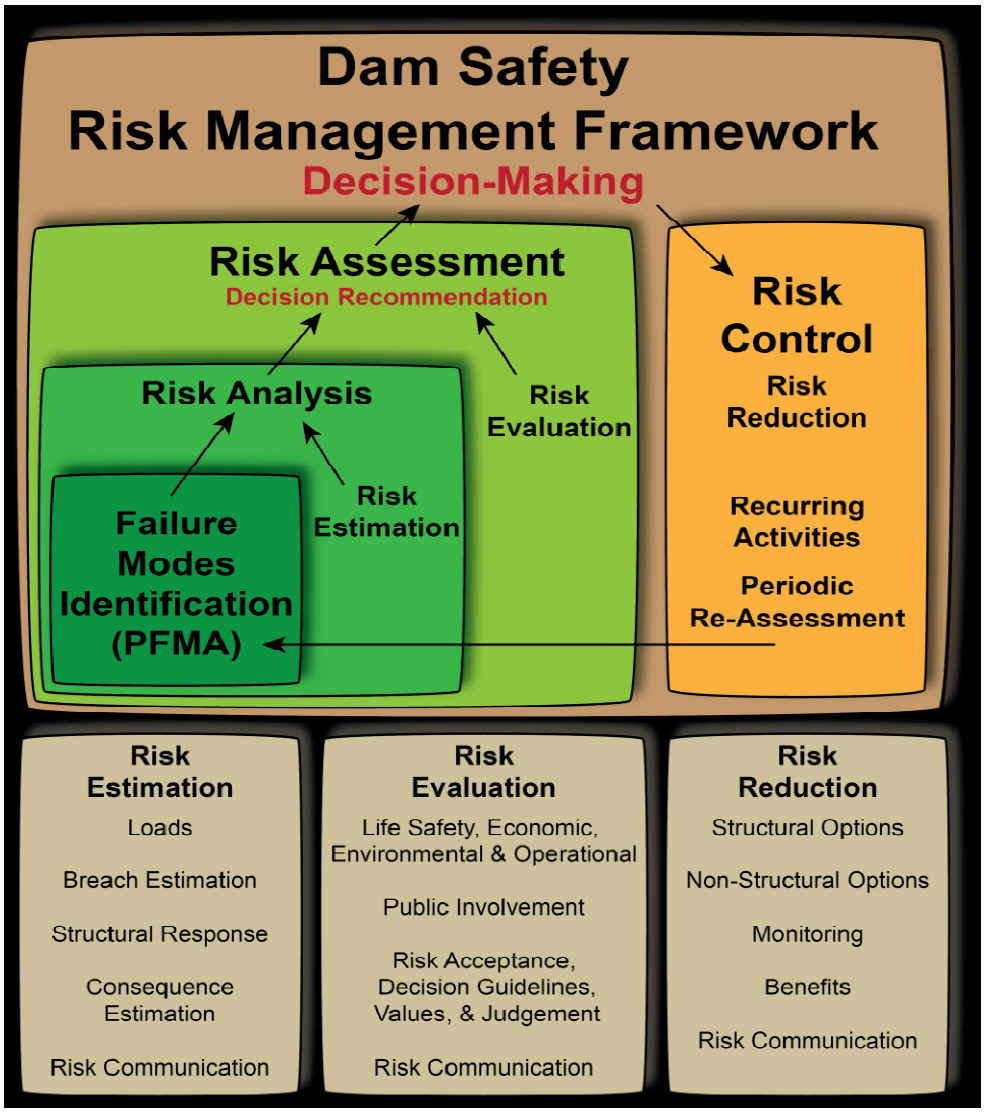

Fig. 3 United State Federal Emergency Management Agency framework for risk management [5].

4. Risk Management Practices Followed by Different Dam Owners

Recent history shows that the concept of risk began to circulate and tested since the 60s of the last century among some industries, which were attempting to quantify the risks of hazards inherent in their practices. Driving actors, among others, were the nuclear energy industry, insurance companies, and the health sector. Risk management began to show its value as a strong tool for the assessment and evaluation of such risks and could serve as a strong basis for informed decision making, especially when it came to safety decisions and optimizing of resource allocation. This development led many entities interested in dam safety to use risk analyses since late 1980s as a way for decision making in the field [5]. Dam safety management, however, may have taken different ways of development and application in different countries and even among dam owners in the same country. In all cases, the goal was always the same, i.e., better understanding, and more informed decision making. This may be explained when comparing dam safety procedures in such countries as the UK, France, Sweden, and USA.

4.1 UK

Dam safety management in the UK is governed; generally, by legislations whereby responsibility is divided between dam owners, councils or local governments, government departments and technical panels of qualified engineers appointed by the ICE (Institute of Civil Engineers). There is no current official support or use by dam owners of QRA (quantitative risk analysis) and societal risk criteria. But, a survey of dam safety management carried out by Scottish and Southern Energy [6] reveals their use of FMECA (failure mode and effects criticality analysis) since 1996 in their 84 dams out of which 56 are considered to be large dams according to ICOLD (International Commission on High Dams) criteria. Their policies rely on emphasizing that surveillance, operations and maintenance practices should be risk based. These issues are addressed by standard procedures and governed by the Reservoir Acts of 1975 and 2011.

Concepts of acceptable risks to human life have been the subject of research conducted by the HSE (Health and Safety Executive) since the 70s. Although their research was mainly oriented towards risks in the industrial and nuclear sectors, it had contributed to the definition of tolerable risk and acceptable risk in general in other areas such as dams. In this respect, HEC reckons that the individual risk/annualized failure probability guideline is generally taken as 1 in 10,000 per year. In the water resources industry, this threshold seems to describe an agreeable guideline. Further work was done to relate these concepts to dams and their risk assessment by the CIRIA (Construction and Industry Research and Information Association). Their work and findings were issued as a report in 2000—"CIRIA 568, Risks and Reservoirs" [7].

An interim guide to quantitative risk assessment for UK reservoir was published in 2004 by the Flood and Coastal Erosion Risk Management Research Development Program [8] which is run by the Environmental Agency and provides tools for management of reservoirs safety. An updated study was published in 2013 which recommended three-tiered structural procedures for identifying potential failure modes as a preliminary step in all risk evaluation [8].

4.2 France

In France, safety concerns are addressed as early as the preconstruction stage and for each new dam with a height more than 20 m and/or the size of the reservoir is 15×106 m^3: a technical file must be submitted to government authorities for approval and it should be subject to emergency planning regulations. The repairs of old dams are normally overseen by a technical committee called the "Standing Committee", which is

formed of members from the Ministry of Industry, Ministry of Environment and the Ministry of Transport.

Dams under construction are also subject to compulsory continuous safety surveys by the construction supervisor, who is also responsible for the safe first filling. From that point onwards, the owners must do periodical visual inspections and monitoring at agreed frequencies and should report the findings of any anomaly or defect. All these are considered as the first line of defense. Comprehensive safety checks should be carried out yearly during the first five years from the date of commissioning followed by similar checks at five years and ten years' intervals. The dam owner is also responsible for preparing an EAP to meet unforeseen emergencies; but inundation maps in case of dam failure are prepared by the local authority of the county in which the dam is located. In France, the term risk assessment is taken to mean the process of checking whether a dam satisfies the standards defined by the regulation otherwise. The philosophy behind this is "not accepting risk on dams". Dam owners in France, therefore, are not engaged in using QRA but some of them are using an FMECA type analysis to manage component safety and optimize resources in maintenance programs. One example is shown by the major utility owner EDF (Electricite de France), which operates about 450 hydro plants. Some of these plants date back to the 19th century with most recent dams completed in 2009. As a result of several incidents in 2005 and 2006 [9], plants showed the need of better tools to detect the progression of aging and to schedule suitable maintenance operations. In 2005, EDF introduced a risk analysis method intended to guarantee long-term generating efficiency at its hydro facilities. The method identifies the principal failure mechanisms, their probabilities, and potential consequences. From 2006 to 2008, every structure and piece of equipment was assessed. The resulting "risk maps" provide a roadmap for the maintenance program [9].

4.3 Sweden

Sweden owns about 10,000 dams of which 190 of them are classified as large dams, the Swedish law puts on the dam owners the full responsibility of the safety of their dams. Government permission is required for dams to be constructed, and such permission is only granted after a thorough examination of the adequacy and safety of the designs. Normally, individual dam owners have their internal safety guidelines and safety organizations to adhere to safety standards and requirements, which are found in many regulatory frameworks, most of which are in the Environmental Code and the Civil Protection Act. Dam safety is part of the "water activates" supervisory area in the Environmental Code, for which the Country Administrative Board is the supervisory authority [10].

Since 1998, the public authority (Svenska Kraftnät or the Swedish National Power Grid) has been responsible for promoting dam safety in Sweden and provides supervisory guidance to the Country Administrative Board. What needs to be mentioned here is that Vattenfall AB which owns 50% of Swedish dams and is one of the Europe's leading power companies and was the first Swedish hydropower utility to formulate a Public Safety Guidelines (2007). In 2008, Swede Energy Power Solutions AB working in its consulting capacity in dam safety sector developed "Guidelines for the Safety of the General Public at Dam Farcicalities and Associated Water Courses" for all Swedish hydropower companies operating within this association. In these guidelines, risk assessment is being considered as a methodology to prioritize the remediation of dam safety deficiencies. In this regard, Vattenfall; with the consultant (Swede Energy Power Solutions AB), has been working with quantitative (FMECA) type analysis to evaluate what methodologies would be suitable for their purposes [6].

4.4 USA

A review of the history of dams in the United States

shows that many dam failures occurred during the past causing immense property and environmental damages and taking thousands of lives [11]. As dams age and population increases, the potential for deadly dam failures grows. Following the death of 125 people as a consequence of the failure of Buffalo Creek dam in West Virginia in 1972, the Congress passed the National Dam Inspection Act in 1973 which prescribed rules for the inspection of US dam and stated the need to develop risk assessment procedures. Research on risk analysis and risk assessment began, with the failure of Teton Dam in June of 1976; but it was not until October, 1979 when President Carter directed Federal Agencies to adopt dam safety standards, which should be overseen and controlled by a newly created FEMA and work closely with the Federal Dam owners and other bodies concerned with the dam safety in the United States. The FEMA in turn adopted the procedures required by the US FERC (Federal Energy Regulatory Commission) which had been established since 1973. Although initial development work in this field began shortly thereafter, it was not until the mid-1990s that the USBR (Bureau of Reclamation) began using risk analysis tools as the primary support for dam safety decision-making in its 350 dams since then [12].

The USACE (U.S. Army Corps of Engineers) recognized the need to implement risk assessment procedures following levee failures that occurred in New Orleans during Hurricane Katrina in August of 2005, and soon after began implementing risk analysis and risk assessment procedures.

In this new framework of dam safety management, the PFMA (potential failure mode analysis) is considered as the first and the most important step in the risk assessment framework (see Fig. 3) developed mainly by the United State Bureau of Reclamation [13].

In the risk evaluation, which is the next stage of safety assessment, USBR developed together with USACE codes or guidelines to quantify the risks and established the necessary criteria; as tools to such evaluation. These tools address both the level of the threats and their likelihood of occurrence together with the magnitude of consequences. A risk matrix was formulated to establish and portray both of these factors. Fig. 4 shows the format of such matrix, in which the level of likelihood of occurrence is plotted on the vertical axis against magnitude of the consequences on the horizontal axis. In this matrix, the cells indicate the category and magnitude of each of these two variables while the alert levels rank from green (no risk) to purple (high risk).

In quantifying the failure likelihood category level, it is recognized that the likelihood failure level is a function of both the critical loading conditions leading towards failure and the chance of its occurrence. The horizontal dashed line shown on the matrix form (Fig. 4) represents the dividing line of 1:10,000 chance of occurrence which separates moderate likelihood from high likelihood zones in the matrix format. The 1:10,000 chance of occurrence is what both USBR and USACE had adopted as the reasonable criterion for acceptable loss of life.

The descriptions of the failure likelihood categories are shown in Table 1, and the consequences' categories are shown in Table 2. In the risk matrix format of Fig. 4, the first category indicated in Table 1 is eliminated following the description of this category as remote and describing its events as being "unlikely" to "very unlikely" to occur and failure potentials are negligible. Similarly, the description of the consequences categories is shown in Table 2. In this table, the magnitudes are quantified according to the significance of their impacts; if such failure occurs. Such impacts include loss of life, destruction of properties, loss of projects' benefits, environmental damage and socio-economic impacts.

Level 0 in Table 2 is not represented in the matrix format of Fig. 4 as its consequences are not significant to downstream population and may result in minor damages to infra-structure. In describing the level of risk in any dam, its location on the format in Fig. 4 will

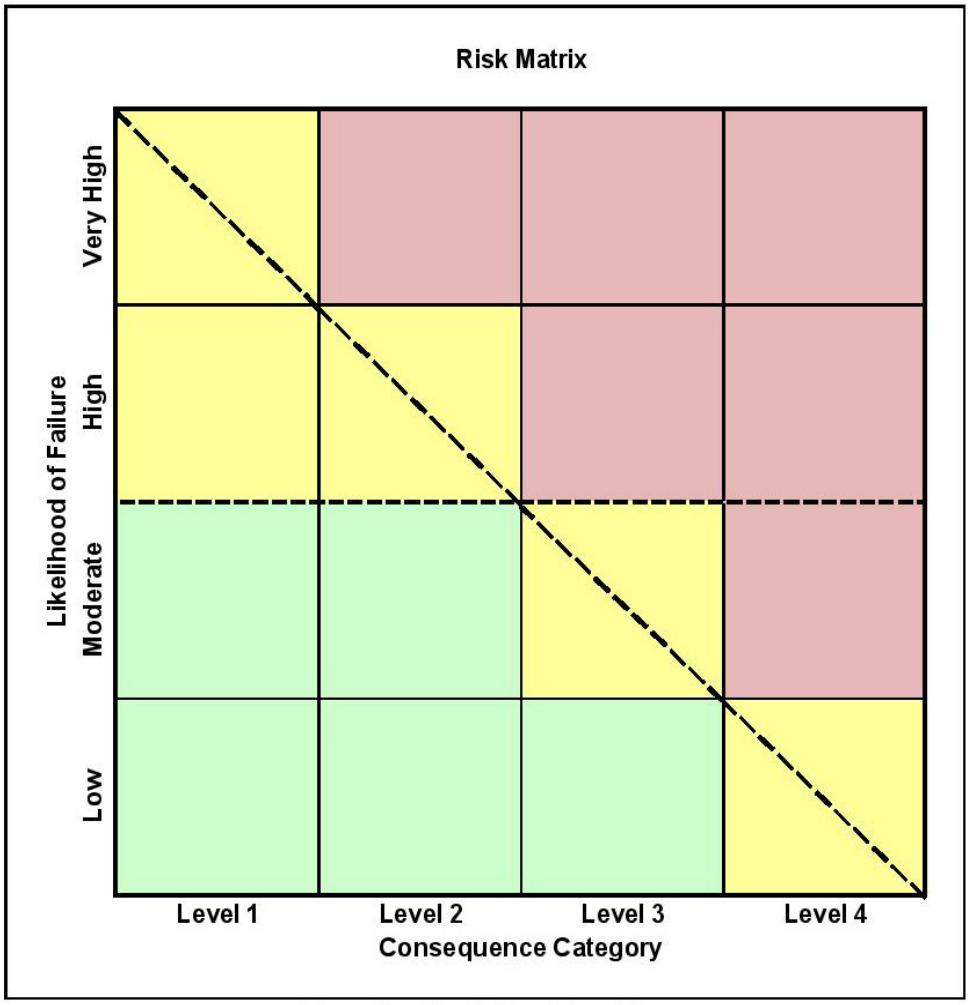

Fig. 4 Quantitative risk matrix format [14].

Table 1 Failure likelihood categories.

Category name	Category description
Remote	Several events must occur concurrently or in series to cause failure. Most, if not all the events are unlikely to very unlikely, and failure potential is negligible.
Low	The possibility cannot be ruled out, but there is no compelling evidence to suggest it has occurred or that a condition or flaw exists that could lead to its development (e.g., a flood or an earthquake with an annual exceedance probability more remote than 1E-05/yr would likely cause failure).
Moderate	The fundamental condition or defect is known to exist; indirect evidence suggests it is plausible; and key evidence is weighted more heavily toward unlikely than likely (e.g., a flood or an earthquake with an annual exceedance probability between 1E-05/yr and 1E-04/yr would likely cause failure).
High	The fundamental condition or defect is known to exist; indirect evidence suggests it is plausible; and key evidence is weighted more heavily toward likely than unlikely (e.g., a flood or an earthquake with an annual exceedance probability between 1E-04/yr and 1E-03/yr would likely cause failure).
Very high	There is direct evidence or substantial indirect evidence to suggest it has occurred and/or is likely to occur (e.g., a flood or an earthquake with an annual exceedance probability more frequent (greater) than 1E-03/yr would likely cause failure).

Table 2 Consequences categories (numbers refer to casualties).

Category name	Category description
Level 0	No significant impacts to the downstream population other than temporary minor flooding of roads or land adjacent to the river.
Level 1	Although life threating flows are released and people are at risk, loss of life is unlikely.
Level 2	Some life loss is expected (in the range of 1 to 10).
Level 3	Large life loss is expected (in the range of 10 to 100).
Level 4	Extensive life loss is expected (greater than 100).

decide whether it falls in a red cell (high risk) or in a green cell (low or no risk).

The estimation of losses and damages may be derived from updated information and statistical data available at government departments or private sector enterprises. In this categorization process, loss of life is taken as the main priority, while other losses are given equal weight; the factors considered in its quantification are: the PAR (population at risk) in the inundated area, the severity of the flooding, the length of warning time given to the population concerned to evacuate and their level of understanding of the coming danger. The risk matrix in Tables 1 and 2 shows that loss of life is in the focus of the established concerns both of the USBR and USACE and it is being given prominence as it is considered in both the likelihood levels and the magnitude of consequences categorization.

Finally, the USACE summaries its use of this matrix for risk evaluation in the following statement:

"In this semi-quantitative risk evaluation, the estimated risk associated with each potential failure mode is plotted on a risk matrix format. Plotting potential failure modes in cells entirely below both the red dashed lines indicate that these potential failure modes should be kept under review and properly managed. This requires continuous monitoring and evaluation. Similarly, potential failure modes with risk plotting in cells above the red dashed lines represent risks that likely exceed risk guidelines and require action to reduce or better define risk." In a portfolio of many dams, risk evaluation of each dam can be made in this way and an overall classification of all the dams is obtained in which they may be ranked according to the degree and severity of risks attached to them. In such way, the prioritization scheme for the decision maker is presented in order to optimize actions and the allocation of resources.

5. PFMA (Potential Failure Mode Analysis)

Potential failure modes analysis was adopted in 2002 by the FERC (Federal Energy Regulatory Commission) as a standard tool in reviewing a significant hazard in dams. Any PFM is defined as a specific chain of events leading to a dam failure. FERC defines such failure for dams as an uncontrolled release of water. Therefore, a failure does not need necessarily to be the complete and catastrophic failure. In any failure mode analysis, a well-defined sequence of steps has to be outlined and followed; the first is to get a thorough understanding of the dam history and its present conditions. A brainstorming should follow to visualize all possible drives that may be of any potential failure mode. These could be anything like reservoir load, deterioration of some component or overall aging, earthquake, upstream flood or an operational issue. What follows is a step by step definition of the progression of the mechanism leading to failure and then concluding with the impacts on the structure under consideration and whether it will lead to full or partial failure and the severity of the consequences of such failure. The categories of PFM according to their severity and their description are given in Table 3.

In 2005, Mosul Dam safety conditions were examined and risk management study was performed [15]. This study included identification of all potential failure modes and their categorization and found that the main concern was due to the foundation's deteriorating conditions. The study went further to

Table 3 Categories of PFM according to FERC.

Category	Desecription
I. Highlighted PFM	PFM of highest significance with respect to awareness, potential for occurrence, magnitude of consequences, and likelihood of adverse response.
II. PFM considered but not highlighted	Considered of less significance and likelihood than Category I., reason for less significance must be documented by reviewer.
III. More information or analysis is needed in order to classify	These PFMs lack enough information to allow confident judgment, filling the gap of information is required to allow proper dam safety investigation.
IV. PFM is ruled out	PMF may be ruled out because possibility does not exist, so remote to be non-credible or those new findings eliminate failure mode concerns.

discuss and evaluate the dam's safety risks and to suggest actions for risk reduction measures. This case is presented here as a case study for such analysis.

6. Mosul Dam as Case Study

Mosul Dam which was completed in 1986 is an embankment dam with a height of 113 m that retains an accumulation of 11.1 billion m^3 of water. It is located 500 km north of Baghdad on the river Tigris. The dam has been suffering from serious defects in the foundation resulting in grave safety concerns to the extent that it is been described as: "The most dangerous dam in the world [16, 17]". The complex geology of the site and especially the severe historical karstification of the beddings are the main reasons for the problems, which started to appear during construction and continued till the present days. The impossibility to bring the deep grout curtain under the dam to the required design criteria in many locations was a warning sign of the coming troubles since many locations were left open before impounding the reservoir.

As the first filling was started in 1985, large flows of seepage water were observed coming from under the dam in the left bank and in the river channel. The water was heavily laden with salts, especially sulfates, which indicated serious dissolution of gypsum and anhydrite rocks. This was a sign a defective curtain and showed that severe dissolution process was taking place in the foundations of the dam, which eventually could lead to the dam collapse. The lithology of the foundation is characterized by heavily jointed and cavernous limestone layers alternating with much-karstified gypsum and anhydrite beds and highly weathered marl strata. The depth of the karstification had reached a depth of 80-100 m in the river section. This was a result partly due to the continuous flow of the ground water over the geological ages and on the other hand due to the tectonic activity over the past geological time. Geological processes have also contributed to the formation of four distinct brecciated gypsum layers, which resulted from the enlargement of dissolution channels in anhydrite beds and the subsequent collapsing of the overlaying marl beds and being filled with gypsum fragments, blocks of various shapes and sizes of anhydrite and eroded limestone fragments and blocks. All these brecciated gypsum layers were weakly cemented by fine-grained clay matrix and are of such complex composition that they did not accept grouting materials, and when they did, the grouting material did not stay therein permanently and was washed away. Four of these brecciated gypsum beds were tagged as GB beds and were marked in the geological profile under the dam; these are GB0, GB1), (GB2, and GB3. The GB0 is the lowest one at about 80 m depth. The other beds followed in upward sequence. GB3 is the uppermost one and it was uncovered in the spillway chute and bucket foundations excavation and also in part of the powerhouse foundations. The reader is referred to the two references [18, 19], written by the authors for the full understanding of the complex geology of Mosul Dam. The presence of the brecciated gypsum beds led to considerable difficulties in constructing the deep grout curtain and caused repeated grouting to the same spots over and over again in what

was a maintenance grouting program, which has continued from 1987 up to now.

Quantities of injected solid grout materials reached astronomical figures. Total quantities injected in the period (1986~2004) were 93,000 tons. Additional quantities of approximately 35,000 tons were added during the period (2005~2014). But, in spite of this huge maintenance grouting works; as it has been called, grouting cannot be seen as a long-term safety improvement measure. On the contrary, studies have shown that a good part of the original rock has been replaced by friable grouting materials resulting in an overall weakening of the foundations [20]. Moreover, continuing grouting did not help in ceasing the dissolution of gypsum and anhydrite beds; but, has resulted in the progress of the dissolution front deeper into the foundations [20] and in the general dip direction of the bedding, which is NW-SE. The dissolution phenomenon was not confined to the dam foundations; but, its manifestations are evident around the site in the formation of many sinkholes downstream of the dam. Many other sinkholes along the rim of the reservoir close to its right abutment were observed, and numerous sinkholes mapped in the reservoir floor itself, in addition to many springs, dissolution caves and tunnels and ground surface cracking [21].

Mosul Dam is plagued with severe problems threatening its integrity and posing serious safety threats to the communities inhabiting the Tigris River flood plain downstream of the dam. This was made clear by the numerous studies performed so far on its potential failure and the catastrophic results of the generated flood wave. The last of these studies together with all the previous ones is discussed in Refs. [22, 23].

During 1987, concerns over the safety of Mosul Dam were building up as a result of the unsuccessful attempts to solve the grout curtain problems and the increasing dissolution in the foundations; such that governmental responsible authorities took the unusual step and drastic decision to build a protection dam 40 km downstream of Mosul Dam in a location called Badush. This dam if completed could retain the full volume of the flood wave resulting from Mosul Dam failure. The dam was designed in a great speed and construction started on the first of January, 1988 but construction was halted at the end of 1990 as a consequence of the war on Iraq in the aftermath of its occupation of Kuwait. Resumption of the work was never done due to the economic sanctions imposed on the country by the United Nations and the following war in 2003. More details are found on this dam in Ref. [23] cited before.

Mosul Dam safety conditions were thoroughly investigated in 2004~2005 by two American companies working in a joint venture and a comprehensive report was issued in August, 2005 [15]. The report investigated all deficiencies of the dam and its safety concerns and threats to downstream communities. A full safety management study was included by using risk management guidelines as stipulated by the FEMA. Definite and concrete recommendations to ensure reducing the risks and the required future actions were made. As a first step, the reviewers had to go through all designs, study reports, monitoring and instrumentation reports in addition to seepage measurement and chemical analysis results of these seepages. The foundation conditions were studied carefully and records of the maintenance grouting program over all the previous years were thoroughly examined. Equal weight was given to all the appurtenant structures and their design criteria. The objective was to possibly outline and define accurately all the potential failure modes as a first step in the risk management processes.

6.1 Categorization and Description of Failure Modes

A screening process was first performed in which all the less likely, likely, and more likely potential failure modes that could impinge on the dam safety and cause risk issues were established and categorized according to the loading condition under which they may occur.

Thirteen such failure modes were established and listed in Table 4.

This compilation did not list the internal seepage/piping and mass stability of embankment failure modes under unusual flood loading as the maximum increase in the hydrostatic head in this case at water level of 338 m.a.s.l is less than 10% of the actual head of 100 m in the usual loading case when the level is at 330 m.a.s.l. Seepage failure mode under earthquake loading was also eliminated as being considered not significantly affected by this type of loading.

6.2 Evaluation of Failure Modes

All the failure modes obtained and shown in Table 4 were studied one by one thoroughly in the next step. The sequence of events that could lead to dam failure in each of them was identified and lists of the expected adverse condition likely to result were also examined. Table 5 gives the final conclusions of this evaluation and ranking processes.

Potential failure modes (N1, N2, and N3) have the highest likelihood of occurrence and the possibility of taking place within limited or no warning time, adding

Table 4 Mosul Dam potential failure modes classification and description.

Type of loading	PFM designation	Description
Usual (normal loading)	PFM N1	Shallow foundation seepage in the main valley
	PFM N2	Intermediate foundation seepage in the main valley
	PFM N3	Deep foundation seepage in the main valley
	PFM N4	Right abutment foundation seepage
	PFM N5	Left abutment foundation seepage
	PFM N6	Internal seepage/piping through empanelment
	PFM N7	Static mass stability of the embankment
	PFM N8	Bottom outlet plunge pool erosion
	PFM N9	Seepage along the penstocks or bottom outlets conduits
Unusual loading (floods)	PFM F1	Embankment overtopping
	PFM F2	Chute failure during spillway operation
Extreme loading (earthquakes)	PFM E1	Earthquakes-induced embankment deformation
	PFM E2	Earthquake-induced damage to spillway headwork

Table 5 Evaluation results of failure modes for Mosul Dam.

PFM	Description	Category	Basis for category assignment
N1	Usual loading—shallow foundation seepage in the main valley	I	Judged to be possible, and also judged to able to develop with limited or no warning of development.
N2	Usual loading—intermediate foundation seepage in the main valley	I	Judged to be possible, and also judged to able to develop with limited or no warning of development.
N3	Usual loading—deep foundation seepage in the main valley	I	Judged to be possible, and also judged to able to develop with limited or no warning of development.
N4	Usual loading	II	Judged to be physically possible but unlikely to progress to failure.
N5	Usual loading	II/IV	Judged to be physically possible but very unlikely to progress to failure, however not sufficiently unlikely to be classified as Category IV.
N6	Usual loading	IV	Judged to be very unlikely.
N7	Usual loading	IV	Judged to be very unlikely.
N8	Usual loading	IV	Judged to be very unlikely.
N9	Usual loading	IV	Judged to be very unlikely.
F1	Unusual loading	IV	Judged to be very unlikely.
F2	Unusual loading	II	Judged to be physically possible, but unlikely to progress to failure.
E1	Extreme loading	IV	Judged to be very unlikely.
E2	Extreme loading	IV	Judged to be very unlikely.

to this the fact that they could result in the full breach of the dam leading to the complete release of the reservoir with catastrophic results. These conclusions were achieved after careful and detailed study which defined the sequence of events leading to them step by step. The full analysis is too lengthy for the scope of this paper; therefore, it is summarized and condensed as shown in Table 6, which also gives required actions and risk reduction measures and more is said on this evaluation later.

6.3 Evaluation of Risk for All Failure Modes

In the assignment of the various potential failure modes to the FEMA categories, the two guiding principles in their evaluation were; their likelihood of occurrence and the magnitude of risk they presented. Risk itself was visualized as: (1) risk to loss-of-life for the downstream population; and (2) economic losses due to the loss of dam benefits in addition to damages to downstream infrastructures, buildings, and facilities which would be substantial. This evaluation process resulted in assigning PFM (N1, N2, and N3) explained already to Category 1. Potential failure mode (PFN 4) which represents right abutment foundation failure and (PFM F2) depicting chute failure during spillway operation was judged physically possible but not likely to progress to uncontrolled release of the reservoir resulting in their assignment to Category II. The failure of Oroville Dam spillway in the United State in 2017 is seen as very similar to PFM F2 [24] Oroville Dam case.

The examination of PFM 5 which describes failure due to left abutment foundation seepage resulted in giving it a rating of II/IV. The judgment was based on the fact that this mode is physically possible which entitles it to Category II but it is believed to be significantly less likely than PFMs N4 and F2. All remaining PFM were judged as very unlikely.

Table 6 Evaluation of PMFs (N1, N2, N3).

PFM	Description	Required actions and risk reduction measure	Category
N1	Cavity/cavern forms u/s at depth (0-10) m below foundation in GB1, GB2, GB3 and possible collapse of cavern and connecting directly to reservoir, flow velocity increase leading to increased dissolution and internal erosion, Embankment is compromised by core collapse, loss of upstream shell dam breaches. Adverse conditions are: GB1, GB2 had been repeatedly grouted, Sinkholes upstream had occurred, blanket grouting does not extend under shells and doubts on the effectiveness of consolidation grouting, dam could fail if erosion starts at dam/foundation interface. Effect of grout curtain temporary and needs repeated grouting.	Continue grouting, construct a shallow cutoff wall, construct more piezometers in downstream shell and improve piezometer monitoring, perform regular program of bathymetric surveys u/s and d/s, drill check holes for evidence of grouting. Study past sinkholes to better evaluate and understand conditions and causes, Build Badush Dam as a protection dam d/s to decrease risk to population but it does not reduce risk of Mosul Dam failure.	I
N2	A large (5 to 30) meters diameter cavern forms u/s at depth (10-60) meters below foundation in GB1 progressing to foundation/dam body interface connecting to reservoir. Increased inflow into foundation and increased dissolution and wash out of materials, embankment compromised, and collapse of section into cavity and dam breaches: adverse conditions: high grout takes were recorded in GB1, sinkholes upstream had occurred, blanket grouting does not extend to this depth and no blanket under u/s and d/s shells, effect of grout curtain temporary and needs repeated grouting.	Continue grouting, refine piezometers monitoring program, perform regular program of bathymetric surveys u/s and d/s, drill check holes for evidence of grouting, study past sinkholes to better evaluate and understand conditions and causes, build Badush Dam as a protection dam d/s to decrease risk to population but it does not reduce risk of Mosul Dam failure.	I
N3	A very large 30to 40 m diameter cavern forms u/s at depth 60-80 m below foundation in GB0, and possible collapse progresses to the foundation/dam body interface connecting to reservoir, leading to increased dissolution and internal erosion embankment compromised by loss of critical components and collapse of a dam section and dam breaches. Adverse conditions: GBO unit has 15-20 m thickness with repeated high takes grouting, sinkholes have occurred u/s and d/s of dam, with only grouting works in the uncertain deep curtain there may not be visible warning signs of deterioration until too late, dam section may collapse leading to dam breach.	Continue grouting, refine piezometers monitoring program, perform regular program of bathymetric surveys u/s and d/s, drill check holes for evidence of grouting, study past sinkholes to better evaluate and understand conditions and causes, build Badush Dam as a protection dam d/s to decrease risk to population but it does not reduce risk of Mosul Dam failure.	I

In addressing the two guiding principles of risk evaluation, i.e., loss of life and economic damages, a previous study which was carried out by the Swiss Consultants Consortium (1985) [25] was utilized. The study had analyzed the hypothetical failure of Mosul Dam and the subsequent flood wave and had indicated the large extent of the flooded areas downstream the dam and the many cities and population centers impounded down to and including the Capital Baghdad. That study, however, lacked population statistics and detailed information on the structures and cultivated lands that would be destroyed and lost to the economy, Nevertheless, only by looking at the map of Iraq, it is apparent that almost 30% of the whole developed part of Iraq lies within the affected zone. A recent study completed by the Joint Research Center of the European Commission in 2016 showed that population statistics and possible human losses are staggering [26].

6.4 Evaluation of the Risk Reduction Alternatives

The final stage of this risk management study as applied to Mosul Dam case was to come up with the risk reduction measures for all failure modes. These were shown in Table 6 and may be summarized and highlighted in the following points:

(1) Construction of Badush Dam between Mosul Dam and the City of Mosul would address downstream loss-of-life risks for all PFMs;

(2) Construction of a diaphragm wall from the crest of the dam using current technology is an unproven alternative that could not, therefore, be relied upon to reduce loss-of-life risk sufficiently, considering the very large downstream affected area. In addition, this alternative would be much, much costlier than building Badush Dam;

(3) Construction of an upstream diaphragm cutoff wall and upstream impermeable face might possibly reduce loss-of-life risk sufficiently, however, it would require an extended reservoir lowering and it would be much costlier than building Badush Dam;

(4) Foundation grouting does not provide the acceptable long-term loss-of-life reduction measure, considering the very large downstream population at risk;

(5) Continued and improved foundation grouting and careful monitoring and visual inspection would be reasonable risk reduction measures to extend the economic benefits of Mosul Dam (power generation and irrigation) as long as practical.

The main conclusion one should infer is: “While grouting may be seen as an interim risk reduction measure; it does not insure the absolute safety neither to the dam itself nor to the downstream population. On the other hand, while Badush Dam guarantees such full safety to the population according to Washington Group International and Black and Veatch experts, it does not contribute to the safety of Mosul dam itself. The Badush Dam site, however, may need further geological investigation to make sure conditions similar to Mosul Dam foundation do not exist at depth.

The Mosul Dam now is in worse safety condition than in 2005. Resumption of construction of Badush Dam was not done but maintenance grouting continued over the years until the middle of August, 2014 when this activity was forced to stop for about 20 months due to the presence of ISIS around the area. The dam during this period showed real signs of excessive foundation deterioration following the progression of the potential failure modes of Category 1 predicted by this study. Signs of intensive gypsum dissolution indicating cavity formation and movement due to the settlement were clearly recorded by a study, which was performed by a United States interagency team led by the United State Army Corps of Engineers in 2015. The main conclusion of the study was that the dam was experiencing an unacceptable level of risk and safety condition, which was worse than anything that had been observed before. This conclusion was shown in a risk matrix format indicated in Fig. 5. This figure shows the probability of occurrence of breaching

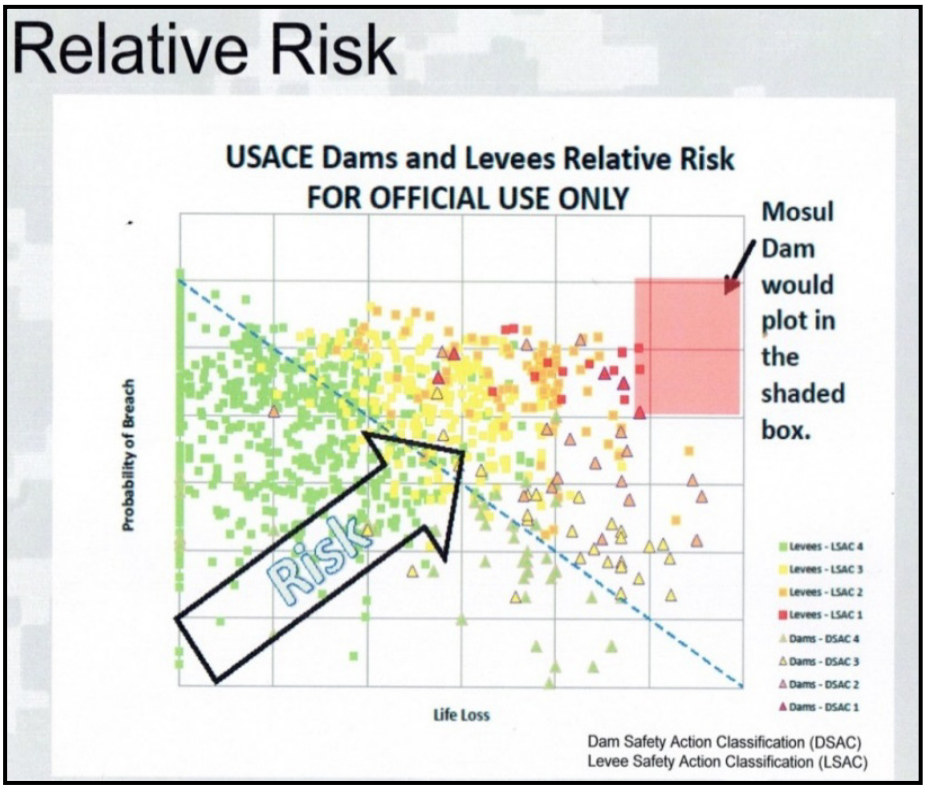

Fig. 5 Mosul Dam relative risk in USACE portfolio of dams and levees.

scenario and the expected losses expressed in terms of loss of life only.

The full report of this study was not revealed for unknown reasons but parts of it were leaked [27]. As a result, from this study, grouting was continued in late 2016 on borrowed money from the World Bank. The decision maker, which in this case is the Iraqi Ministry of Water Resources, is facing the hard fact of what to do next. This situation led the ministry who appreciates now fully the gravity of the situation to organize a conference on Mosul Dam on March 22-24, 2017, to discuss the full problem. Two important resolutions came out from the conference in addition to other resolutions; the first one is to approach the international community for technical and financial support to solve the problem, and the second is to work towards allocating of funds needed to complete the studies on Badush Dam as a protection dam.

7. General Conclusion

Risk management as applied to dams is considered as a very powerful tool in the field of safety evaluation processes and dam risk management. Compared to the traditional safety evaluation processes, it adds to the conventional technical analyses the concept of "risk" in viewing all possibilities of failure and the range of possible social and economic consequences. The importance of this new development has been emphasized by the increasing numbers of aging dams and their possible failure and the gravity of the consequences. Social values and their influence in estimating human and economic losses were catalysts in these processes, and in the decision-making policies. Risk management has become a dependable way for prioritizing actions and resources allocation.

Dam owners in different countries have applied always dam safety procedures within the technical standards and the legislative frameworks prescribed by the authorities in their countries, but the new awareness of the value of risk management is leading many of these owners to follow the new trends also. This is

driving governmental responsible authorities to introduce changes to their legislations to conform to the new trends. Risk assessment, which is at the base of risk management is the processes of tracking potential modes of failure and their progression leading to failure, and from that point, risk evaluation takes over to categorize the levels of consequences as a mean leading to decision making.

Taking the example of Mosul Dam, the risk management study indicated clearly not only the technical defects of which the dam is afflicted by, but also showed the most likely course leading to its failure, and judged the consequences of such failure prescribing at the same time possible solution to address them. In a country like Iraq, which owns a number of large dams and has the potential for constructing many future ones, the application of risk management policies is clearly needed. The fact that all these dams are located where they could pose great dangers to population and infrastructures makes this an urgent task. The limitation of recourses available to the government may drive towards a policy of scheduling necessary actions, but prioritization of these actions can only be made through a risk management approach and this process must be started now and not tomorrow.

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Journal of Civil Engineering and Architecture 11 (2017) 653-662
doi: 10.17265/1934-7359/2017.07.003

Determination and Removal of Endocrine Disruptors in Wastewater by Activated Carbon

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Abstract: This study aimed to evaluate the EDC (endocrine disruptors compounds) in the city of São Paulo's water sources, from samples collected at predetermined sampling points and to evaluate the adsorptive capacity of these compounds in different types of activated carbon. The effects of these EDC on humans are not well established due to the necessary large exposure time for the effect's manifestation. After tests using powdered and granular activated carbon, all samples were filtered under vacuum using cellulose acetate membrane (0.45 μm) to remove eventual impurities, and posteriorly carried out the solid-phase extraction SPE (solid-phase extraction) and chromatographic analysis. The results lead to the conclusion that both powdered activated carbon have removal effectiveness of these compounds by adsorption. Furthermore, great amount of endocrine disruptors were found at several sampling points in river and city's water reservoirs, which shows different levels of pollution of water sources, some of them responsible for the watersupply of the city of São Paulo, Brazil.

Key words: Activated carbon, endocrine disruptors, adsorption, solid-phase extraction, chromatographic analysis, micropollutants.

1. Introduction

Increasing cities' urbanization due to increased population, has generated several environmental impacts worldwide, and these changes have happened quickly and uncontrollably [1], highlighting the disposal of municipal wastewater, which collects much of the by-products regarding this intense urbanization.

In this regard, measures to control the pollution have, as one of the main objectives, to protect water bodies from compounds and materials dumps that can cause eutrophication processes, oxygen depletion, toxicity, among other negative impacts, which consequently reduce biological diversity and also turn it dangerous for drinkable water and other human consumption purposes. Among these compounds, whose most part has final destination directly to the environment, are highlighted PPCPs (pharmaceutical and personal care products) [2, 3]. With the increasing in production and consumption of more and new chemicals compounds, which in many cases have yet unknown properties, but harmful to the health and the environment, or even recognized with deleterious properties, there is a worsening of the problem because of the inefficiency in collection and treatment of municipal sewage and industrial effluents in developing countries, which are often thrown inadequately into the environment. These facts enable emerging concentration of contaminants in the environment [4].

The emerging contaminants class, such as PPCPs, covers various groups of anthropogenic and natural substances, among which are included drugs, toilets, industrial byproducts and hormones that, even if in the environment at low concentrations (μg/L to pg/L), are capable of causing organisms' harmful effects. Some of these emerging contaminants, such as estrogens, phytoestrogens, alkylphenols, brominated flame retardants, are classified also as endocrine disruptors. These compounds are harmful to ecosystems and, despite its occurrence in different environmental compartments, do not have specific regulation in Brazil and many countries and, therefore, are not properly

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monitored [4, 5].

The endocrine disruptors are substances that have the ability to interact and cause changes in endocrine system's functions, simulating the activity of endogenous hormones that may cause damage to the body and their descendants. These substances are divided into three groups: the natural estrogens, synthetic estrogens and xenoestrogens [4].

Synthetic estrogens are steroids with a modified molecular structure, found in drugs, especially those assigned to hormone therapies replacement, treatment of neoplasms and contraceptives. They have high potential to interfere and cause damage to the human endocrine system, and the 17α-ethinylestradiol (EE 2), derived from the 17β-estradiol (E2), is one of its greatest representatives found in oral contraceptives. In the case of natural estrogens, these substances constitute a portion of the hormones produced by the organism, mainly the 17 β-estradiol (E2), estrone (E1) and estriol (E3). These hormones are related to feminine characteristics and other important processes, such as growth, development and behavior, immune and cardiovascular systems, with influence to brain development. Xenoestrogens, for example, BisphenolA monomer, they are generally less harmful and more widely found in the environment, but also possess the ability to mimic and block the endogenous estrogens activity [4]. Natural and synthetic estrogens act in ng/L order of magnitude and alkylphenol compounds (nonylphenol) demonstrate estrogenic activity in mgL^{-1} concentrations [6, 7].

Although the effects of these substances in humans are not well known due to the long time required for the manifestation of the effects, the impacts of environmental estrogens in aquatic life are already known [8]. Studies regarding environmental estrogens involving animals confirm that these compounds are manifested differently, when compared in terms of toxicology to the term "dose-response" traditional, so, these studies produce significant responses at extremely low concentrations [9]. Several studies have studied the major toxic effects of pharmaceutical compounds and natural hormones [10], although these emerging compounds presence is the subject of studies in STPs (sewage treatment plants) in Europe and United States, little has been studied under Brazilian conditions.

2. Treatment Technology: Activated Carbon Adsorption

Several solid materials have been applied to remove endocrine disruptors in water, and among those, the processes and techniques currently in using activated carbon, are promising due to their high efficiency in removing various contaminants [11, 12]. PAC (powdered activated carbon) is more widely used in relation to GAC (granular activated carbon); it is more common to apply PAC in conventional treatment stations, because it is easier to control the dosage and needs a lower investment cost. However, it cannot be regenerated after its use and is difficult to remove from water after treatment. Also, the GAC use is more restricted to situations in which the water is very polluted. Nevertheless, this type of treatment has the advantage of GAC's regeneration, in addition to providing the development of biological activity enabling the organic compounds removal which has greater biodegradability than adsorption [8].

Activated carbon is a microporous adsorbent with a high surface area and the presence of various functional groups on this surface, due to the thermal treatment made under high temperature. It can be derived from various carbonaceous materials (vegetable, mineral and animal) and is widely used in the treatment of industrial effluents for adsorption of organic compounds. The compounds adsorption by activated carbon occurs mainly by physical or chemical processes (chemisorption). In physical adsorption, there is a predominance of Van der Waals Forces between the adsorbent (activated carbon) and the adsorbate (organic micropollutant). In relation to chemisorption, the adsorbent and the adsorbate create a

chemical bond due to the electrostatic forces' predominance (polarization interactions), resulting in molecular structure change [8].

To characterize the affinity sorption between endocrine disruptors and organic material (activated carbon), it is used the octanol-water partition coefficient (K_{OW}). Two sorption types can occur: hydrophobic interactions related to absorption, which is given by logK_{ow} value; and adsorption, that is determined by acid dissociation constant (pKa). Substances with higher logK_{ow} and molecular weight tend to be adsorbed, while those with lower logK_{ow}, due to their less potential for adsorption, tend to appear in higher concentrations in water sources [4].

3. Experimental Methods

This research aimed to evaluate: (1) the effectiveness of analytical standards removal of environmental estrogens estrone (E1), 17β-estradiol (E2), estriol, 17α-ethinylestradiol (EE2), and xenoestrogens BPA (bisphenol A) and NP (nonylphenol), dissolved in deionized water in fixed concentrations by adsorption on powdered activated carbon (106/90 and 108/90) and granular activated carbon (8x30 and 12x40); and (2) surface natural water samples were collected at sampling points of Billings and Guarapiranga Reservoirs and Tietê river in São Paulo, Brazil, conducted bimonthly by CETESB (Environmental Company of São Paulo State). After all analysis with activated carbons, the concentration of these compounds was also determined at selected sampling points.

Samples were stored in amber glass bottles (1 L) with polished cover, and transported from CETESB to the laboratory in a thermal container with ice. Posteriorly, the filtration of the sample was made by cellulose acetate membrane with 0.45 μm porosity. Sulfuric acid was added to preserve them stored under 4 °C refrigeration until their use in the experiments.

4. Material and Methods

4.1 Compounds' Determination

The identification and quantification processes of estrogens estrone (E1), 17β-estradiol (E2), estriol, 17α-ethinylestradiol (EE2), and xenoestrogens BPA (bisphenol A) and nonylphenol (NP), were conducted in stages [13-15]. Firstly samples of 500 mL were filtered in vacuumn through a cellulose acetate membrane (0.45 μmporosity); the compounds of interest were extracted from the water samples through a solid-phase extraction using Strata X cartridges. Subsequently, the matrix interferences were removed (particularly those with high polarity), isolating the analytes which were retained in the cartridge with 5 mL of deionized water (flow rate of 3-5 mL/min), leaving it for 5 min in the vacuum.

The samples were eluted and concentrated using the organic solvent ACN (acetonitrile) (HPLC-UV (high performance liquid chromatograph with ultravioletgrade)). The elution was carried out using two volumes of 5 mL ACN in each cartridge connected to the vacuum manifold (flow rate of 3-5 mL/min), and posteriorly collected in vials of 10 mL capacity for each one. After all ACN flowed, the cartridges remained about 5 min in vacuum to ensure the passage of entire solvent. Thus, each eluted sample in the vial, with 10 mL ACN concentration, remained in contact with a nitrogen flow (gas) to evaporate until completely dry. Then the samples were reconstituted in the same vial with 0.5 mL MeOH (HPLC-UV grade) to desorb the analytes of interest and concentrate it in 0.5 mL (Fig. 1). Consecutively, 0.5 mL samples were analyzed using a HPLC-UV detection.

The whole process was adapted from Araújo [16], Lanças [14], López de Alda and Barceló [17], Raimundo [18], and Verbinnen et al. [19].

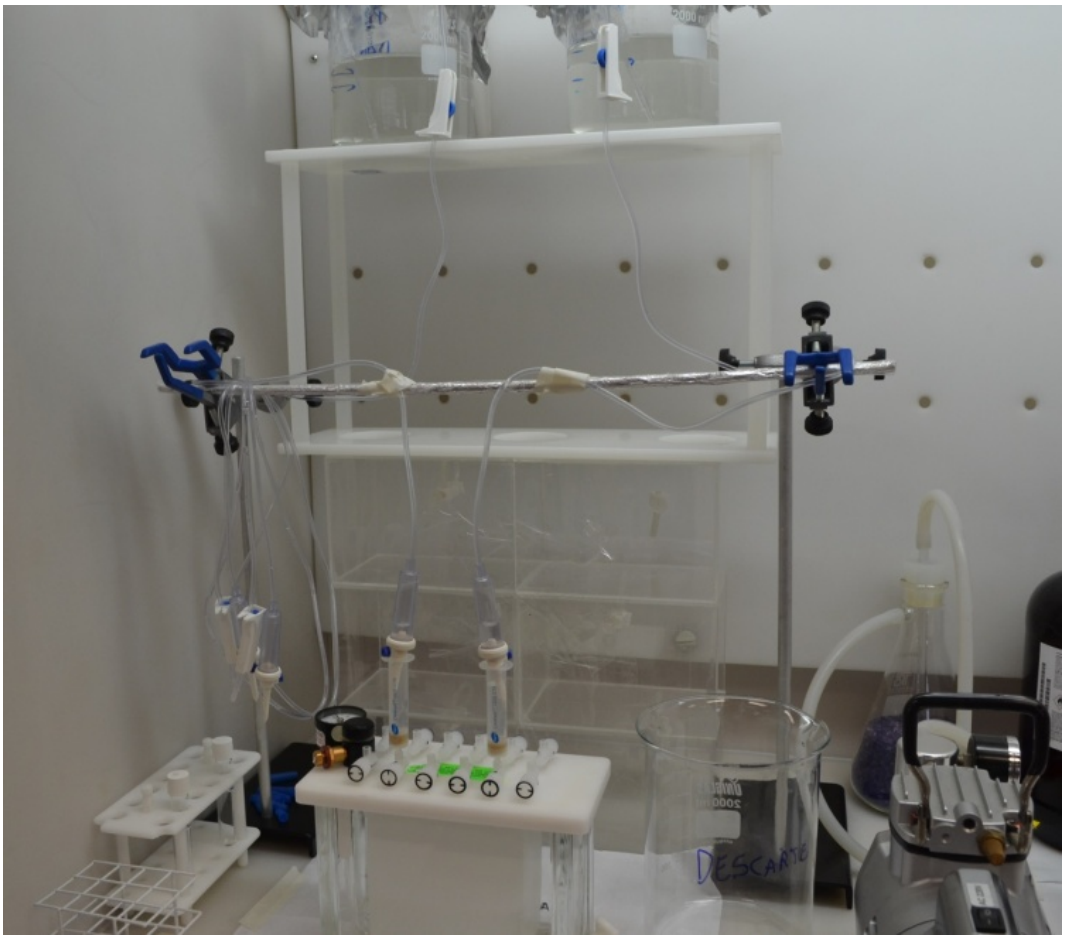

Fig. 1 Experimental equipment used in the SPE (solid-phase extraction) phase.

5. Adsorption by Activated Carbon

5.1 PAC (Powdered Activated Carbon)

Two types of PAC produced from vegetable source (Pinus), one of them 106/90 (600 mg/g iodine number) and other 108/90 (800 mg/g iodine number). Powdered activated carbon was used to treat 500 mL standard solutions of deionized water containing 1 mg/L compound of interest's solution (estrone, 17β-estradiol, estriol, 17α-ethinylestradiol, Bisphenol A and nonylphenol).

Experiments were performed in triplicate for both types of powdered activated carbon totaling 54 tests, varying the activated carbon concentration and its contact time with the standard solution. Solutions with powdered activated carbon treatment were submitted to constant agitation (120 rpm) in the jar test equipment (Fig. 2). After mixing, the samples were filtered under vacuum using cellulose acetate membrane (0.45 μm porosity) to remove the PAC, and posteriorly carried out the solid phase extraction SPE and chromatographic analysis aforementioned.

5.2 GAC (Granular Activated Carbon)

Two types of GAC were used in experiments, one with smaller granulometry (8 × 30 mm) and other with largergranulometry (12 × 40 mm). Experiments were conducted in glass column 5 × 30 cm (internal diameter × height), filled with 33 g of each GAC to the percolation of 500 mL standard solution in descending continuous flow, varying the time of standard solution passage by flow control. Although the CAG can be regenerated, in this present study, it was discarded and completely replaced at the moment that its saturation started in the columns.

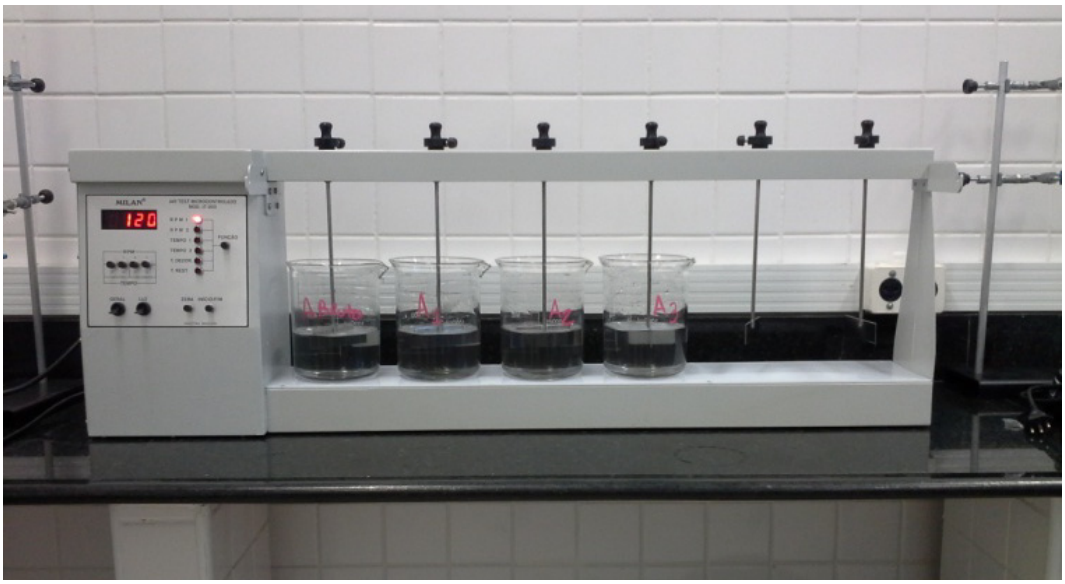

Fig. 2 Jar test equipment.

Table1 *p*-values for each factor.

Compounds	*p*-values time	*p*-values concentration	*p*-values time × concentration
Estriol	0	0	0
Estrone (E1)	0.434	0.458	0.008
17α-ethinylestradiol (EE2)	0.442	0.476	0.001
17β-estradiol (E2)	0.284	0.006	0
Bisphenol A (BPA)	0	0	0
Nonylphenol (NP)	0.313	0	0.761

After the conclusion of the assays, the samples were filtered under vacuum using cellulose acetate membrane (0.45 μm porosity) to remove any eventual impurities from the GAC, and posteriorly also carried out the SPE and chromatographic analysis aforementioned.

6. Results and Discussion

6.1 Evaluation of Estrogens Removal Process by Powdered Activated Carbons (PACs)

ANOVA (analysis of variance with interaction) was used to evaluate the estrogens removal by powdered activated carbon (106/90 and 108/90), which enabled the comparison of quantitative factors (treatments): time (contact time between PAC and samples), concentration (PAC concentration in the sample) and time versus concentration (interaction between two factors). The factors showed statistical significance (probably true), so, they influenced the estrogens removal by adsorption when *p*-value was lower than 0.05. Thus, the factor's significance will be greater for removing the compound of interest.

6.2 Powdered Activated Carbon 106/90 (PAC 106/90)

Tests performed by PAC 106/90, only estriol and Bisphenol A presented *p*-value less than 0.05 for time factor, i.e., the contact time between these compounds and activated carbon influenced its removal. In this case, one hour of contact showed more effective removal for both compounds. In relation to the concentration factor, the *p*-value less than 0.05 was obtained for removal of estriol, 17β-estradiol, bisphenol A and nonylphenol, and 50 mg/L of activated carbon was the most effective concentration in the removal process (Table 1).

However, the interaction analysis between time and concentration was significant for all compounds

(except for nonylphenol) with 1 and 2 hours of variation in removal time, and 50 mg/L activated carbon as the most effective concentration This result was expected because there is a contact surface loss with minor amounts of PAC. The mechanical agitation of samples by jar test may also have interfered in the kinetics of chemical reaction hindering the chemisorption process by collisions between the adsorbent (PAC) and adsorbate (estrogens/xenoestrogens), with a possible predominance of physical adsorption. In physical adsorption, weaker chemical bonds (Van der Waals Forces) between activated carbon and estrogen/xenoestrogens enable the occurrence of desorption, affording the return of the compounds to the sample again.

6.3 Powdered Activated Carbon 108/90 (PAC 108/90)

For removal using PAC 108/90, estriol was the only compound that presented a *p*-value less than 0.05 for the time factor, which indicated that contact time between compounds and activated carbon, in general, was not decisive in the removal process. Nevertheless, concentration factor was significant for removal of estriol, 17α-ethinylestradiol, 17β-estradiol, bisphenol A and nonylphenol (*p*-value less than 0.05 or very close to 0.05), with 50 mg/L of activated carbon as the most effective concentration in the process. In relation to factor interaction between time and concentration, the greater significance was obtained from removal of estriol and bisphenol, with 4 hours and 50 mg/L of activated carbon as the most effective time and concentration, respectively (Table 2). As previously seen for PAC 106/90, concentration was the greater significant factor (50 mg/L activated carbon as more effective), due to the larger surface contact and therefore more binding sites for compounds.

6.4 Evaluation of Estrogens Removal Process by GACs (Granular Activated Carbons)

From the experiments using granular activated carbon (GAC), it was verified the efficiency of removal process (Table 3) by two different granulometry (8 × 30 and 12 × 40).

Table 2 *p*-values for ecah factor.

Compounds	*p*-values time	*p*-values concentration	*p*-values time × concentration
Estriol	0.013	0	0
Estrone (E1)	0.387	0.195	0.483
17α-ethinylestradiol (EE2)	0.253	0.053	0.180
17β-estradiol (E2)	0.318	0.053	0.439
Bisphenol A (BPA)	0.404	0.001	0.001
Nonylphenol (NP)	0.920	0.015	0.523

Table 3 Removal efficiency by GACs.

Compounds	CAG 8 × 30 (%)	CAG 12 × 40 (%)
E1	21.1	38.2
E2	17.4	41.4
E3	14.1	41.9
EE2	14.1	36.8
BPA	19.6	48.2
4n-NP	12.8	25.1

The removal efficiency percentages shown (Table 6) were lower than expected, according to studies using granular activated carbon [20], which obtained up to approximately 99% organic compound removal (2,4-D), using a concentration solution 100 times higher and lower granular activated carbon mass, compared to the concentrations used in this study. The lower removal efficiency of compounds in this research compared to Loureiro [20], may possibly be related to the filling of GAC in the columns, due to occurrence of air bubbles in some tests, or because the sample flowed quickly through the column. However, as it was expected, the GAC with large granulometry (12 × 40 mm) showed more effectivity in compounds removal than GAC with smaller granulometry (8 × 30 mm).

6.5 Determination of Estrogens/Xenoestrogens in São Paulo's Water Sources

The determination step for estrogens estrone, 17β-estradiol, estriol, 17α-ethinylestradiol and xenoestrogens bisphenol A and nonylphenol, from sampling points at Billings and Guarapiranga Reservoirs, and Tietêriver (near to Remédios and Bandeiras Bridges), in São Paulo, Brazil, showed a high level of water quality degradation as expected. The raw sewage, untreated wastewater and the variety of waste released directly in the water sources can be responsible for this degradation in São Paulo.

Figs. 3-6 show the distribution of estrogens/xenoestrogensat sampling points selected in the dams and Tietêriver.

Billings and Guarapiranga reservoirs presented higher levels for estrone and nonylphenol. In Tietêriver, at sampling point near to Bandeiras Bridge, bisphenol A and estriol showed the largest concentrations while at Remédios Bridge's sampling point higher amounts of estriol and estrone were detected.

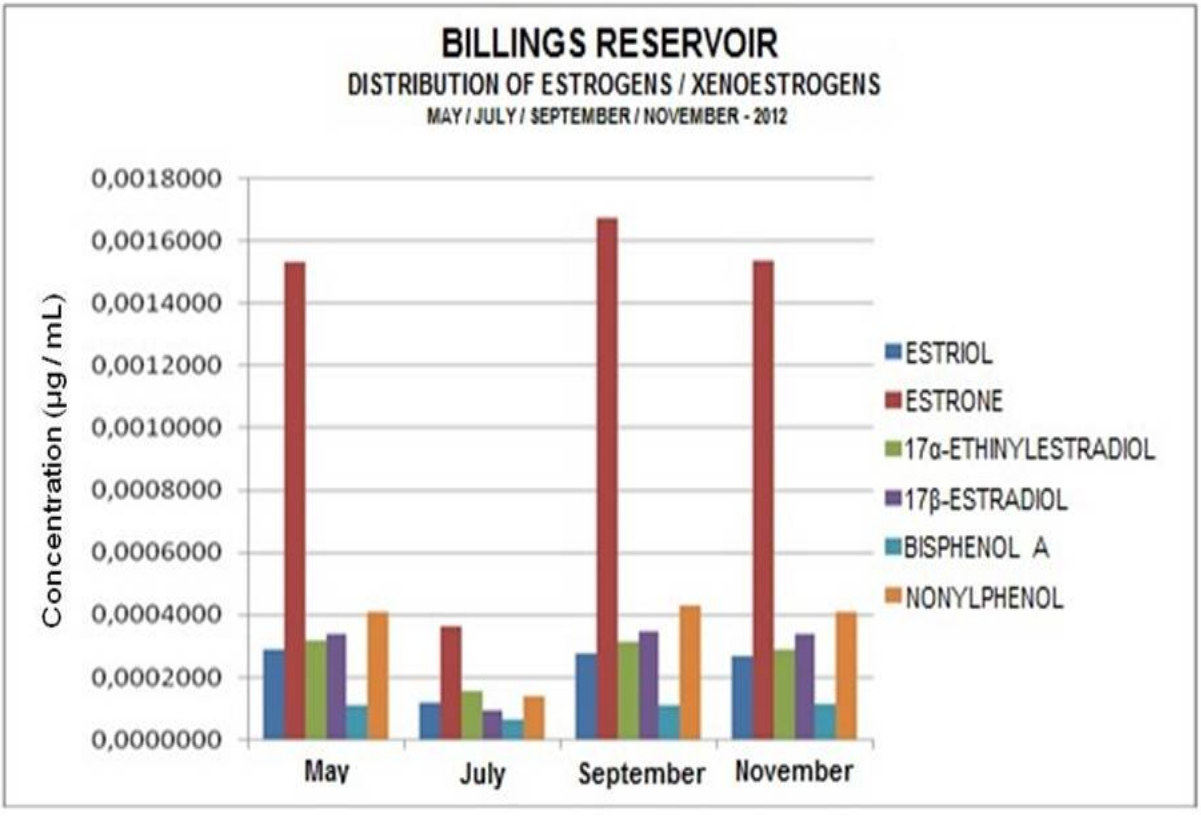

Fig. 3 Distribution of estrogens and xenoestrogens at Billings reservoir (sampling point) during May, July, September and November, 2012.

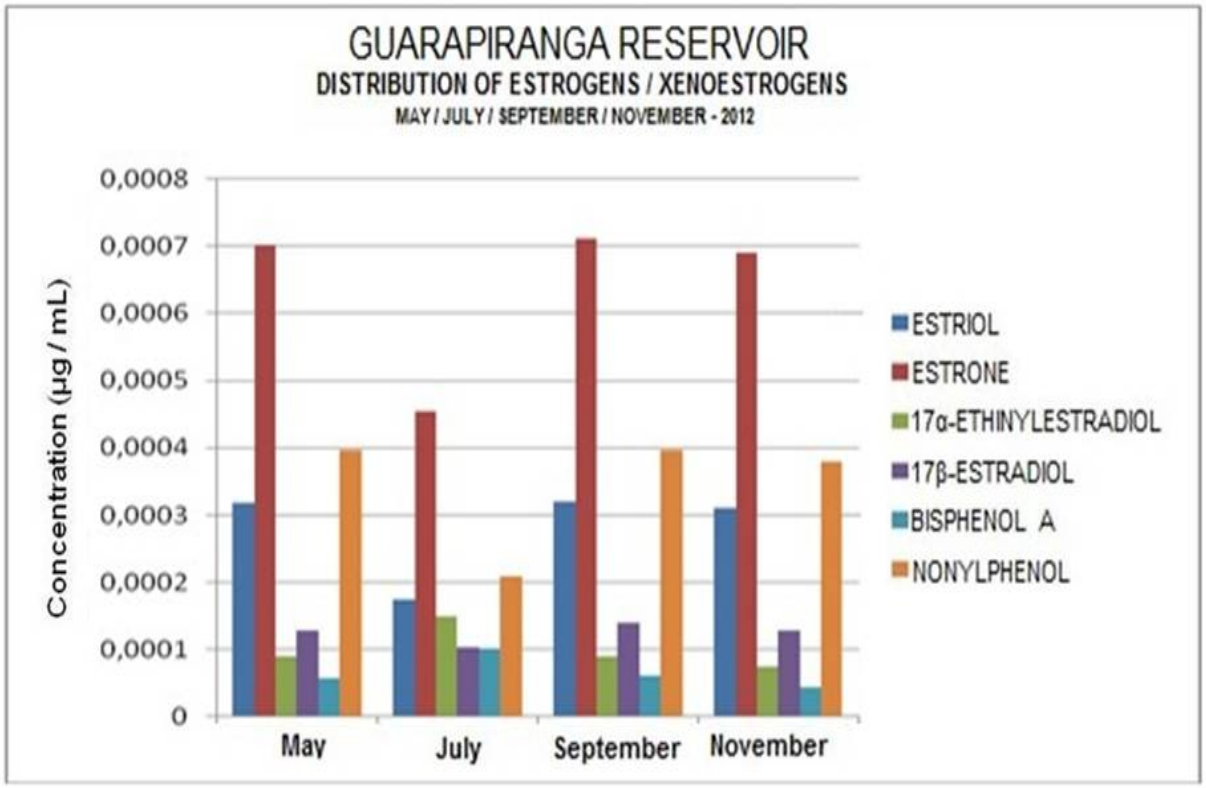

Fig. 4 Distribution of estrogens and xenoestrogens at Guarapiranga reservoir (sampling point) during May, July, September and November, 2012.

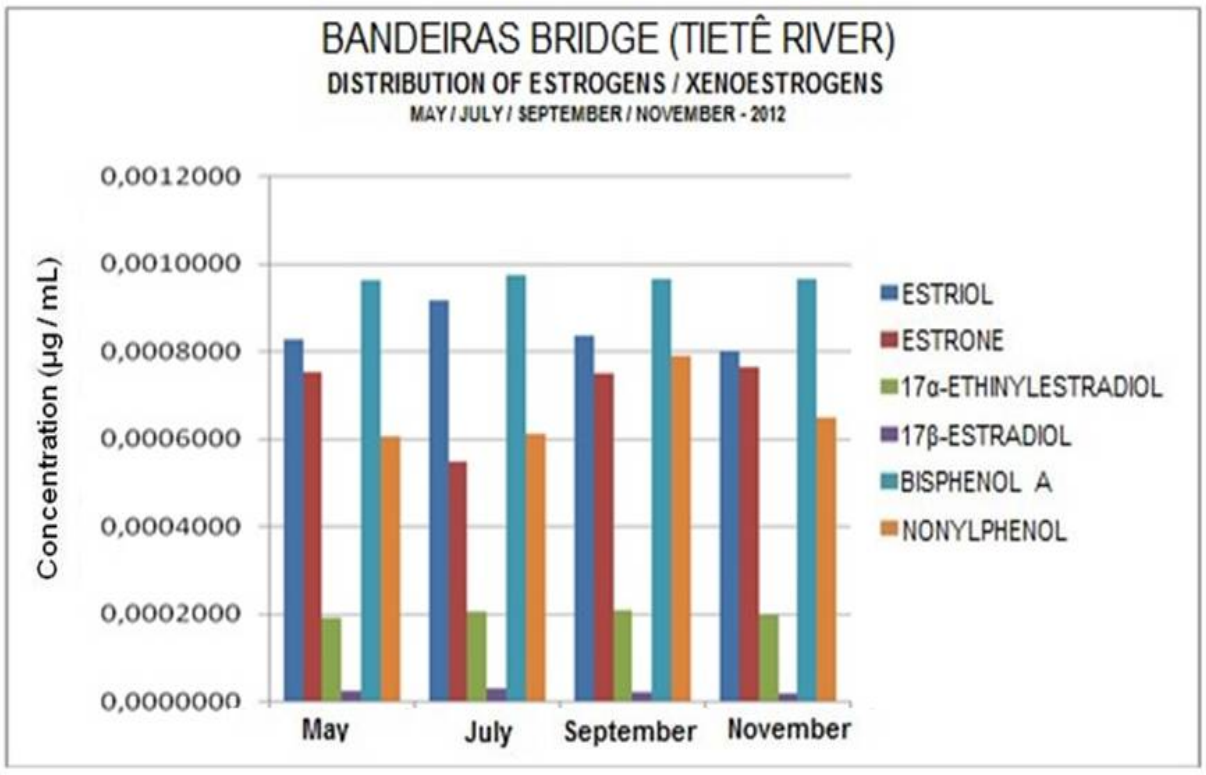

Fig. 5 Distribution of estrogens and xenoestrogens at Bandeiras bridge (Tietêriver sampling point) during May, July, September and November, 2012.

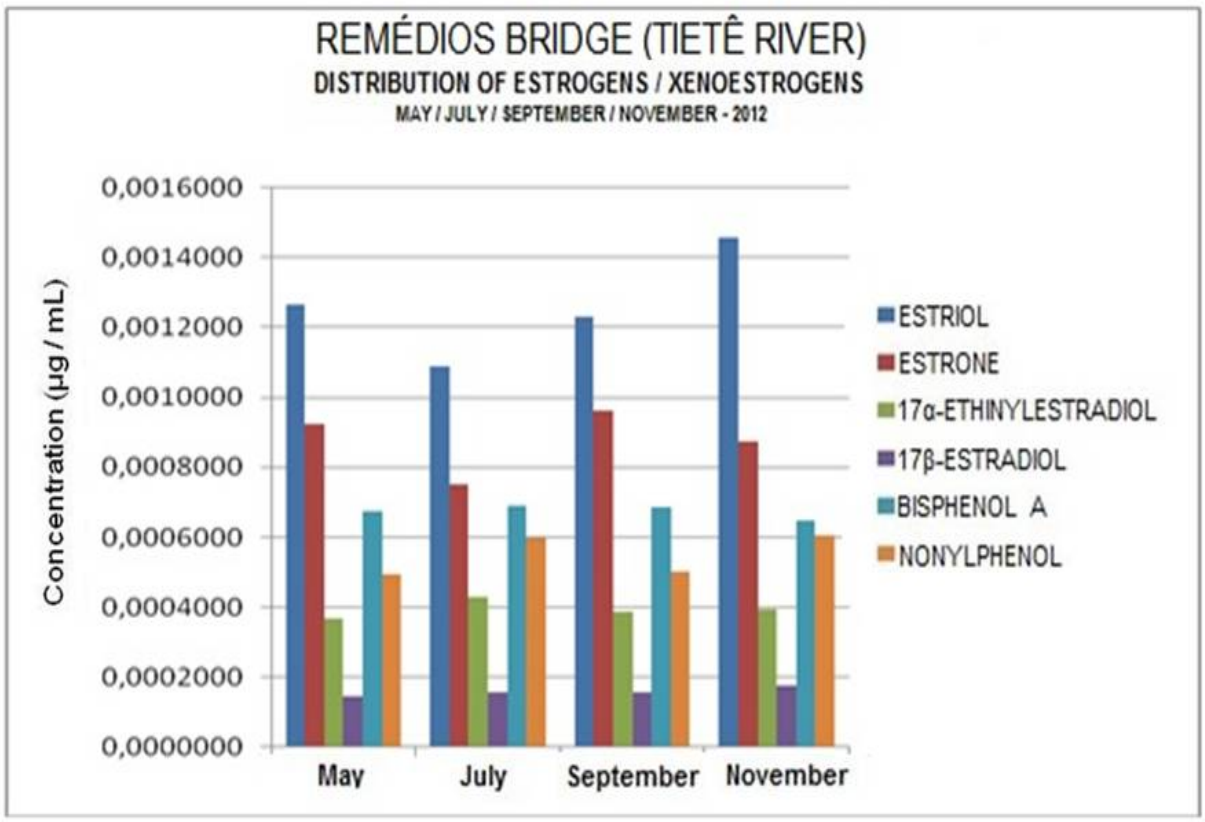

Fig. 6 Distribution of estrogens and xenoestrogens at Remédios bridge (Tietêriver sampling point) during May, July, September and November, 2012.

7. Conclusions

In the experiments with estrogens estrone, 17β-estradiol, estriol, 17α-ethinylestradiol, and xenoestrogens bisphenol A and nonylphenol, it was verified the removal effectiveness of these compounds by adsorption using powdered activated carbon 106/90 and 108/90. For both types of PAC, the concentration factor was decisive, wherein 50 mg/L carbon concentration was the most effective. However, for both types of granular activated carbon, only removal efficiencies were checked, which proved unsatisfactory, possibly due to operational problems.

As for the determination of interest compounds in water sources that supply São Paulo, they were found at selected sampling points. This situation concerns for water's degradation and pollution that currently do not receive specific treatment to remove these compounds, and it has been used for human consumption in the city.

Nevertheless, more research is necessary in order to investigate estrogenic potential of more chemicals substances, as well as the search for viable technology for removing such compounds, with the goal to regulate and reduce these substances in the environment, besides avoiding the irregular disposal of several wastes.

Acknowledgments

The authors would like to thank the National Council for Scientific and Technological Development (CNPq), and the Meridional Foundation IMED, for all financial support to the development and publication of this work.

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Journal of Civil Engineering and Architecture 11 (2017) 663-676
doi: 10.17265/1934-7359/2017.07.004

Sustainable Identities in the Technological Esprit of Architecture

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Abstract: Innovation and energy efficiency are the essential paradigms of the new technology and design culture, in the sustainable economic and social development, highlighting the performance of new technologies, systems and intelligent materials, such as sustainable identities in architectural envelopes. Then, contextualized sustainable architectural objectives favor material and energy flows, pointing to the constructive flexibility, identity and compatibility of technological innovation, which contrasts with climate change. So sustainable use of natural resources, renewable energy, in line with the principles of the 2030 Agenda for SDGs (Sustainable Development Goals). The well-being of the community with the valorisation of places and the environment, indicates the technological excellence of architecture, synchronous with territorial metamorphoses. Thus, vision glass principles in the environmentally responsive wall, and engineered wall, in external awareness, cellular flooring for eco-efficiency. The methodologies indicate the applications of new design models for new constructions and regeneration, with dynamic, efficient and integrated envelopes integrated with renewable energy storage technologies, neomaterials and high performance insulating. Then HPP (high performance polymers) nanotechnologies are based on efficient pigments, intelligent bioPCM (PCM for phase change material) nano technologies, thermoregulators with high thermal inertia. The goal is towards an escalation of sustainable architectures that contrasts with climate change and pollution of anthropic origin, for smart and sustainable growth.

Key words: Architecture, technology, sustainability, energy storage, intelligent materials, nanotechnologies, quality.

1. Introduction

The constructive iter, consolidated by emerging sustainable systems, integrates into new spatial articulations marked by a dialectics of identity and highlighted the technological excellence of architecture. It is synchronous with territorial metamorphoses and the work in progress of innovation and building production by highlighting efficient technological and material systems. For this reason, it is necessary to apply new and exclusive operating models with the realization of sustainable architectures, low environmental impact, through a metaproject of a framework and user activities, focusing on material and energy flows, across the cycle of the life of the building. They distinguish a pyramidal optimization of morphological, technological and functional choices and where the nature becomes the protagonist of building transformations.

In these, we distinguish the physiognomic and landscaping aspects of a modern public garden, in the synthesis of an anthropic space. It represents the ideal fulcrum of socio-economic and political development with contextual architectures that highlight the excellence of sustainable technological systems, intelligent materials and components, and new nanostructures based on natural pigments [1]. For this reason, an interaction between Genius Loci, efficient envelopes, served by different spatial infrastructures and aimed at valorization of the environment is generated, favoring the comfort and well-being of users in Gemütlichkeit's performance [2], the continuity of fruition between indoor and external spaces. Highlighting dynamic façades and neomaterial with the different colors that camouflage, sustainably,

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in nature. It integrates architectures that distinguish technological excellence, interacting with the climate, with the rational use of environmental resources and context, as the focus of new design. So sustainable types, according to the UPDP (United Nations Development Program) and the New ONU (United Nations Organization) Summit of 2015 in NY, for the adoption of the 2030 Agenda for Sustainable Development, with its 17 SDGs (Sustainable Development Goals) [3]. These highlight the use of renewable resources with accessibility, the adoption of urgent measures against climate change with sustainable use of the earth ecosystem. In particular, the EC (European Commission) 2020 strategy (COM (2010) 2020 final) projects towards smart, sustainable and inclusive growth, fostering innovation, digital society and skills acquisition. So they point to a new integrated technologies in new design processes, with architectures aimed at territorial valorization and natural resources with sensory perception and environmental visibility. And then they evoke feasibility, compatibility and technological quality with the use of natural and ecological materials according to prescriptions, to improve asset values subordinate to management policy of transformation, depending on economic and productive needs and dynamic/anthropic and fixed/natural interrelations. To this end, European standardization organizations develop the technical specifications of various types of processes, materials, products and services, CEN (European Committee for Standardization), CELENEC (European Committee for Electrotechnical Standardization) for Electrotechnics and ETSI (European Telecommunications Standards Institute) for ICT (Information and Communication Technologies), ensuring the interoperability of digital technologies, like the WHO (World Health Organization) and US.EPA (United States-Environmental Protection Agency) recommendations, also focusing on efficiency, energy saving, ecosystem quality, clean air, EEA environment (European Environment Agency). In line with COM (2013) and the new EU 2016/2284-NECD (National Emission Ceilings Directive), for new air quality limits, with emission reduction targets up to 2029 and from 2030 onwards , for the protection of public health, to this end, European Community strategies become more stringent for the ecological and bioclimatic sectors for sustainability, CO_2 reduction, polluting factors both human and environmental, adopting measurements against the emission of particulate-thin powders (PM10, PM is short for particulate matter) (Fig. 1). In Europe, it is noted that the management of inefficient domestic installations, which dissipate in the PM10 or PM2.5 environment through combustion, becoming the main cause of environmental pollution and silk building.

So, sustainability and eco-efficiency in the growing media debate and in IPCC (Intergovernmental Panel on Climate Change).

2. Sustainability in Architecture

2.1 BioPCM Technologies and High Performance Materials

The identification of sustainable design criteria for a new construction process, according to a demanding and performance-based system, is based on the quality requirements of interior environments, contextualization and lifecycle of the building, with reduction and containment of resources, in a productive increase in climatic resources. For this reason, selective and dynamic control criteria [4] are developed for the regulation and conveying of the climatic and environmental flows, through the adoption of clean construction technologies, components and devices capable of interacting with light, air and thermo/hygrometric stresses. Vertical enclosures, for example, typically characterize vision glass through glass curtain wall systems, unit systems (cellular), double or triple skin façades, and so on. They are designed according to the design criteria of the environmentally responsive wall, in interaction with

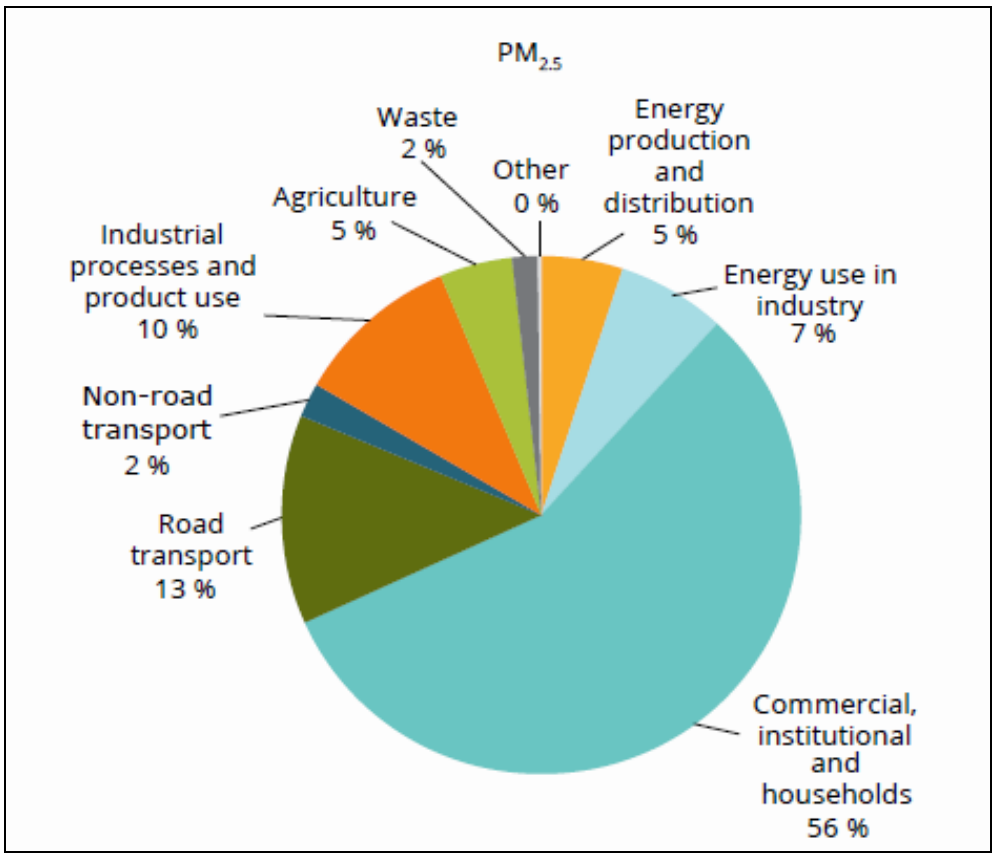

Fig. 1 Emission of PM25 in housing, in Europe.
Source: Ref. [5].

Fig. 2 Buffer DSF (double skin façade) zones with blind system.
Source: Ref. [6].

context and environment, through a perceptive and organic contact, with the dual function of transmitting the heat of air to the cavity (Fig. 2), in the interior , in winter, instead of removing the heat of the indoor outdoors, in the summer. In addition, the same vertical enclosures are also carried out according to the criteria of engineered wall, for hygrometric thermo control, passive natural ventilation for the interior, light transmission and heat. They have the absorption and control function for the compatibility of external noise, reduction and increase of radioactive heat exchangers, between user and surface, control of the dominant

summer and winter winds, and so on. Additionally, sustainable design criteria for external awareness and cellular floor planning for eco-efficiency are used. So in solar planning and relationship with the user, in building systems, it is indicated by a reduction of about 20% for shading, orientation with the adoption of innovative low-E, passive and active technological systems, high tech, innovative quality criteria, right/product/right, level/right, costumer, and the use of bio-materials, with high energy efficiency. These façade systems are integrated with the management of BMS (building management system) systems, to control solar radiation, lowering the darkening (for example, if solar radiation is greater than 200 W/m², leaving the transparency of the glasses) and to reduce the energy consumption, in many works, among which, in the architectural envelope of The Shard, by arch. Renzo Piano, in London (Fig. 3).

In these principles of efficient façades, is also highlighted the application of nanostructured intelligent materials and thermoregulators PCMs (phase change material). PCM materials are considered as melting latent heat storage (referred to the building).

They include the cement, plexiglass, wood, such as the laminate used, with its various aesthetic-functional

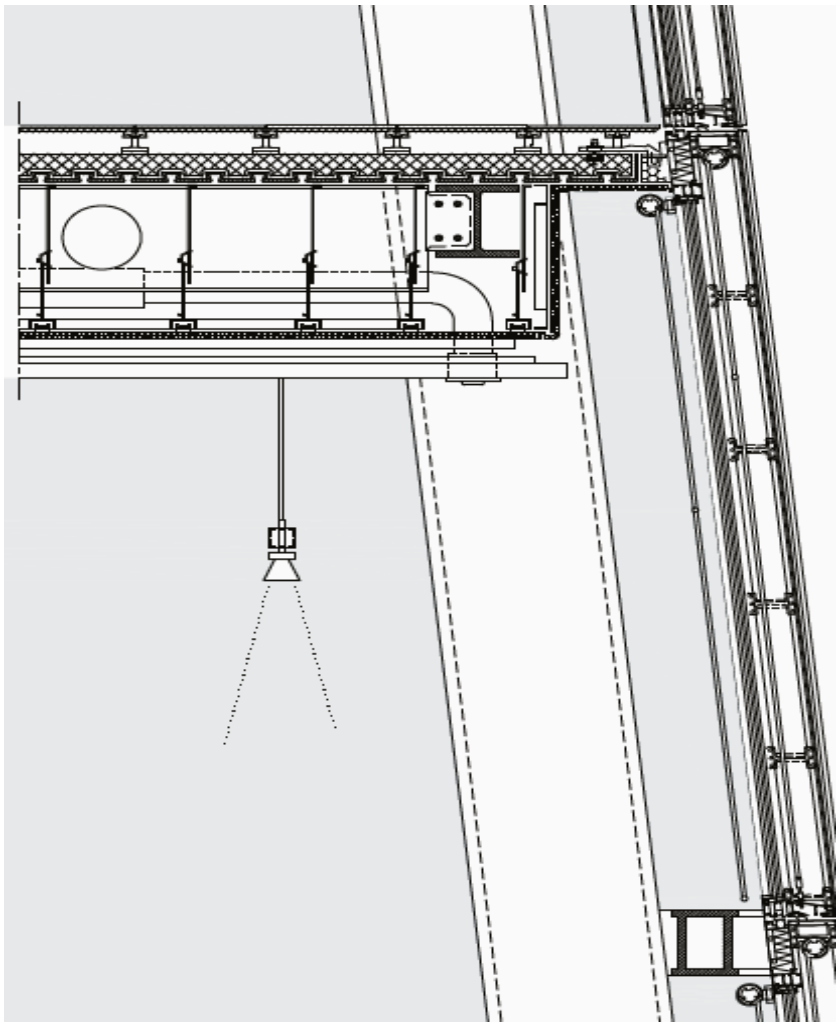

Fig. 3 The Shard, London. Detail of façade with extra clear glass, triple glass DFS, "cellular"system: external with single layer laminated glass, in middle-ventilated space with a roller blind (controlled by BMS system), interior with double insulating glass. BIM (building information modeling) design.

Source: Ref. [7].

performance and ecological characteristics, high antisismic, plasterboard, glass, plaster, building materials, prefabricated blocks, bricks, etc. In some cases for interiors, PCM plaster panels are realized where, depending on the requirements, the amount of thermal accumulation performance of the components can be controlled, according to the thicknesses of the layers. While for prefabricated masonry, aerated green cement blocks are enhanced with latent heat storage capacity and with high thermal, and indoor humidity insulation, environmentally compatible and constant temperatures, as it has a low temperature of internal surface fluctuation, at the same U transmittance value. So their storage capacity does not depend on the thickness of the materials. Some types of PCM-based panels such as those produced in nanoPCM Micronal® PCM (micro capsules) are equipped with high thermal inertia and low transmittance with thermal conductivity values λ = 0.18 W/mk with low thicknesses of about 15 mm. In addition, they exhibit high permeability performance in addition to the latent heat storage (distributed with a certain delay), maintaining their temperature constant up to the melting point, accumulating heat until the complete transformation of the material, from solid state to liquid or from liquid to gaseous, using hydrated salts or paraffin. They are used as heat conductors usually contained in plastic modules, except for hydrates, which also require stainless steel for their corrosion, and also promote the integration between active and passive building systems. Therefore, the advantages of these materials for their use are those that are mainly adopted in the passive technology of bioclimatic architectures, as they reduce the internal temperature peaks of the environments and consequently, energy consumption, for air conditioning. In fact, having capacity to absorb thermal energy and use latent heat (Fig. 4), they can eliminate or reduce the internal conditioning by mitigating the daily temperature thermal fluxes in buildings. In these, because in winter, the insulation reduces thermal dispersions, through the walls while, through glazing anclosures, it increases

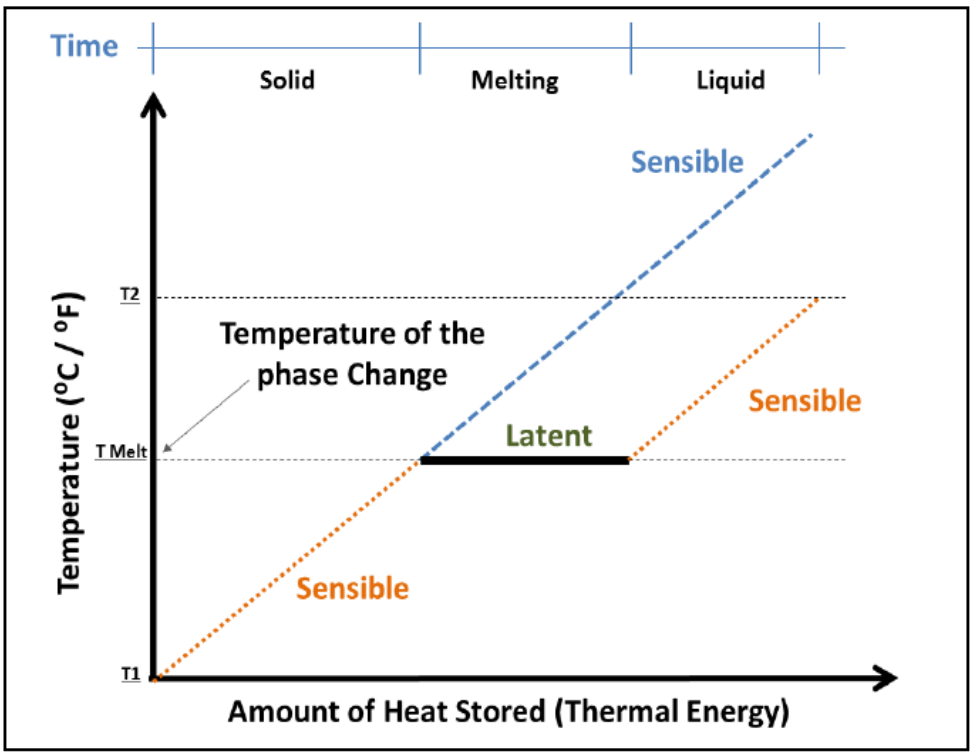

Fig. 4 Graph with temperatures of sensible and latent heat.
Source: Ref. [8].

the flow of solar radiation, with the passive integration of these PCM heat storage materials [9], we can get results of energy efficiency and indoor temperature control. In fact, this is achieved mainly through thermal insulation, latent storage heat, shading, and nighttime ventilation. But to optimize the performance of the envelope, improving the durability of the system [10], the main requirements that PCMs should have, are that they are not hygroscopic, inflammable, toxic or corrosive, with a melting temperature of ca. 25 °C, from the solid/crystalline to the liquid/viscous phase, of its phase change, and a relative high phase transition heat, from the liquid state to the solid state. They must also be equipped with greater management, for their use in the building, through low-cost availability on the market. PCMs are organic (paraffin compounds, non-paraffin compounds), inorganic (salt hydrate, metallics) and eutectic (organic/organic, inorganic/inorganic, and inorganic/organic). They apply to the following different components of the building system: wallboards, ceiling tiles, floor panels, interior wall constructions with micro-encapsulated paraffin wax, interior wall constructions, attics/drop ceiling plenum floor with bio-based (organic), and eutectic salt mixtures materails toot. They were derived from paraffinic organic composites, such as heat conductors usually contained in plastic modules, except for hydrates that also require stainless steel for their corrosion, and some hydrocarbons, but also saline solutions (hydrate salts) derived from inorganic composites. The paraffin, biodegradable and non-corrosive material, microencapsulated in acrylate film or salt hydrate, is much more fluid than salt hydrate, requiring greater compensation space in containment modules due to radiation heat. So in summer, its thermal state remains unaltered, facilitated by prismatic glass plates that dampen the irradiation. According to the 2017 report by the Fraunhofer Institute for Solar Energy Systems ISE, paraffin dispersions such as PCM are stable for more than 20,000 thermal cycles, according to which PCM dispersions are distributed between two plate heat exchangers, whereby the material crystallizes and melts once in the cycle. So a search for materials that significantly and safely reduce super-cooling, even for a large number of cycles, is experimental in several cooling applications in the building, in ceilings and storage units for cooling power, up to cooling of batteries for stationary and mobile applications.

2.2 Applications with Integration in Buildings

The flexibility of components of the architectural envelope provides opportunities for extending its lifecycle (for new or retrofitting), improving its sustainability, or encreses the performance of the buildings. This condition occurs in the building as a function of new functional or commercial requirements by highlighting its identity values, in possible contemporary transformations with the adoption of innovative technologies and materials . The nPCM (nanoPCM) technologies, microencapsulated inorganic composites, distributed in powder forms, are integrated throughout the building envelope for both new construction and retrofitting operations, in which the coat-jacket in the façades is often adopted. Then they are applied in roofs, in double or triple façades that become thermodynamic, in the heating floor (Fig. 5) and in the interior walls, highlighting also plant solutions in heat exchangers, solar collectors and HVAC (Heating, Ventilating And Air Conditioning). In the sustainable project MESSIB (multi-source energy storage system integrated in buildings) financed by the European Commission [11], the accumulation systems are based on the distributed energy on “on time” and hybrid thermal-electric grids. A thermal, multi-technological energy storage system based on PCM materials, microencapsulated paraffin and fluid transmitting energy to the envelope building components, built into the GS (grund storage) thermal storage system, built-in ground energy storage radiant systems.

Fig. 5 Underfloor energy storage with PCM materials.
Source: Ref . [12].

The system becomes a backup for RESs in buildings, which increase EE (energy efficiency) and become more self-sustaining and intelligent (integrated in smart city and smart grid) through the integration of energy storage systems, that reduce energy consumption and environmental impact. Since RESs are variable and intermittent, MESS integration is needed, reducing CO_2 and primary energy demand, with greater market access. In fact, these nanomaterials are systems for energy efficiency and sustainability in buildings, with high thermal accumulation and thermal transmission, high thermal inertia, even with very low thicknesses with the benefit of volumetric and energy saving and low transmittance. The heat storage is obtained when the crystals are melted with their heating, while regaining solidity during the cooling. PCM technologies are therefore also used to alter accumulation masses of opaque envelopes, such as concrete, with a storage capacity of about 10 times lower than that of salt hydrates and favor the integration of active and passive systems' building. In fact, as a passive system, a type of bioPCM technology operating at 20-24 °C, it will be able to maintain indoor climate comfort at the same temperature, without the use of conventional mechanical plants, but with automatic transfer of thermal accumulation, through cooling and natural ventilation, resulting in energy savings from 20% to 40%, and an investment ROI (return on investment) of 1 to about 7 years. Active systems integrate into the accumulated energy, some devices for the additional power supply of the heat and cold transmission process. Additionally, heat accumulators store certain temperatures from renewable energy and transmit them to the environment, depending on the needs, even for the supply of hot water. Recently, NASA (National Aeronautics and Space Administration) has developed a heat exchanger with a PCM HX (heat exchanger) that stores energy by thawing a phase change material based on wax, a device that can support smart grids and smart city. Integrations of PCMs in buildings can occur through heat mass

(passive heating system), and cooling (active systems). Finally, excellent aesthetic performances of façades cladding are identified in diffused translucent stone materials too, from new technologies with minimal thicknesses, laminated marble slabs and hybridized by glass reinforcement and polymer films and PCM integration with photovoltaic technologies.

Like the application of thin-film solar collectors on the south façade of the "Smart Material House", by zillerplus Architekten, residences in Hamburg, Fig. 6 shows a passive building where the heat requirement is calculated by approx 19,250 KWh per hour, per year, or 12 KWh per m^2 per year (passive house guidelines). The building is heated, above all, by solar energy. Radiant floors, such as cold drinking water, are heated by means of a heat exchanger, two storage tanks of up to 2 m^3 containing solar energy passive and energy from the Wilhelmsburg Central network. An automated BMS system controls the intelligent management of the distributed power generation, with its energy saving and access to the distribution local heat grid. Additional efficient technology applications are the BAT (best available technology), as indicated by the European IPPC (Integrated Pollution Prevention and Control) Strategy and the normative AIA (Integrated Environmental Authorization) of Directive 96/61/EC aimed at reducing the environmental impact of production processes.

So technological solutions in various sectors, include waste management, resources in industrial production, ICT (information communication technology). They follow the operating management tools including LCA (life cycle assessment), ecodesign, etc., and diagnostic tools for measuring environmental data. Particularly in the building sector, clean technologies are used, especially in the environmental management of the building to reduce greenhouse gas emissions, VOCs (volatile organic

(a) (b)

Fig. 6 Residences in Hamburg: (a) section; (b) perspective. PCM integration into façade and PV-vacuum tube collectors on the parapet wall.

Source: Ref. [13].

compounds) in indoor environments, but also to reduce energy (thermal and electrical) consumption, raw materials, water consumption, dangerous substances and waste, ect. For the treatment of pollution, we aim at "end of pipe" technologies. The same nano-pigments are innovative thermal energy-efficient materials used in construction, such as in the automotive industry. These HPP (high performance polymers), (polymers, paints and concrete) are added by colored pigments which, with low cost production, avoid production process changes and the building has thermal performance that contributes to the reduction of thermal power plants. Daylighting technologies, prefabricated systems, with dry technologies, reducing thermal dispersion, and self-sufficient planting of active systems to complement passive (photovoltaic and solar panels), optimized by planimetric conformation and envelope configuration. Thus, dual leather envelops with technologies that focus on sustainable identities with

(a) (b)

Fig. 7 Musée D'Arts de Nantes: (a) suspended façade with portuguese white marble on metal frame; (b) Cube's inner perspective.

Source: Ref. [14].

technological exprit with high performance levels. In fact, transparency, slimness and security are also essential parameters of excellent contemporary architectural envelopes, that integrate into the context, including within new sustainable upgrading plans, highlighting continuous, suspended façades (Fig. 7). As in the recent intervention of 2017, for the regeneration and extension by arch. Stanton Williams of the Musée D'Arts de Nantes in France, with works in three areas: the new Cube building, which represents the contemporary art gallery with circular areas, with a suspended façades, the transformations in the palais, and the appropriation spaces of the chapel. The Cube (Fig. 8), a monolithic space with a flexible layout and a simple façades to the north, without windows, resembles the white color of the palais stone and the local *tuffeau nantais*. This new volume, compact and slender, has a suspended façade to the south, on a metallic structure with portuguese white marble, finishes and translucent stratified glass. Then, in the palais tunnel skylights, new daylight systems are introduced, on a pre-existing frame, with layered system of glass, woven fabric and adjustable blind shading.

Thus, high-performance sustainability is both perceptive and qualitative energy, with new design process models and open source envelopes. They exhibit glossy and opaque surfaces with tested and certified neo materials [15], with integrated façade to photovoltaic cells, thermotropic facades, facades with

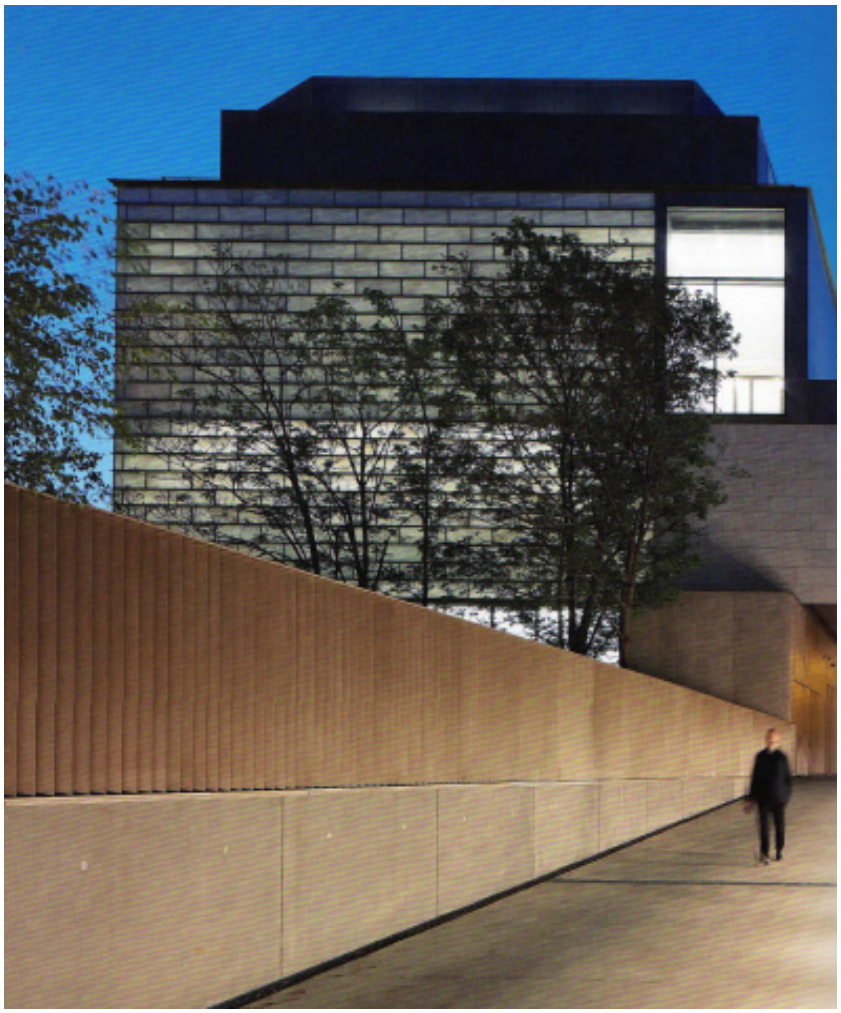

Fig. 8 Musée D'Arts de Nantes. The Cube with connection to the museum. Perspective to the south.
Source: Ref. [16].

metal/glass/ceramic coating hybrid modules, fiber reinforced concrete panels, wood X-LAM, ceramic and clay, bricks, etc. The color also becomes dominant in the various texiture, characterized by homogeneity and glossy and ultra-opaque alternations, integrating energy performance of façade and interior components.

In architecture, for the purpose of reducing energy dispersion, in the sustainable building, parameters are adopted, above all, of compactness and slimness, pointing to the most efficient distribution solutions. Compatibly with different energy responses, linear, central, radial, aggregates, variables in relation to their configuration S/V (exposed surface/envelope/volume) coefficients, depending on the size and the height/width ratio, not determining the degree of efficiency with respect to the energy flows. For exposed envelopes to the south with large surfaces, the real S/V index, although high, does not affect the volumetric compactness. This changes itself under environmental conditions of isotropy, the absence of solar radiation, orientation and geometries that, if obliquely set, improves the compactness of the building with its relative thermal equilibrium, smaller envelope surface, and interchangeability with the outside.

3. Case Study

The Haute Ecòle building in Liège Province, Belgium, is currently being retrofitted (Fig. 9), started in 2015, within the European BRICKER (Energy Reduction in Public Building Stock) project, involving Belgium, Spain and Turkey [17]. The sustainable project aims at energy efficiency and low environmental impact with a 50% reduction in energy consumption through the retrofit of existing buildings

Fig. 9 Haute Ecòle, Belgium. Retrofitting façade with replacement windows. Block No. 6, patio, perspective.
Source: Ref. [18].

Fig. 10 Haute Ecòle, Belgium. Ceiling insulation with PCM materials, perspective.
Source: Ref. [19].

of public property. The building indicates a high demand for heating of 180 kWh/(m^2y) for a 23,600 m^2 conditioned area. Thus, retrofit interventions concern hybrid cogeneration with ORC (organic rankine cycle) boiler with biomass of 1.5 MW, which uses thermal oil, the main façade curtain, thermal insulation of PMC material, insulation façade heat, fixtures and decentralized ventilation.

In it are distinguished the efficient passive and active systems technologies that reduce the energy consumption. The former aims, above all, at reducing demand for heating, the latter, instead, using thermal and electrical energy from the biomass source. In particular, for passive systems, the interventions are characterized by thermal insulation (Fig. 10) of 1,045 m^2 of shells for blocks No. 1 and No. 6. These roofs are the first in the world to handle temperatures, through an innovative thermal insulation system, with PCM technologies based on polyurethane foam integrated with PCM microcapsules. This system was installed by the Department of Technological Innovation at ACCIONA (Agua, Concesiones, Construcciones, Industria y Servicios) Construction. This type of technology contributes to the integration of others through the replacement of 1,155 m^2 of main curtain wall in Block No. 1, the isolation of 2,486 m^2 of façade with the replacement of 1,293 m^2 of high-performance thermal windows integrated into the system, decentralized ventilation and aimed at reducing energy consumption. For electricity, the reduction is 86%, while for gas, it is 75%. In the classrooms, offices and laboratories, 22 prototypes of decentralized ventilation units are installed. The investment costs of new technologies would account for 20% of the total cost over a 7-year of ROI with PCM insulation.

4. Conclusions

The disamina indicates sustainable architectures that highlight flexibility with technological compatibility and feasibility, such as the identity of its environment related to the context, the environment and the metamorphoses of the places. Therefore, it is essential to promote various interdisciplinary strategies and approaches to reduce the complexity of fragmentation, territorial atrophy and improve planning, community and environmental well-being. To this end, the socio/political/economic and managerial platforms are indispensable, with objectives, methodologies and intervention measures

on various scales. Since many buildings are responsible for high pollution rates in the world, sustainable and environmentally friendly construction and regeneration [20] is needed, with retrofitting and building recovery with the adoption of clean technologies, intelligent components and materials and bio-building, awareness of several causes including planetary carryng capacity. In this respect, technological innovation that represents the esprit in sustainable design, highlights transformational performances, type morphological and distributive, focusing on efficient envelopes, zero environmental impacts that contrast the climate change. So they, often, use the environmentally responsive wall and engineered wall criteria and the natural and intelligent neo materials, such as bioPCM nano technologies, HPP nanopigments, etc. The challenge is to create sustainable architectures, new frontiers for the building's climate control, energy management and the "neu Sachlihckeit" (new objectivity) of a harmonious elegance between functionality and essentiality with the places.

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Journal of Civil Engineering and Architecture 11 (2017) 677-690
doi: 10.17265/1934-7359/2017.07.005

Le Corbusier and a New Structural System as the Germ of the Modern Grammar

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Abstract: The opposition between the terms *carcasse* (carcass), conceptualized by Auguste Perret, and *ossature* (frame), proposed as an alternative by Le Corbusier, gives rise to the exploration of the capital contribution of the "Dom-ino" prototype as the basic and in escapable condition for an aesthetic operation. Some issues addressed are: the importance of the question of the structure—which remains implicit in *Toward an Architecture*—as key to a quest for the specificity of architecture; Le Corbusier's troublesome relationship with Perret and the debates between them, which convey two different ways of understanding the potential contributions of concrete to the redefinition of architectural vocabulary; the "Dom-ino" system considered as a new structural type in the sense ascribed to this category by Violletle Duc; the topic of the *abri souverain* (sovereign shelter) fit for all programs, which triggered typological invention; the ways in which Le Corbusier plays with Gottfried Semper's *Urformen* and, finally, how this new structural type anchors Le Corbusier's radical redefinition of the elements of the discipline, the making of a new grammar.

Key words: Structure, modern architecture, concrete, structural type, architectural vocabulary.

1. Introduction

"Finding a free, comprehensive structural system applicable to all the programs and that allows to use all the materials and is suitable for all applications, from the most complex to the most simple ones; cover this structure in a way which is nothing else but the expression of the system itself; decorate the structure without ever contradicting it, explaining it by means of the combination of profiles outlined by using a geometrical method which is a corollary of the method used to conceive the ensemble; apply to the architecture—i.e., to the structure covered by an artistic shape—the stability principles which are most simple and understandable to the eye… In short, this was what our secular school at the end of the 12th century did" [1].

"Over the centuries, architecture has left pure systems. These systems constitute the different architectures of history. These systems extend their effects from the house to the temple. Every time an age has failed to elaborate a system, the architectural moment has failed to exist. These systems entail the rigorous solution to a statics problem: each architecture is linked to a type of structure" [2].

In the 19th century, hand in hand with the possibilities associated with the changes in construction technologies, the issues of the structure and of the relationship between the shape and the support system were topics that structured the debate between essence and appearance, simultaneously with the questioning of historical styles and the erosion of the aesthetic grounds of Vitruvianism. They represent a clear progress towards the acknowledgment of the resources and the constituent laws of architecture as a discipline with a nature and a purpose independent from social conventions or tradition.

The issue of the structure is key for modern architecture's first theorizing efforts, under the operative hypothesis of a need to focus on the specificity of architecture's characteristic resources as

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a strategy to explore in greater depth the autonomy of a self-referential art. We will analyze the importance of the issue of the structure in *Toward an Architecture* (1923), which was perhaps the first doctrine for a new architecture.

What bigger evidence of a search for the specificity of means than the very notion of "purism", in the light of which the articles contained in *Toward an Architecture* were written? In the concerned view taken by Amédée Ozenfant (who was following Stéphane Mallarmé), purism was a call to clean the plastic language not only of representative connotations, but also of terms parasitic upon literature or of any appeal to science—cubist sin [3]. Le Corbusier reinterprets purism for architecture in formal terms and advocates for a purity associable with geometry and the smooth surfaces typical of industrial production, leaving behind any traces of craftsmanship or of the heterogeneity of the natural material.

This was his contribution to *Après le cubism* (1918): the collective fierceness of a new society, forged in contact with the clarity and power of machinery and its products, the shapes of which, rigorously conditioned by calculation and accurately executed, would have determined, according to Le Corbusier, a new way of seeing and new aesthetic demands [1]. This was exactly what the use of reinforced concrete was offering to architecture: an artificial material, homogeneous and tested in the laboratory, which can be strictly determined by means of calculation and offer an accurate execution through the use of metal formwork, which, reinforced by the homogenizing action of roughcast, can obliterate any reference to the hand of man.

However, despite Le Corbusier's insistence that reinforced concrete would start a revolution in architecture, the issue of the structure is not raised in any of the "Three Reminders to Architects" which organize *Toward an Architecture* [4]. Moreover, the term only appears three times, and in a nonspecific sense, within a text that repeatedly rejects any attempt to assimilate architecture to construction—"Architecture is an artistic fact, an emotional phenomenon that is outside questions of construction, beyond them. Construction: That's for making things together. Architecture: That's for stirring emotion" [4]—or to enhance the expressive manipulation of architecture as tectonics—"Emphasizing construction is fine for students at the Arts et Métiers who want to show what they are worth. Our good Lord indeed emphasized wrists and ankles, but then there's all the rest" [4].

However, not few people have pointed out that Le Corbusier's normative codification in "The Five Points of a New Architecture" (1927) can be read as a transformation of the new building techniques into architectural resources, a starting point for a new aesthetics and for the reformulation of the foundations of the discipline [5, 6].

2. Frame versus Carcass

"Through their works and, sometimes, in our discussions, the Perrets told me "You don't know anything". Through my study of the Romans, I became aware that architecture was not a matter of an eurhythmy of the form but something else... But what? I still was not sure. Then I studied the mechanics and, after that, the statics…, and today, I angrily take notice of the gaps on which I have based my science of modern architecture. Angrily, but yet with joy because I finally get to know where the good thing lies: I studied the forces of matter. It is hard but beautiful—this mathematics so logic and perfect. With the Perret brothers at the construction site, I saw what concrete is and the revolutionary shapes it demands. The eight months I spent in Paris screams to me "Logic, truth, honesty and leaving behind any dreams of an art of the past! Eyes up and forward!." One talks about an art of tomorrow. This art will happen. Because humanity has changed the way they live, the way they

[1]Ozenfant, A., and Corbusier, L. 1921. "Le purisme." op. cit.: 99.

think. The program is new. The dawn of this art is shining because from iron—a material subject to destruction—reinforced concrete has been made, an amazing creation that, because of the monuments it will allow to build, will be a bold landmark in the history of peoples."[2]

The importance of Auguste Perret's influence cannot be left aside when considering the issue of the structure in *Toward an Architecture*.

We know that the notion of "structure" was introduced as topic of the discipline by Éugène Viollet-le-Duc—structure as internal reason, as a principle that generates and organizes the shape in accordance with the dominant static logics in a construction system. This internal reason would be the basis for establishing aesthetic registers and the supreme value of style, in a clear step forward towards the recognition of the discipline's constituent laws and resources, of its nature and purpose beyond tradition or social conventions.

This viewpoint is not very different from Karl Bötticher's notion of *Tektonik*, which he states in his reflections on the dialectics between *Kernform* and *Kunstform*: a relationship of a necessary and constitutive interdependency, wonderfully achieved in Ancient Greece, between a "core" which resides in the material, static and functional aspect, and an artistic "skin" which expresses and high lights the function of the core with which it is intimately linked [7]. With this, Bötticher issues a moral demand that resounds once and again in Le Corbusier's notes.

Tracking in Le Corbusier's thinking, the organizational survival of these 19th-century conceptualizations—which, many times, happen on the quiet, with transformations and changes of meaning[3] also places us in the historiographic debate on his formative years. We refer to the alleged dominance of idealism over any flirtation with the French rationalist tradition, which would have been reduced to a weak note or reinterpreted as absolute principles underlying Nature [8-10]. It is a debate in which the importance of Le Corbusier' s references to Perret and the concepts and registers of constructive rationalism are at stake.

Perret is the interlocutor in *Toward an Architecture*. He is the ghost behind Le Corbusier's reference to the aesthetics of the engineer with which he decides to start the compilation. Perret's concept of carcass is the one that organizes—by means of a subversion, but without a change of register—Le Corbusier's arguments around the issue of the structure.

It was through the Perret brothers that Le Corbusier came into contact with the French rationalist tradition and, in general, with architecture as a discipline. We know that their relationship started in July 1908, when Le Corbusier joined the studio under a work schedule which left the afternoons free for him to visit libraries and museums and take courses. It was Auguste who acquainted him with mathematics, the writings of Viollet-le-Duc (Le Corbusier bought the *Dictionnaire Raisonné* with the money from his first salary), Auguste Choisy and Adolf Loos, and who introduced

[2]"Les Perret… ils me dirent -par leurs œuvres et parfois dans des discussions—Vous ne savez rien. Je soupçonnais par l'étude de Roman que l'architecture n'était pas une affaire d'eurythmie des formes mais… autre chose… quoi? Je ne savais encore bien. Et j'étudiai la mécanique, puis la statique (…) et aujourd'hui, avec colère, je constate les creux dont est formée ma science d'architecte moderne. Avec rage et joie, parce que je sais enfin que là es le bon, j'étudie les forces de la matière. C'est ardu mais c'est beau, ces mathématiques, si logiques si parfaites. …Sur le chantier des Perret je vois ce qu'est le béton, les formes révolutionnaires qu'il exige. Les huit mois de Paris me crient: logique, vérité, honnêteté, arrière les rêves vers les arts passés. Les yeux hauts, en avant! …On parle d'un art de demain. Cet art sera. Parce que l'humanité a changé sa manière de vivre, sa façon de penser. Le programme est nouveau. ...L'aurore de cet art devient éblouissante parce que du fer, matériau sujet à la destruction, on a fait du béton armé, création inouïe et que dans l'histoire des peuples par leurs monuments marquera un jalon hardiesse." Jeanneret, Ch. E. 1908. Letter of November 22nd to Charles L'Eplattenier. Jenger, J., 2001. *Le Corbusier. Choix de Lettres*: 65. Berlin: Birkhäuser.

[3]In *Toward an Architecture*, Le Corbusier explains what he still has not imagined. He lays down the principles of a new aesthetics before he moves on to concrete projects where these principles are put to the test and can serve as examples. Thus, he has to resort to the work of engineers, to the products of technology, to the poetics of avant-garde movements—but also to concepts from the nineteenth-century debate on architecture as shortcuts to lead a way that he can barely make out.

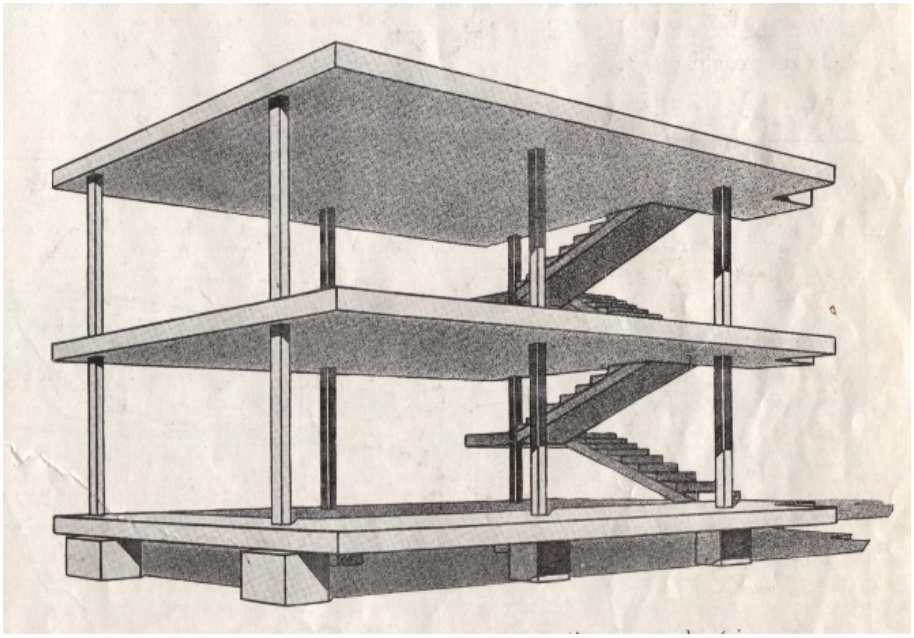

Fig. 1 Perspective of a "Dom-ino" module, 1915 [12].

him to Ozenfant and Tony Garnier. To Le Corbusier, Perret was a father figure, and he would constantly turn to him for guidance and advice—even with regard to the "Dom-ino" system; Perret also supported Le Corbusier's *L'Esprit Nouveau* magazine project by being a member of the publishing society.

Their relationship was full of tensions, as can be easily noticed in several *Toward an Architecture* statements where Le Corbusier contradicts Perret' s principles. The conflict became more virulent when Perret attacked Le Corbusier in an interview by saying that he was "a disciple of a school of volume creators". This sparked off a fierce public debate that was resolved through the press and focused on the role of the structure in the process of the formal description of architecture, on the expression of materials, on the *fenêtre en longueur* and the elimination of cornices. What was at stake was Le Corbusier's will to differentiate himself from Perret's continuity with tradition. The conflict eventually led to a breaking-off of the relationship around the year 1925, with Le Corbusier accusing Perret of being, among other things, a simple engineer and inviting him to mind his own business [11].

As we have already mentioned, Le Corbusier borrows the notion of *carcasse* (carcass)—only bones, no flesh, no modeled details—from Perret. This notion led Le Corbusier to become absorbed in a reflection on the building itself.[4] The carcass as an element which is beyond contingencies, is determined by permanent factors (like the materials and the laws of stability) can be assimilated to Charles Perrault's concept of "positive beauty" and resounds in the "Dom-ino" system and its purist retrieval in *Toward an Architecture*.

Perret conceives the notion of carcass in terms of woodwork (*charpente*)—first translated into stone, then into steel and, at that time in France, into reinforced concrete.[5] This is why, for him, the framework—not only the support frame but also the enclosure frame with its infilling areas—is a formal

[4]To this, Le Corbusier refers with the note he wrote on a page of the first volume of the *Dictionnaire raisonné*: "These lines allow to see that this art lives because of its carcass. It is also a monolith, a cage of iron wires—where vertical and oblique pressures are located in the cement of the Roman walls and in the steel bars of concrete. Or, August Perret would say to me, 'If you have the carcass, you have the art'." Reproduced by Turner, P., *La formation de Le Corbusier.* op. cit.: 63.

[5]Auguste Perret, A. 1952. *Contribution à une théorie de l'architecture.* Paris: Cercle d'études architecturales. Reproduced in Roberto Gargiani, R., 1993. *Auguste Perret 1874-1954. Teorie e opere*. Milan: Electa: 43, 46.

issue, and it enables him to reintroduce composing topics of classic or gothic inspiration and to define interior space in accordance with the rhythm and the modulation of the support frame and the enclosure frame.

In Le Corbusier's thinking, this relationship between carpentry and the classic language is lost. The carcass, that monolithic reinforced-concrete cage, no longer defines the outer shape. The *ossature* (as structural skeleton) and the membrane (as architectural external "skin") are now considered as two separate entities, different in terms of material nature, resolution and construction role. Thus, the internal space no longer depends on the vertical structural frame, and the external skin of the building dissolves the presence of the *ossature* through the veil of a surface without sutures, free to get involved in an autonomous plastic interplay since it is now free from any tectonic reference.[6]

While for Perret, the reference to carpentry was based on the need of a wooden form work that would work as the negative of the reinforced concrete carcass, Le Corbusier makes several extreme attempts to break this bond. He resorts to complex technical tricks to get rid of the wooden formwork and to set the structural concrete frame free from carpentry as a model, all this without being disloyal to the rationalist maxim that establishes that the shape cannot but be the result of the exact construction nature of the thing.

3. Revolution

"Architecture finds itself with an amended code. If we set ourselves against the past, we see that the old codification of architecture, weighed down by forty centuries' worth of rules and regulations, ceases to interest us, it is no longer our concern; there has been a revision of values; there has been revolution in the conception of architecture."[7]

We know that, once and again, Le Corbusier held that the laws of architecture are always the same and that they do not change along with the transformation of technical means, within a logic that seems to refer more to absolute laws present in all ages under different forms than to positive principles—as is the case with a very similar statement by Viollet-le-Duc.[8] However, both reinforced concrete and, later on, *everite* and other innovative techniques for the construction of light partitions (slag, plaster, compressed straw, wood, laminated sheets) arose his interest and stimulated him to devise a construction system which could be industrially exploitable in the promising post World War I reconstruction scene.

We refer to the "Monolythe" system—later on, "Dom-ino system" with its connotations of house and flexible assembly. In *Toward an Architecture*, Le Corbusier relegated the subject to the last two chapters dealing with mass production housing [13]. However, the "Dom-ino" system, reinterpreted as the core of purism in architecture, functions as the through-line and justification of the whole book.

Stimulated by the mass destruction of houses in Flanders, Le Corbusier conceived the "Dom-ino" system in the solitude of Chaux de Fonds in late 1914. It was a construction system devised with the technical support of Max Du Bois, a friend engineer who had

[6]Within Perret's logic (as well as in the examples of structural grid which define the shape and the internal space in the industrial buildings chosen as examples by Le Corbusier in the illustrations of "The second reminder: Surface"), the showing up of the carcass seemed to achieve, by means of the radical exposure of the *Kernform*, the coherence between essence and appearance pursued in the nineteenth century. By establishing that frame and membrane constitute two independent orders, Le Corbusier avoids reopening the discussion: the external "skin" would not be a *Stillhülse* which has the mission to reveal the logic of a structural *Kernform*. As Oechslin points out, instead of penetrating the essence of the shape, the eyes rest on the new exterior: the surface has been set free and constitutes a corporeal and pure volume that moves, the quality of which must be ruled by a proportion-regulating system typical of pictorial composition.

[7]Le Corbusier, *Toward an Architecture,* op. cit.: 304.

[8]"Let's learn to know the art of ancient times better; by analyzing it patiently, we will be able to lay down the foundations of the art of our century and we will become aware that along with the material data that change all the time, there are invariable principles, and that history not only arises the curiosity but also reveals, to those who know how to search for them, treasures of knowledge and experience that the intelligent man must use." Viollet le Duc, E., "Proportion".*Dictionnaire Raisonné…* op.cit. Vol. VII: 561.

translated Emil Mörsch's book on reinforced concrete and with whom Le Corbusier went into partnership to patent the system and obtain commercial profit from it as a way to launch his career in France.[9]

It is not worth tracking and discussing the potential references for each component. We will focus on the changes that Le Corbusier introduced with respect to similar structural proposals inspired on the possibilities open by reinforced concrete, since these changes are the ones which allowed him to make the "Dom-ino" frame the key to a redefinition of the vocabulary and the syntax of a new architecture.[10]

The system is supported by Le Corbusier's intention—which is clear from the very beginning—to consider, in a radically independent way, that frame and membrane constitute a vital separation of powers.[11]

Such independent stance is not limited to the rejection of the resolution of the supporting structure and the enclosure on the same plane: Le Corbusier also rejects the vertical window due to its ambiguous status of opening in the wall or gap between two supporting elements.

With a reformulation made possible by the new construction procedures, Le Corbusier, in a way, makes use of the *Urformen* identified by Gottfried Semper, each one of them associated with precise technical operations. The membrane (*Wand*), as the enclosure and the light partitions that delimit and orientate the interior space through the figurative inscriptions of horizontal movements (*la marche* in depth), is textile: by eliminating any reference to the material; the roughcast transforms the membrane in a painter's canvas, in a freed surface that can be treated with the compositional resources of Purist painting.[12] The frame would be the roof's support (*Decke*) translated into horizontal slabs. The concrete dices—later on, the pilotis and the free ground plan, would serve as mound (*Mauern*), protecting the building from the damp and differentiating it from the soil.

There are five other attributes of the "Dom-ino" system: (1) The rectangular proportion of the slabs in order for them to be attached to one another by the ends, with the possibility of orienting them in different ways; (2) The cylindrical character of the six pillars, the autonomy of which is reinforced by the elimination of all the elements of passage with respect to the bearing and support planes, for which lightened beamless slabs would be used; (3) The recessed location of the pillars with respect to the longer side of the projecting slab, in order to make the facade (as well as internal partitions) totally independent from the structural frame; (4) The emphasis on the smooth character of all the elements, reinforced by the use of roughcast in order to eliminate any reference to the material nature; (5) The replacement, of course, of the pointed roof by a terrace.

Many of these architectural choices negatively affect the structural behavior, so much so that Perret warned Le Corbusier that it would be impossible to build such

[9]Although in *Toward an Architecture* no credit is given to Du Bois, his collaboration was important: he prepared the construction details with the engineer Juste Schneider, he discussed the terms and covered the costs of the patent request.

[10]We refer not only to technical solutions, but also to the devising of prototypes suitable for mass-production housing during the post-war reconstruction. In this regard, in his carnets, Le Corbusier transcribes a quotation from D. Adshead, reproduced in Benoît-Levy's book, on the urgent need of a totally different type of building, leaving aside sloping roofs and glass-paned windows. This new type would express the energy and refinement of urban life in accordance with the possibilities offered by the machine as new tool. It would be in accordance with a new urban design, understood as art and responsible for the communication of the ideas and emotions typical of the spirit of a modern industrial era. Cf. Turner, P., *La formation*... op. cit.: 144.

[11]"Construction systems suitable to be juxtaposed according to infinite combinations on the ground plan thanks to a uniform sub-multiple module for monolithic reinforced concrete skeletons, with monolithic and smooth slabs. A separation of powers over 6-pillar foundation which permits, through (resistance) calculations, the construction at any point of any type of enclosures in the facade or in the interior. Special characteristics: the interior pillars do not appear in the facade. Interior distribution. To be intervened later on through automatic casting, allowing to build a house in 20 days." Le Corbusier, 1915. Brevet. p. 120, carnet A-2. Reproduced en Turner, P., *La formation*..., op. cit.: 218.

[12]This was one of Perret's harshest criticisms to Le Corbusier. For Perret, the membrane is just cosmetics, an easy and ephemeral formula to disguise the duality between structure and enclosures made with materials with different coefficients of thermal expansion.

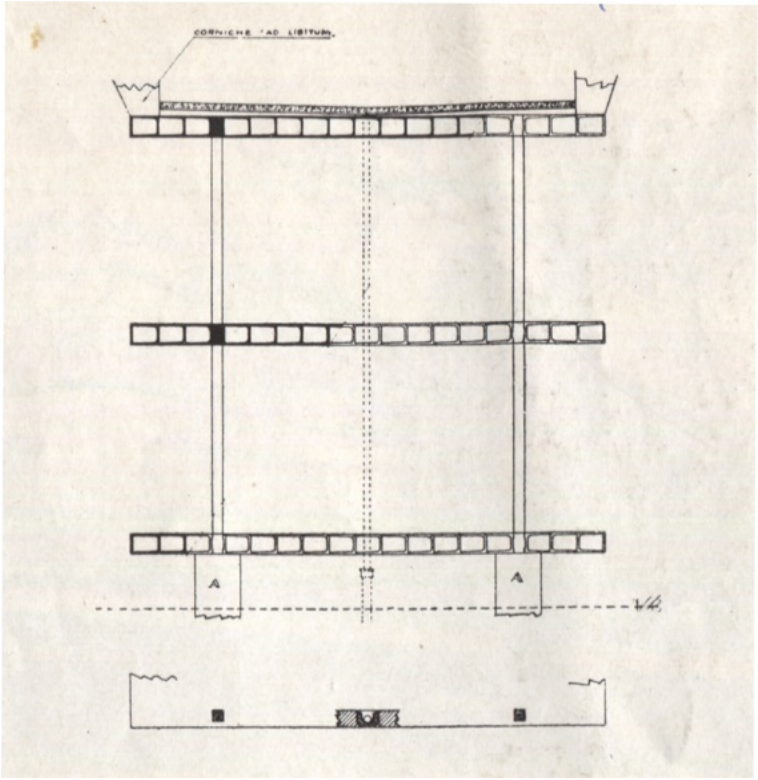

Fig. 2 Cross section on the ceiling of "Dom-ino" module [12].

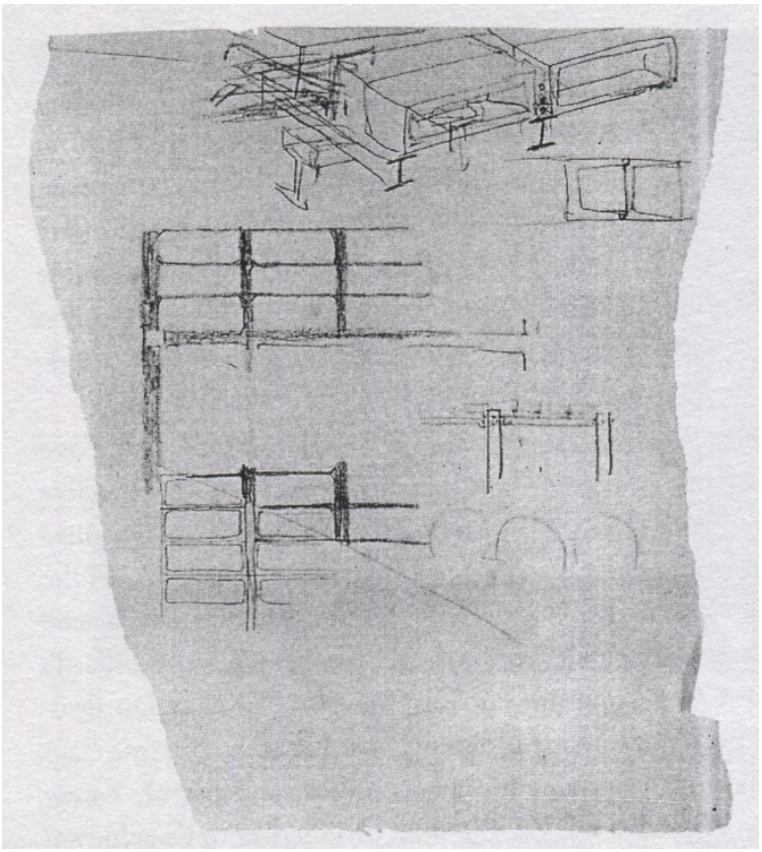

Fig. 3 Study of I beams and hollow tiles, 1915 [9].

houses, and Le Corbusier did not even use this system in the many commissions that he got between 1917 and 1919 to build groups of houses for the working-class.[13]

The recess of the pillars with respect to the edge of the slab had been used by Perret in the interior of the Ponthieu garage in order to improve the performance of the monolithic slabs. However, Le Corbusier resorted to a complex lightened system with hollow blocks that made the execution of the overhangs and the infrastructure installation very difficult. The beamless slabs had been used by François Hennebique and Robert Maillart, but they resorted to mushroom-shaped columns to ensure a rigid joint with the slabs. Le Corbusier also made complicated efforts to avoid resorting to wood formwork as the negative of the concrete structure and potential determining factor of its shape. Despite the increase in weight that this entailed, instead of removable waffle slabs, he made use of hollow bricks supported by a double framework of angle iron pieces that would demand a two-stage casting for each level.

The "Dom-ino" system productively intermingles the design of a prototype for mechanical reproduction and the definition of a new structural type that partly makes use of, and is defined in counterpoint to, the three structural types defined by Viollet-le-Duc. Le Corbusier attempted to achieve the synthesis and coherence of the Greeks (separate pieces resting on one another), and he made use of reinforced concrete based on the Roman construction principle (monolithic unit, small construction elements, support system autonomous from the enclosures that define the inner space), but starting from the radical distinction between "frame" and "membrane" of the gothic.

The new structural type not only allowed him to leave behind the means of the old architecture but also more than half a century of trials—still engaged in a dialogue with the oldest principles of the discipline—at defining the formal and spatial resources of a post-wall architecture with regard to the structural frame. The frame/membrane polarity as essentialist reduction of the primitive cottage enabled Le Corbusier to make a revolutionary return—like M. A. Laugier in 1753—to a point zero of the discipline in order to radically reconsider its resources—i.e., by re-elaborating the logical support in a new construction base, he was able to review the values and even the concept of architecture.

The amendment of the code is internal to the discipline and it is supported by the devising of this new structural type underlying the "Dom-ino" system.

4. Elements

"The purist element born out of the depuration of standard shapes is not a copy, it is a creation aimed at materializing the object with all its general and invariable character. Thus, the purist elements are comparable to words whose meaning is well settled; the purist syntax is the application of construction and modular means."[14]

What is the relationship between this construction system—which Le Corbusier devised in 1914 with the purpose of starting a career in Paris in the novel capacity of architect-entrepreneur—with the *L' Esprit Nouveau* adventure he undertakes with Ozenfant in the Parisian cultural circle, and of which *Toward an Architecture* is a direct result?

From the first issue of the magazine—in "Sur la plastique" and continuing in "Le Purisme" in the fourth issue—it is clear that the main purpose of its publishers was to build the foundations of a rational aesthetic in order to reach that utmost degree of the sensations that they called "mathematical lyricism" and which, up to that time, had been exclusive to some architectural works. It was a physics of the arts that was supported

[13]This is one of Turner's strong argumentative points to stress the predominance of Le Corbusier's idealism over any rationalist concern: although the apparent purpose is a new structural system for the mass-production of houses, its elements would embody, in almost a platonic way, the ideal of column and the ideal of slab, with Le Corbusier following the method recommended by Henry Provensal of creating from ideas, with pure and general shapes.

[14]Ozenfant, A. and Le Corbusier, 1921. "Le Purisme", op. cit.

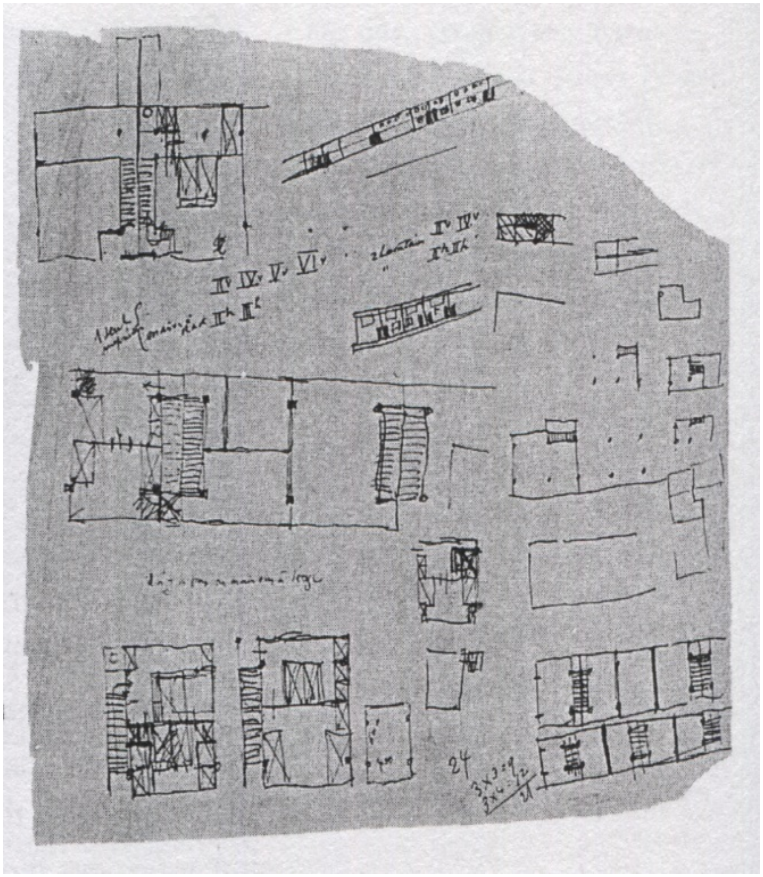

Fig. 4 "Dom-ino". Study for plans, 1915. FLC 19140 [9].

Fig. 5 "Dom-ino" house, residence and workshop [12].

by the definition of the primary elements and the syntax of a plastic work.

This would be the contribution of the "Dom-ino" system, recovered and reinterpreted from a purist standpoint.

Since Le Corbusier's initial formulation of the system, it was evident that there was a search for a simplification that would allow to polish and reduce each one of the construction system's parts to "elements" (in the sense given to the term by J. N. L. Durand—objective, invariable elements resulting from an empiric systematization, devoid of figurative or

historical dimension) to which he repeatedly alluded in *Toward an Architecture*.[15]

These elements were a series of pieces that became words of an autonomous, universal language. For this reason, these pieces underwent a visual and conceptual cleaning-up operation that turned them into clear, distinctive elements by means of a process that was similar to the mechanical selection of industrial production objects. They are smooth elements that keep us at a distance, re-creating the impersonal experience that we have in front of mass-production objects but dodging the subjective nature of the consumer [14].

This purist retrieval of the "Dom-ino" system matures in consonance with Le Corbusier's collaboration with Ozenfant. In the initial 1915 projects, Le Corbusier still resorts to the use of lintel windows—although of landscape layout, well-defined 45-degree-angled cornices used as crownings, with flowerbeds that soften their silhouettes. The cornices and the entablatures of the openings will only disappear in the 1919 Troyes project in order to ensure the integrity of the cubic shape *à la Garnier*, and the pure, smooth, geometric resolution is applied to the whole building. The ambiguous notion used by Le Corbusier to re-signify these construction elements as purist objects is the notion of "economy"—the natural selection law, driving force of the industrial civilization, but also a substitute notion for *venustas* in Durand that Le Corbusier recovers, linking it to the rational satisfaction of the spirit: "…a will to the purest, the clearest, the most economical… to leave only those concise and violent things, sounding clear and tragic like bronze trumpets".[16]

In this sense, it is rather a depuration typical of the standardization of production by means of applied science that what Wilhelm Worringer, in *Abstraktion und Einfülung* (1907), called "a drive towards the absolute when facing with the uncertainties of reality". In the same way as the Parthenon would have been be the climax of Doric temples, through a selection and refinement process that made use of a standard comparable to that of automobiles, planes and boats, the "Dom-ino" system was the result of the improvement and purification of the frame structural system. It is comparable to Le Corbusier's attraction to industrial production objects as heralds of a new formal freedom. In the same register is his strategy to present himself as an architect manager of a serial production project for the market, taking a very different stance regarding production modes from the one taken by the Bauhaus (still linked to the will to redeem industrial production through art).

For Le Corbusier, machinery and the selection and depuration associated with it have a rigor which is comparable to that of the great works of architecture: in the Parthenon, "plastic mechanics is realized in marble with the rigor that we have learned to apply in machines".[17] This extreme precision enables him to keep the "Dom-ino" system's radical bareness and its cubic resolution away from any aesthetic notion of balance, beauty or solidity, making them fall, notwithstanding—concise and violent—within the register of the sublime. Thus, through formal abstraction, a bridge is created between the mere construction and architecture as machine for stirring emotion: "Architectural abstraction has the distinctive and magnificent quality that, while being rooted in brute fact, it spiritualizes it".[18]

[15] Throughout the text, Le Corbusier makes a distinction between architectural elements that are invariable with time (light, shadow, materials, wall and space) and construction elements. The latter ones, transformed by the serial-production spirit in the construction site, can be classified in: (1) elements of detail that are interchangeable and, thus, are devised and manufactured according to modules (*les cloisons légères*, standard windows and furniture) that guarantee the indispensable unity for the creation of architectural beauty; and (2) general elements typical of the support system that are designed for a longer permanence and that, if "soundly set up and combined into a unity", can produce a "beautiful arrangement." Cf. Le Corbusier, *Toward an Architecture*, op. cit. p. 154.

[16] Le Corbusier, *Toward an Architecture*, op. cit.: 236.
[17] Ibidem: 246, 203.
[18] Ibidem: 101.

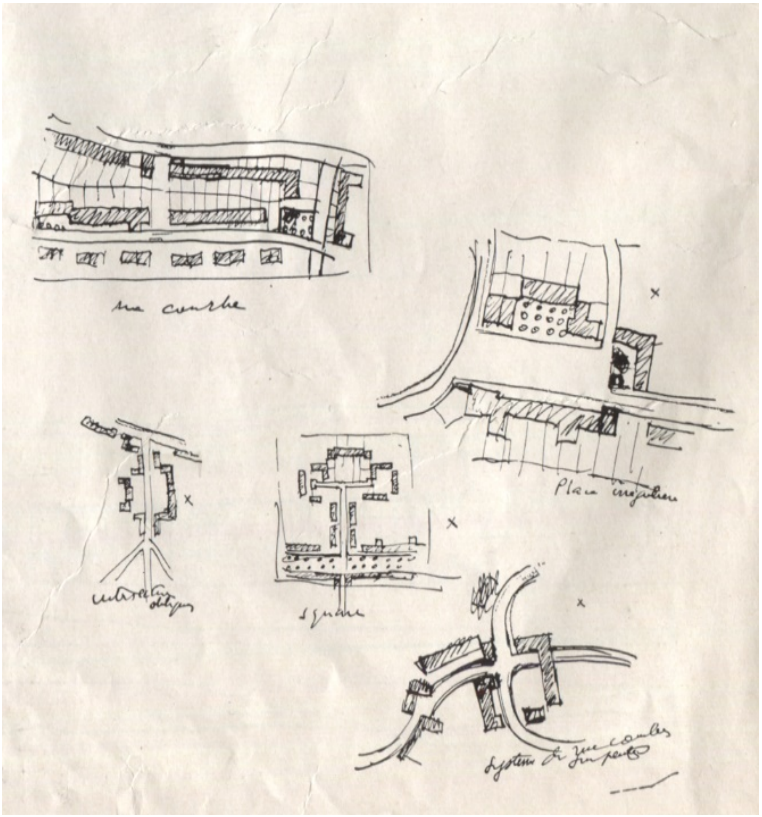

Fig. 6 Cluster of mass-production houses with Dom-ino frames 1915 [12].

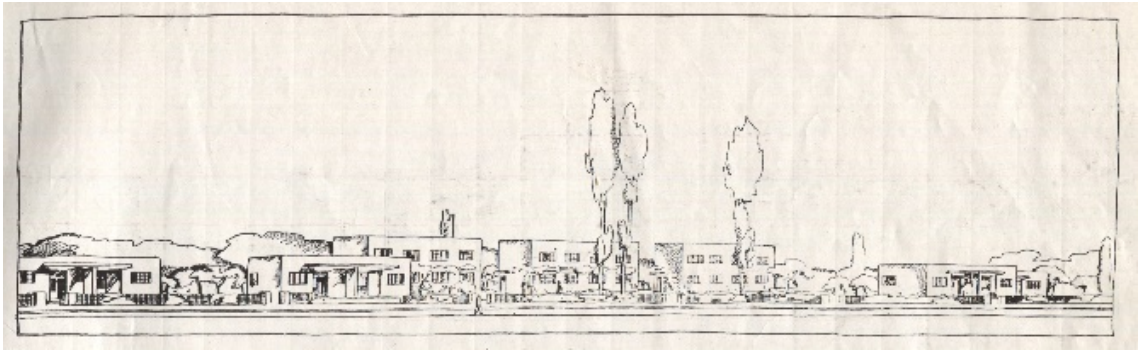

Fig. 7 Project workers' housing for J. Jourdain & Co. at Troyes. October 1, 1919 [12].

5. Syntax: Beyond the Human Factor

"Perspective only offers an accidental appearance of objects—what the eye would see if it were situated in the corresponding visual angle, always specific and, thus, incomplete. A painting that is created based on perspective resorts to poor-quality sensations and deprives itself of what can be universal and true."[19]

As it happens in the attempt of purism to achieve a scientific aesthetic for painting, in the "Dom-ino" system not only the construction parts are defined as architectonic elements, but also organizational rules are settled: a syntax.

The "Dom-ino" elements are not independent; they create a system according to which the relationship between the rectangular slab, the pillars and the staircase is not interchangeable. It is a system that guarantees the separation of powers between the frame and a membrane that can be perforated unlimitedly (as is explicit in the *fenêtres en longueur*) and the articulation by means of the longitudinal aggregation

[19]Ozenfant, A., and Corbusier, L. 1923. "Le Purisme." op. cit.

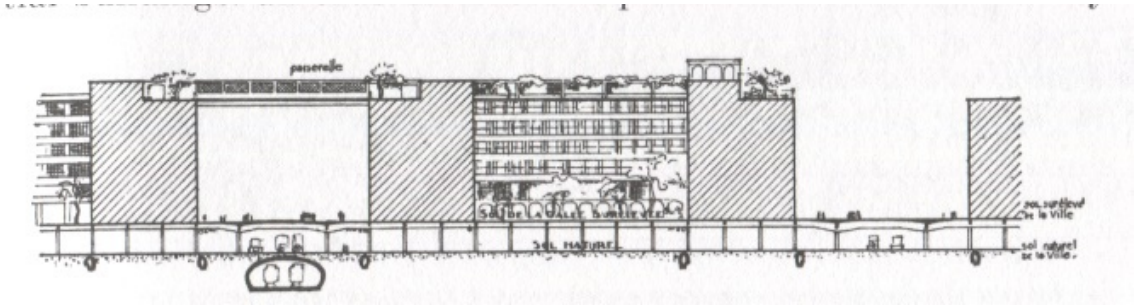

Fig. 8 Pilotis-Cities, 1915 [12].

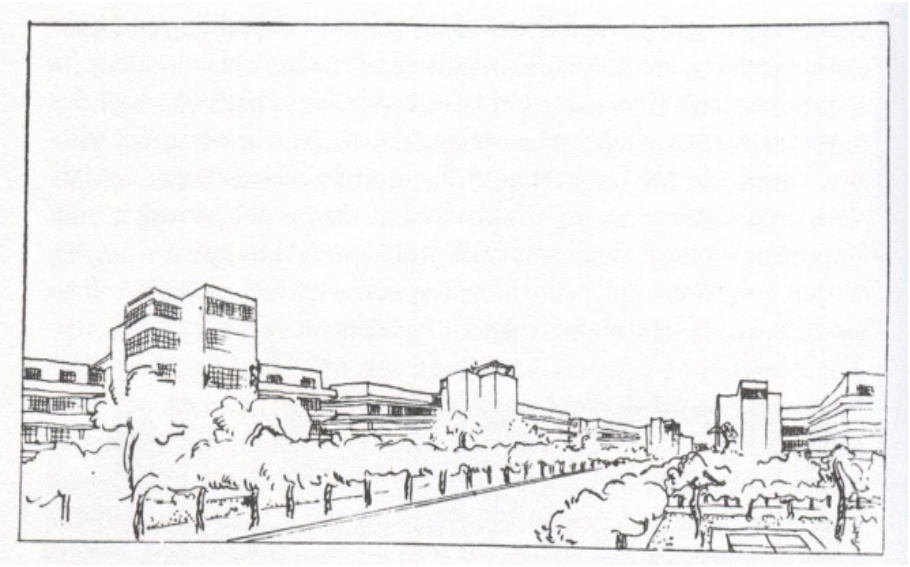

Fig. 9 Streets with Indents, 1920 [12].

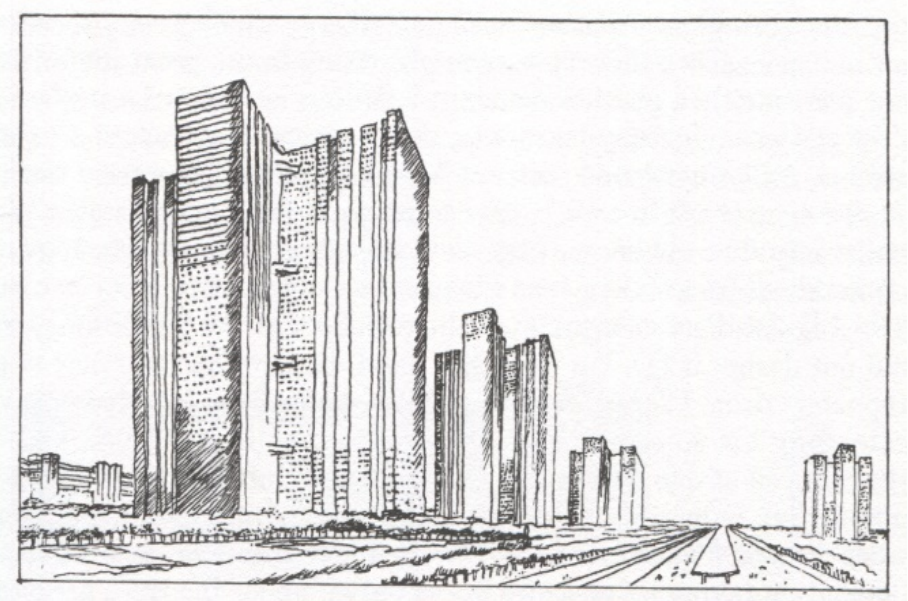

Fig. 10 Tower-Cities, 1920 [12].

of the slabs as unanchored surfaces to achieve an unprecedented spatial freedom with reference to the horizontal plane.

Another generative rule is the modular organization

that, according to Choisy himself, was a principle present since the beginning of monumental architecture. It creates order and simplifies the design processes, multiplies the combinatorial possibilities of the different elements, adds an aesthetic quality associated with the pleasure that results from the visual economy, and re-establishes the value of proportion as architectonic quality.

But perhaps the most outstanding thing is the abandonment of perspective as register of the architectural formal syntax—the same abandonment promoted by purism in the pictorial field. This becoming engrossed in the internal logics—unchanging with respect to the historical changes and the actions of men, this autonomy that is pursued even for the subject who perceives, putting the communicative dimension in suspense, are pursued in several convergent registers. It is given by the cylindrical or flat definition of each element, which is unchanging even from different points of view; by the autonomous nature of the membrane that liberates the front plane from any external visual register of the structural frame; and by making the compositional keys fall within the ground plan, as notations in a diagram that is not affected by deformations with respect to the point of view of the potential observer and that is confirmed by means of the axonometric projection (borrowed from Choisy) chosen to represent it. Peter Eisenman has underlined that this operation is evidence of the condition of self-referential sign of the "Dom-ino" system (he says that "the Maison 'Dom-ino' can be seen to reflect a Modernist or self-referential condition of sign"), which is a substantial turning point after four centuries of humanist culture [15].

6. Conclusions: The Structural Type, a Grammar

"Almost all periods of architecture have been linked to structural investigations. The conclusion has often been drawn: architecture is construction, but this is not reason to confuse the two. It is clear that the architect ought to have mastered his construction at least as the thinker has mastered his grammar."[20]

In short, without taking it for a crass concern for the constructive determination of architecture expression or for an ontological tie between manners of doing and form, the "Dom-ino" system was a key piece in the appeal to become aware of the specific means of architecture and to re-create the language of a new art.

As a new structural type for which reinforced concrete is a means and not an end, the "Dom-ino" system provided Le Corbusier with the grammar for a new, purified architecture. It provided him with a construction means capable of revolutionizing the elements and the syntax of the discipline. Later on, he will state that: Reinforced concrete is a revolution in the history of the window. "Reinforced concrete backs the flat roof and revolutionizes the use of the house. Reinforced concrete gives us the pilotis, the house is in the air. If the skin of architecture is a new one, that is because its structure is completely new, the system is a new one. The architectural aesthetic is subverted by a new technical phenomenon: reinforced concrete."[21]

It is a construction system that guarantees the utmost freedom regarding the ground and the interior arrangement, and is able to meet the changeable and temporary needs of people in a changing world by means of a permanent structure—idea that will be taken up again by Perret in 1931 in terms of the *abri souverain* (sovereign shelter).[22] It is a matrix that boosts architectonic events for the rich and for the poor, for the working-class house, for the villas and *les*

[20]Le Corbusier, *Toward an Architecture, op. cit.: 245*

[21]"Le ciment armé fait révolution dans l'histoire de la fenêtre. Le béton armé apporte le toit plat et révolutionne l'usage de la maison. Le ciment armé nous donne les pilotis. La maison est en l'air loin du sol. ...si l'épiderme de l'architecture est autre, c'est que de fond en comble sa structure est autre: le système est autre. …l'esthétique architecturale se trouve bouleversée par un phénomène technique nouveau : le ciment armé." Le Corbusier, *Almanach.* op. cit.: 14- 16 and 31.

[22]"A porche, a container, a ship, a sovereign shelter able to receive in its unity the diversity of organs necessary for the functions. It is through construction that the architect meets both permanent and temporary conditions." Auguste Perret, "Contribution…" op. cit.: 39.

appartements à redents.

Le Corbusier made use of these compositional possibilities at *la Ville Contemporaine* (1922), the first of a series of projects in which the urban scale is the device he needs to account for the potential of his typological investigations, enabled by a construction system strained to bold extremes.

Because, lifting it up to the destiny of architecture (i.e., to stir emotion), it is a complete and pure construction system. Besides, it is a system that is taken to bold extremes to express the economy, in a spiritual sense.

"When a construction system allows us to build a hangar or a church, i.e., when that system is the most perfect one that can be devised to serve as shelter, architecture is possible—made by depurating the shapes, with harmonious arrangements, with the spiritual intention that puts its constituent elements into proportion."[23]

To sum up, it is in connection with the invention of a new structural type that Le Corbusier created a turning point in the tradition of the discipline, subverting its codes internally. [24] The "Dom-ino" frame, reformulated as new structural system, defined the elements (*pilotis*, *cloisons legéres*, roof garden, *promenade architecturale*, *fenêtres en longeuer*) and the syntax (independence of powers between frame and membrane, compositional notation on the ground plan autonomous with respect to the observer's point of view). Thus, it became the grammar for a sovereign shelter, a grammar that enabled typological invention and, thence, the redefinition of the city and the relationship between architecture and landscape through big dimension. It was a sharp turning point in the development of architectonic form, and it is analogous to the one set forth by Viollet-le-Duc in the epigraph that introduces the present work.

[23] Le Corbusier. "Un standart ne résout pas un problème d'architecture." *Almanach*... op. cit.: 115.

[24] "The abandonment of the plaid grid of the Paris Opera House for the free plan of Dom-ino, possible one of the most critical changes ever in the continuous cycle of changes, appears to herald a decisive cultural phenomenon: the birth of a Modern sensibility that is to parallel and even supersede classical Western thought." Eisenman, P., "Aspects of Modernism…", op. cit.

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Journal of Civil Engineering and Architecture 11 (2017) 691-700
doi: 10.17265/1934-7359/2017.07.006

A Feasibility Study for New Transport Connections between Italy and Algeria

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Abstract: The present study is part of the Executive Scientific Project 2 in the ItalMed Project which aims to elaborate a feasibility study for new transport connections between Italy and Algeria. The main objectives of the study are to increase the degree of economic integration between the two countries and improve commercial exchanges and direct investments in Algeria by Italian private companies. Moreover, the study tries to promote Italy's role as logistic platform for Mediterranean Countries along the east-west and north-south corridors and to improve the capacity of Italian regions to manage international cooperation programs on transport and logistics, finally, to support regional entrepreneurship in the foreign services sector.

Key words: Freight, stated preference, potential demand, cost model.

1. Introduction—Current Dynamics of Algerian Economy

Algerian economy is nowadays based on production and manufacture of hydrocarbons (natural gas and oil); natural gas fields are almost inexhaustible so as to ensure future continuity of the most important sectors in the budget of the country.

This sector (production and manufacture of hydrocarbons), therefore, contributes to almost half of the country's GDP (gross domestic product).

For transports and logistics features, the hydrocarbons sector does not present special problems because the exchange with Italy occurs mostly via pipelines that link Italy with Algeria, crossing Tunisia.

In the last years, the value of Italian export to Algeria is increasing while import of Algerian goods to Italy is always fluctuating.

Among Italian exports to Algeria, there are thermal and hydraulic turbines and other machines that produce mechanical energy, including parts and accessories which constitute the second largest item of export; moreover, emulsions of bitumen, tar and binders for road use are, in terms of value, the third largest export in 2008.

The Algerian government is generally committed to open the country's economy and attract more foreign investments, particularly in areas not related to hydrocarbons. The expansion of the construction sector is guided by the government program to improve infrastructure and building economic expansion for the growing young population.

This should also encourage the creation of new jobs and a strong demand for material and construction equipment.

This policies and dynamics are a good opportunity for Italian firms from both manufacturing than distribution companies, from the logistics and infrastructure modernization process currently underway in Algeria.

A large part of active population works in agriculture and the government is committed to this area, strongly

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rooted in the culture of the country, trying to increase their yields through programs for the expansion of irrigated areas. Despite Algerian government efforts, the country is still heavily dependent on other countries by importing large quantities of food and agricultural products. This is another chance for many Italian farms.

The success of the "Made in Italy" in the Algerian market (usually characterized by the 4A—Agribusiness, Furniture, Clothing/Fashion, Industrial Automation, in italian language Agroalimentare, Arredamento, Abbigliamento/Moda and Automazione industriale) occurs mainly through the industrial automation sector, which represents over 75% of the Algerian demand of Italian goods.

Among consumer goods, before the decline in the clothing sector, which is affected by smuggling, we report the growth of luxury goods with respect to the field of jewelry, showing big boom in 2007, amounting in absolute terms at around €33 million in sales. Even the first half year of 2009 confirms the trend with a sales progression of more than 50%.

Between interesting sectors for investments, as well as the exploitation of oil fields, infrastructure is another big investment, including enlargement of Algiers port and the restructuring of other ports, construction of roads, tunnels, new whether railways, water works and sewage treatment works.

Very interesting are the high-tech sectors: the eGovernment, the pharmaceutical industry, the defense industry and the public utilities. Also very promising is the field of telecommunications, for which Algeria will be opened in a short time to market.

The analysis is divided in four parts:

- hypothesis definition of scheduled services between Italian ports/airports and Algeria;
- comparative analysis of the competitiveness of hypothetical scheduled services in relation to existing services;
- analysis of constraints to the development of the proposed routes;
- estimation of the potential demand for the scheduled services envisaged in the project.

In this paper, only the first, second and third parts are described due to their geographical and modeling approach.

2. Analysis of Existing Connection between Italy and Algeria

This first part consisted in the research and analysis of existing connections, with a focus on actual quantities of goods exported and imported from Algeria, so as to allow the analysis of transport supply and demand.

With regard to information on existing routes between the two countries, it has been collected data from specialized journals (Messaggero Marittimo and Avvisatore Marittimo of September 2011) which set forth the current routes, represented schematically in Fig. 1.

The analysis of existing routes showed that the connections are prevalent in the north-central area of Italy, while the central area between the south of Tuscany and Lazio is totally absent of links. In real-world, this area is comprised in the center Tyrrhenian-Adriatic Logistics Platform (as called in the National Logistics Plan).

A second phase regards the actual import-export trends analyzed starting from the data of European section of ISTAT (Italian Statistical Agency) called COWEB. In this database, traffic of goods is quantified in euro for each year, for each goods type and for each province.

The following Figs. 2, 3 and Table 1 show the elaborated data by means of GIS (Geographic Information System) [1, 2] software and they represent the total import and export values between Italy and Algeria in the years 2009 and 2010.

These first results show that the import market from Algeria is limited to only 20 Italian provinces with the first four that cover more than 98% of the total. The result is a very concentrated market (see Table 1).

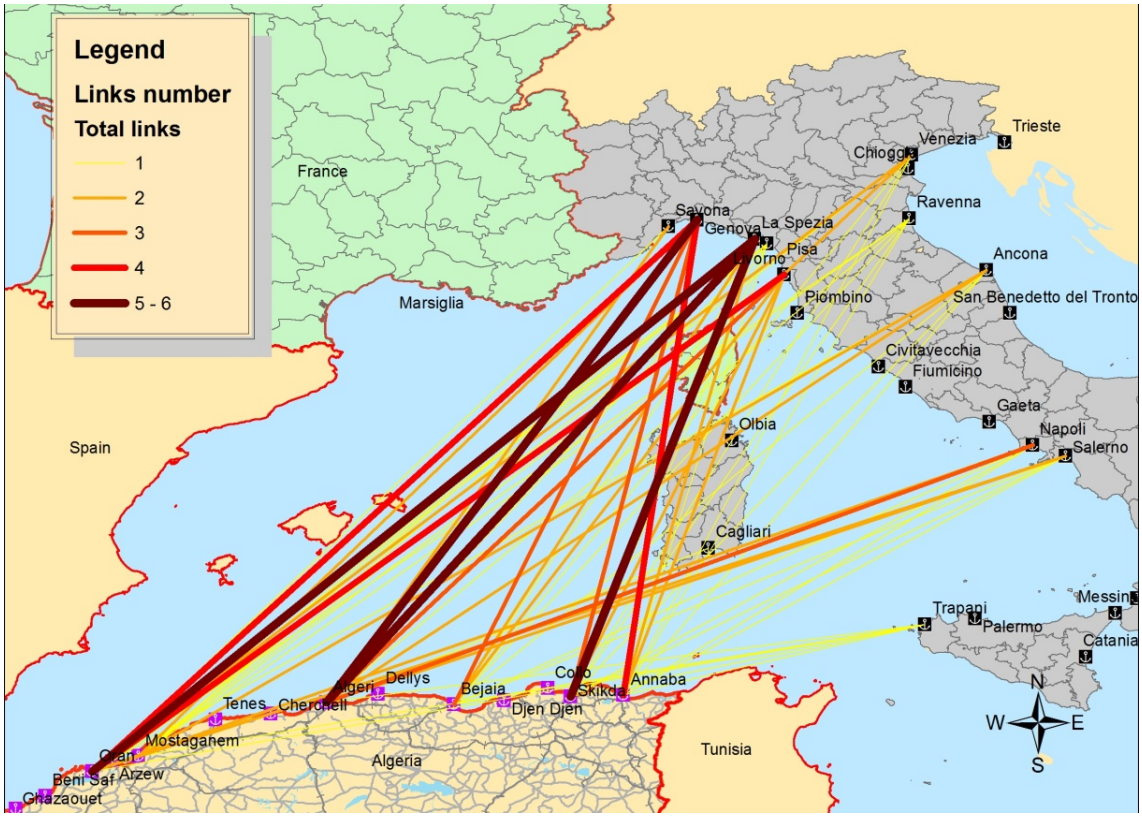

Fig. 1 The actual sea routes between Algeria and Italy.

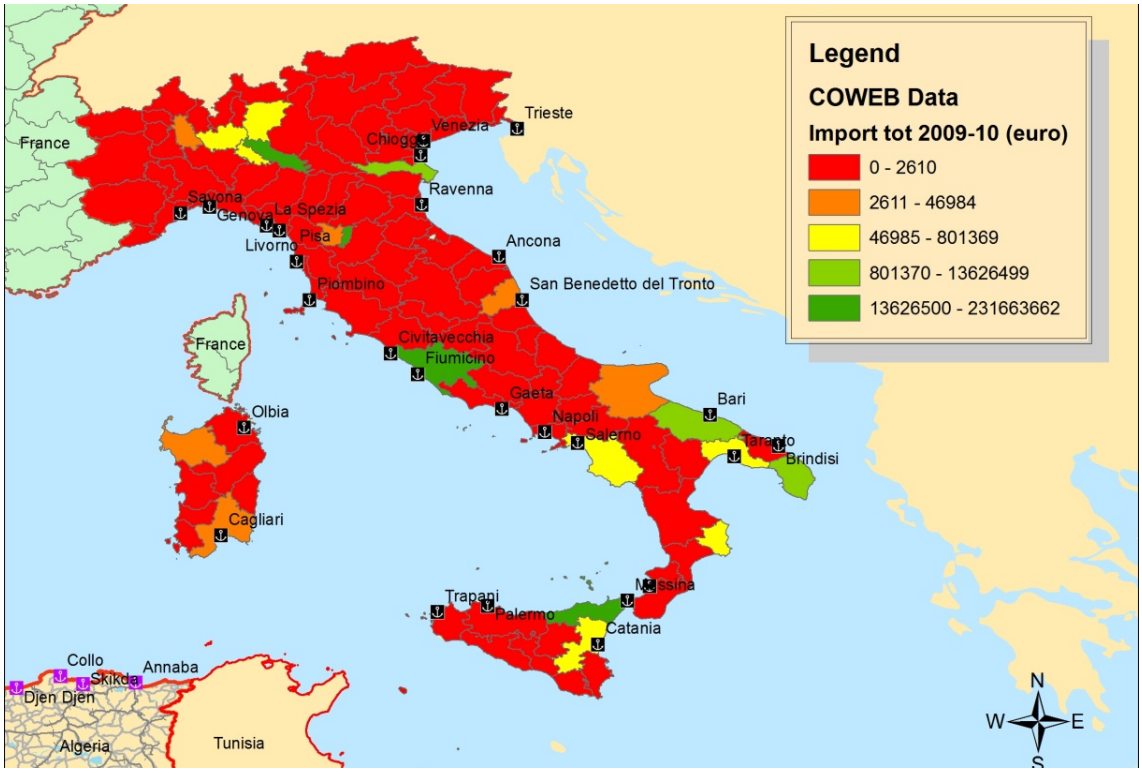

Fig. 2 Total import from Algeria to Italy (total freight traffic in euro, Year 2009 and 2010).

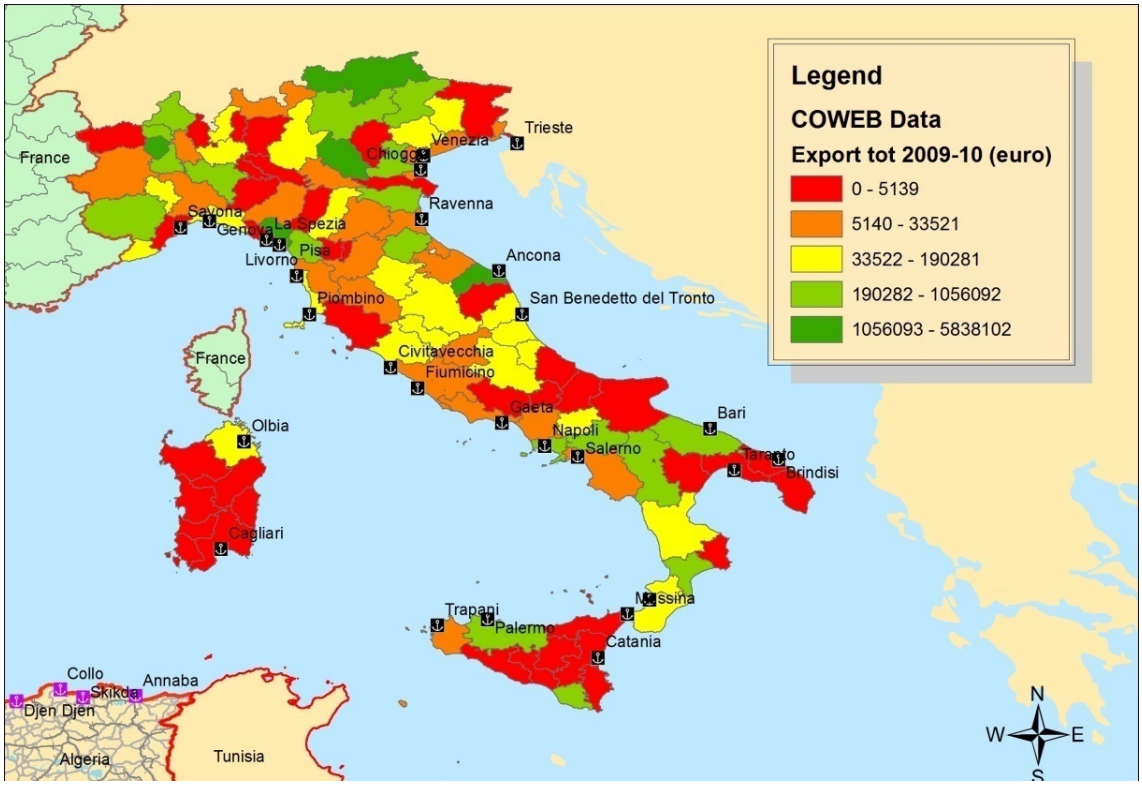

Fig. 3 Total export from Italy to Algeria (total freight traffic in euro, Year 2009 and 2010).

Table 1 Total import and export from Algeria.

Pseudo-subsections	Cluster	IMP2009	EXP2009	Province
BB—Mineral extraction products from quarries and mines		2,167,967,435	0	Not specified Province
BB—Mineral extraction products from quarries and mines		80,561,605	19,752	Roma
BB—Mineral extraction products from quarries and mines		74,485,608	0	Prato
CD—Coke and refined petroleum products		71,691,629	38,000	Napoli
BB—Mineral extraction products from quarries and mines		32,353,808	41,726	Milano
CD—Coke and refined petroleum products		4,928,092	61,000	La Spezia
CD—Coke and refined petroleum products		4,898,864	0	Caltanisetta
CD—Coke and refined petroleum products		4,000,733	32,700	Livorno
CE—Chemicals		3,326,680	52,878	Ravenna
CB—Textiles, clothing, skins and accessories		2,106,303	0	Avellino
CG—Articles of rubber and of plastics, other products of the termination of non-metallic minerals		2,027,017	57,851	Cuneo
AA—Products of agriculture, forestry and fishing		2,001,561	216,810	Bari
CD—Coke and refined petroleum products		1,612,260	4,255,620	Roma
CH—Basic metals and metal products, except machinery and equipment		1,243,147	6,847,541	Udine
VV—Goods declared as on board, national goods return and rejected, various goods		897,983	0	Milano
CH—Basic metals and metal products, except machinery and equipment		627,884	75,780,873	Brescia
CE—Chemicals		558,044	7,514	Trieste
CD—Coke and refined petroleum products		480,262	0	Sassari
AA—Products of agriculture, forestry and fishing		413,600	0	Bergamo
CL—Transport means		326,800	0	Crotone
CE—Chemicals		323,948	0	Frosinone

Unlike imports, exports from Algeria have a greater geographical spread, but smaller quantities of goods (5.5% of imports, that is to say 21.6 mil. € vs. 394 mil. €).

Finally, the data from the European project DATELINE were collected to evaluate the demand from passengers transport from EU to Algeria. In fact, this project has elaborated a survey to European citizens (interviews with a sample of more than 86,000 residents in the European Union and their journeys with distance greater than 100 km). From these data, it was reconstructed the O/D matrix for all long distance journeys and relative to all transport modes (see Fig. 4).

The previous Fig. 4 shows that in the central-southern Italy, the only area with a good number of long distance journeys to Africa is the region Lazio. The European countries with more LD journeys are France, Germany, United Kingdom and Spain; the proposed routes must create a network with these countries with maritime ro-ro types or air connections.

3. Definition of Hypothesis of Scheduled Services between Italian Ports and Airports and Algeria

In terms of airplane traffic, the company with the largest number of links between these four countries and Italy is Ryanair. After Milan and Rome airports, the biggest number of connections are destinated to Pisa Airport; for these reasons, it has been hypothesized a route between Pisa and Algiers, which allows to build a network of connections throughout Europe.

In the following Table 2 and Fig. 5, all the proposed connections are described in their geographical and qualitative features.

3.1 Analysis of Constraints to the Development of the Proposed Routes

The analysis carried out shows that the potential

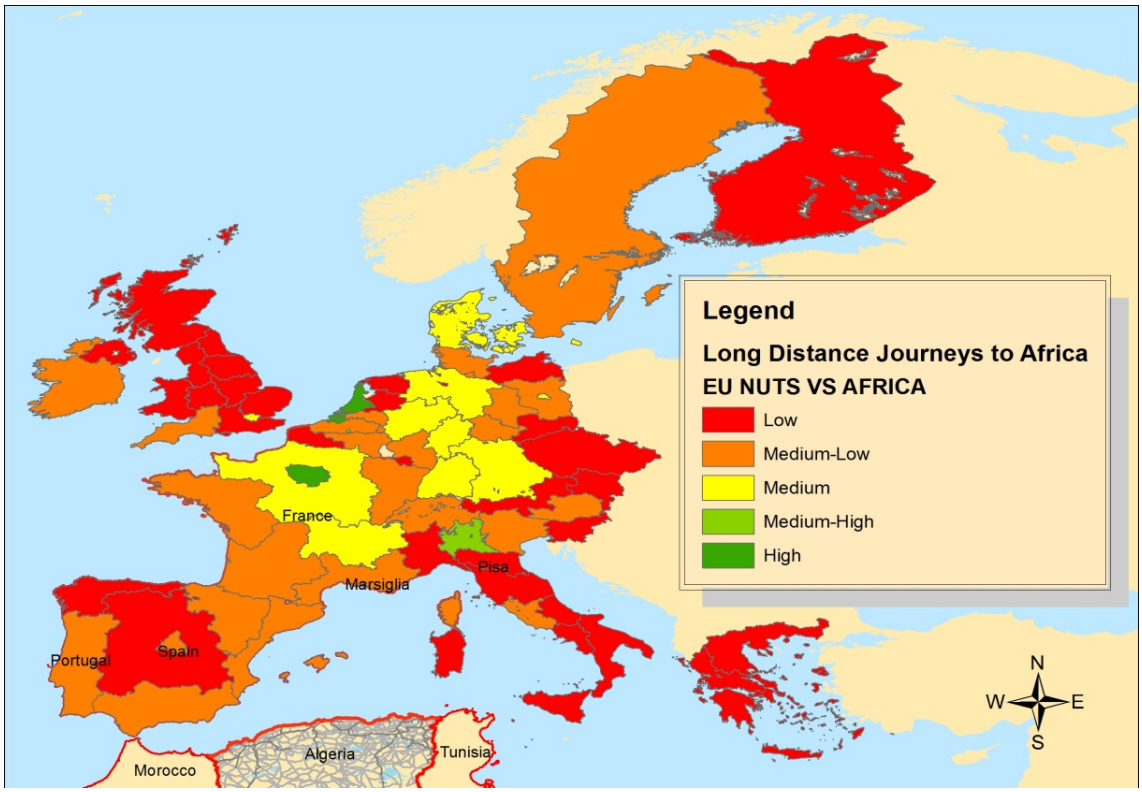

Fig. 4 Number of LDJ (long distance journey) made from European citizens with destination Africa.

Table 2 Proposed routes properties.

Hypotesis 1	Route	Service type	Frequency
Shipping line	Civitavecchia-Algeri	Ro-ro-pax	Weekly
Air line	Pisa-Algeri	Passengers	Biweekly
Shipping line	Marsiglia-Livorno-Napoli-Algeri	Ro-ro-pax	Weekly
Shipping line	Livorno-Algeri	Container	Weekly

Fig. 5 The proposed routes between Italy and Algeria.

attractiveness of the new routes is very high for both imports than exports to Algeria, but, at present, this possibility is limited by high port costs (e.g., cost of goods handling) and excessive bureaucracy impact (e.g., number of documents and others).

In the following, shipping cost and time for some north-african countries are compared (Figs. 6 and 7).

Algeria seems to be the countries with the biggest port costs (eight out of ten cost items are the major) and the countries with the biggest port times (eight out of twelve time items are the major).

Therefore, one of the causes of the high increase in freight traffic to Morocco facing a more static (even political) behavior of the Algerian country is clear.

3.2 Estimation of the Potential Demand for the Maritime Scheduled Services Envisaged in the Project

3.2.1 The Cost and Time Transport Model

Once outlined the possible routes and the existing constraints to their growth, it was investigated the possible demand both from Italy side than Algeria one. To do this, the land-side road network was reconstructed for both countries.

Moreover, by means of the following cost functions (see Figs. 6a, 6b and 7) [3, 4], the travel impedance for each road segment was evaluated so as to construct the gravitational area of each port both for Italy than Algeria. The network was classified with a hierarchical structure so as to apply different cost function for each road.

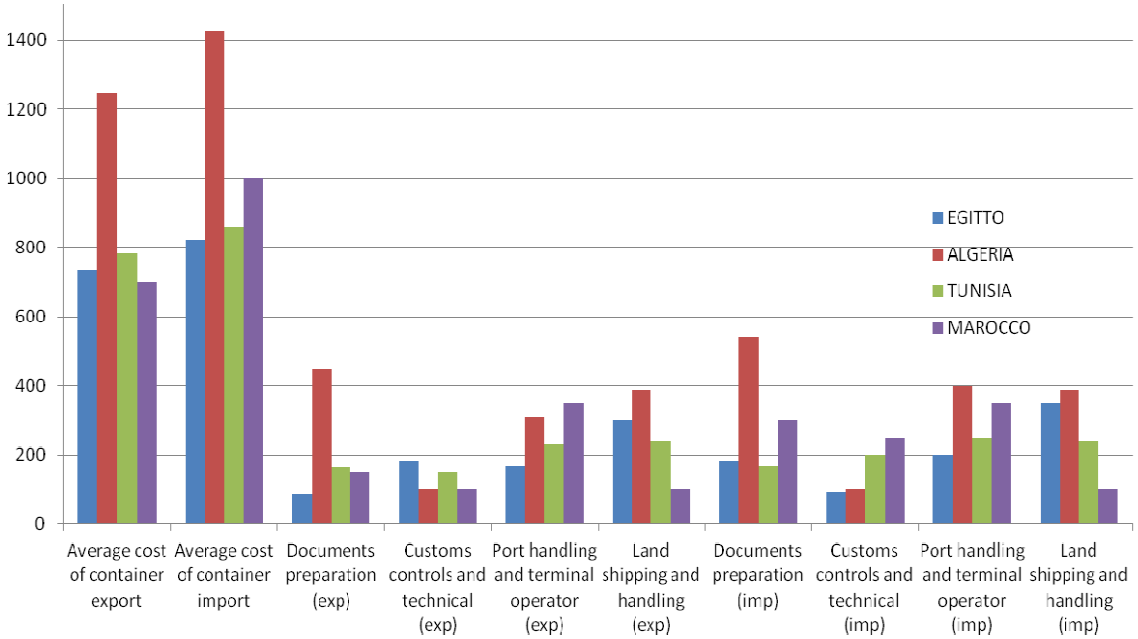

Fig. 6 Cost (euro) comparison for some African countries.

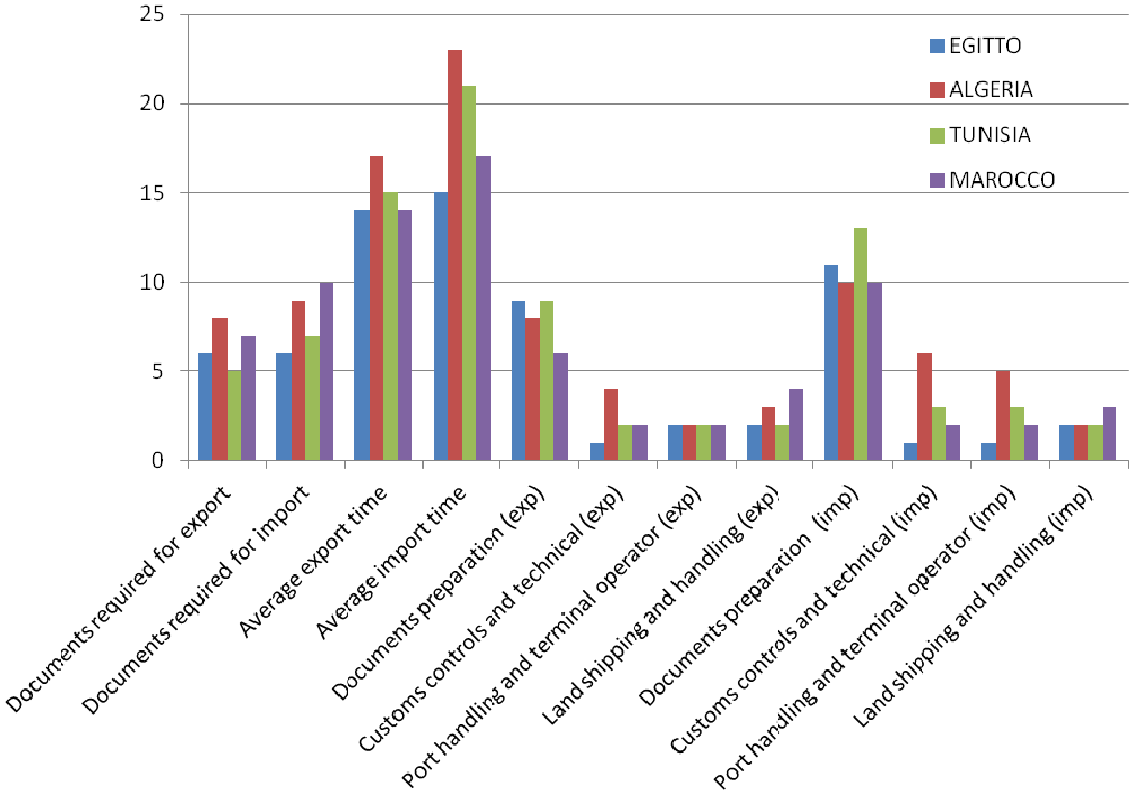

Fig. 7 Time (days) comparison for some African countries.

After the transport model construction, a survey was started with an interview to some companies that have been identified as possible users of the shipping services designed or that currently trade with Algeria.

The survey is divided in three parts: in the first part, there is the collection of data about each company (for

example, geographical localization, size, logistic organization, etc.). In the second part, there are some questions about actual market (origin/destination of goods, frequency, mean cost and time for each leaving and arriving goods). In the third part, there is a stated preference survey [5-7] related to one of the new scheduled service where the future service is characterized by different levels of cost, time, frequency, reliability and punctuality.

Stated preferences are conceptually equivalent to a laboratory experiment that can be designed with a larger number of degrees of freedom. These surveys are a set of techniques that use the statements of respondents about their preferences in hypothetical scenarios or contexts. They are based on the possibility to control the experiment by designing the context of choice to be submitted to the interviewee rather than retrospective record as in usual Revealed Preference Surveys.

The survey is still ongoing but, once completed, it will help to establish the category and the internal and external characteristics (for example, the type of logistics present) in order to reconstruct the potential demand [8], always remaining within the calculated gravitational areas; in fact, it will be a support to design, in detail the future service by comparing the importance of different service attributes included in the choice scenario and their variation with the company characteristics (Sections 1 and 2 of the survey).

The first results of the model, still to be completed with the part about the discrete choice model (see Figs. 8 and 9), show how the demand Italy-side, intercepted from the port of Livorno, is mainly regional, due to the conformation of the Italian road network (see Fig. 10) with a possible expansion to Emilia Romagna and Veneto regions. Instead, the Civitavecchia and Naples ports have a greater gravitational basin so, therefore, to fully justify the suggested routes. In addition, the route Marseille-Algiers-Livorno-Napoli is also appealing for passengers movement because of the touched touristic destination and the results of the long distance journeys analysis.

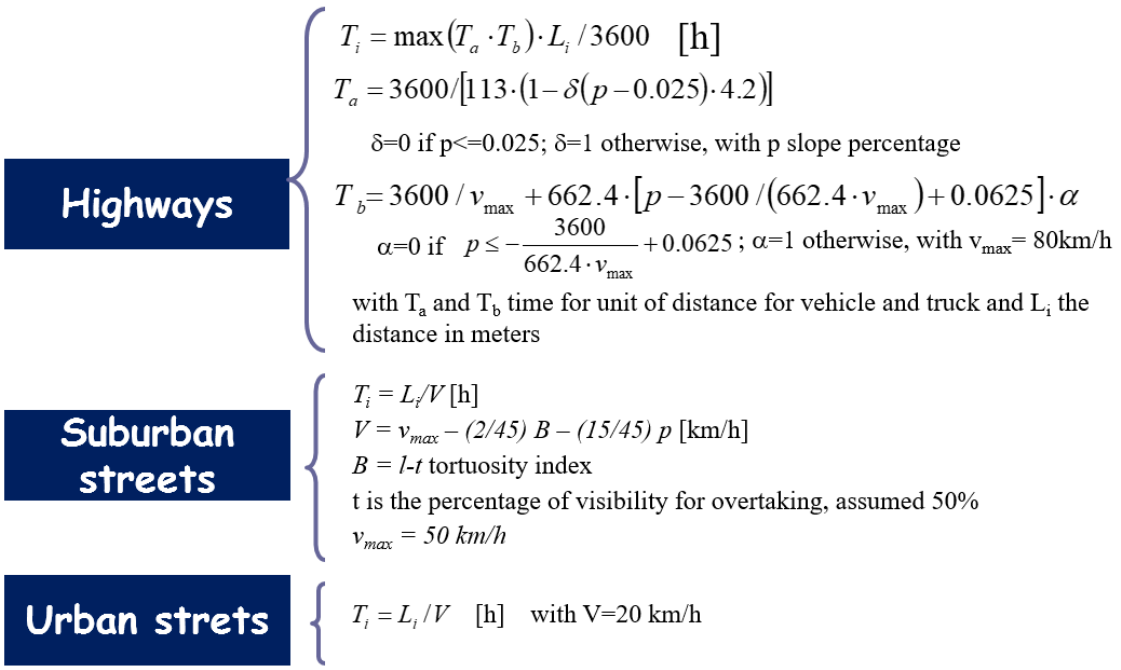

Fig. 8 Time cost functions for different street types.

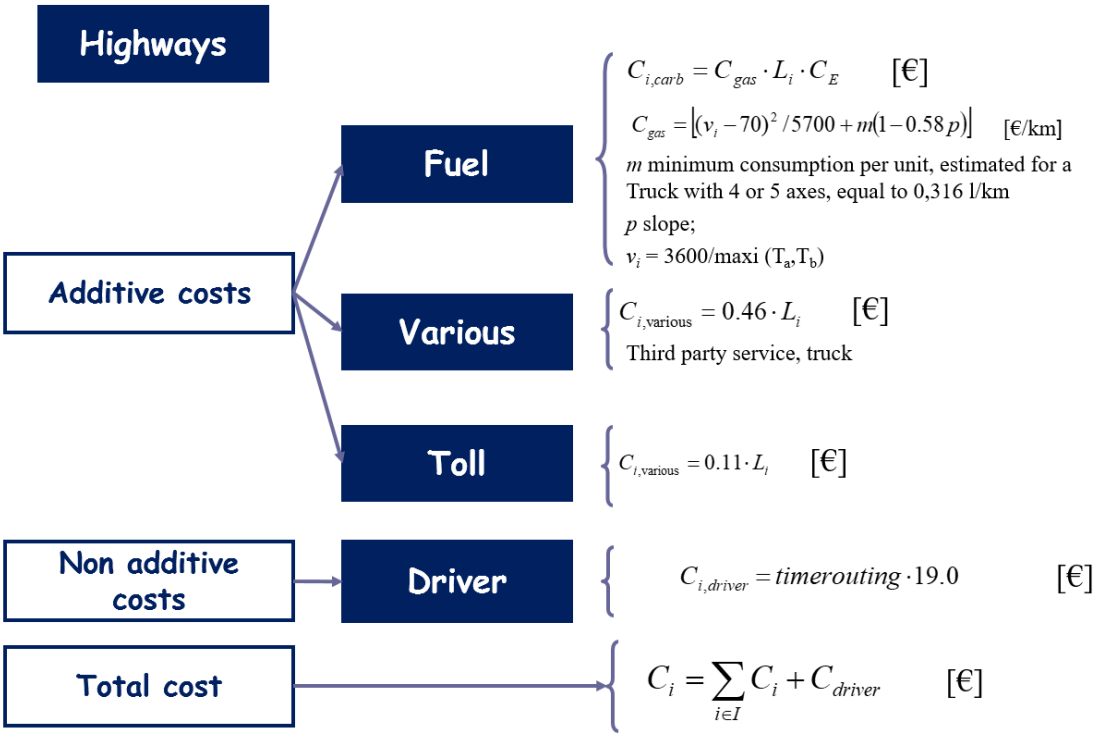

Fig. 9 Monetary cost functions for highways.

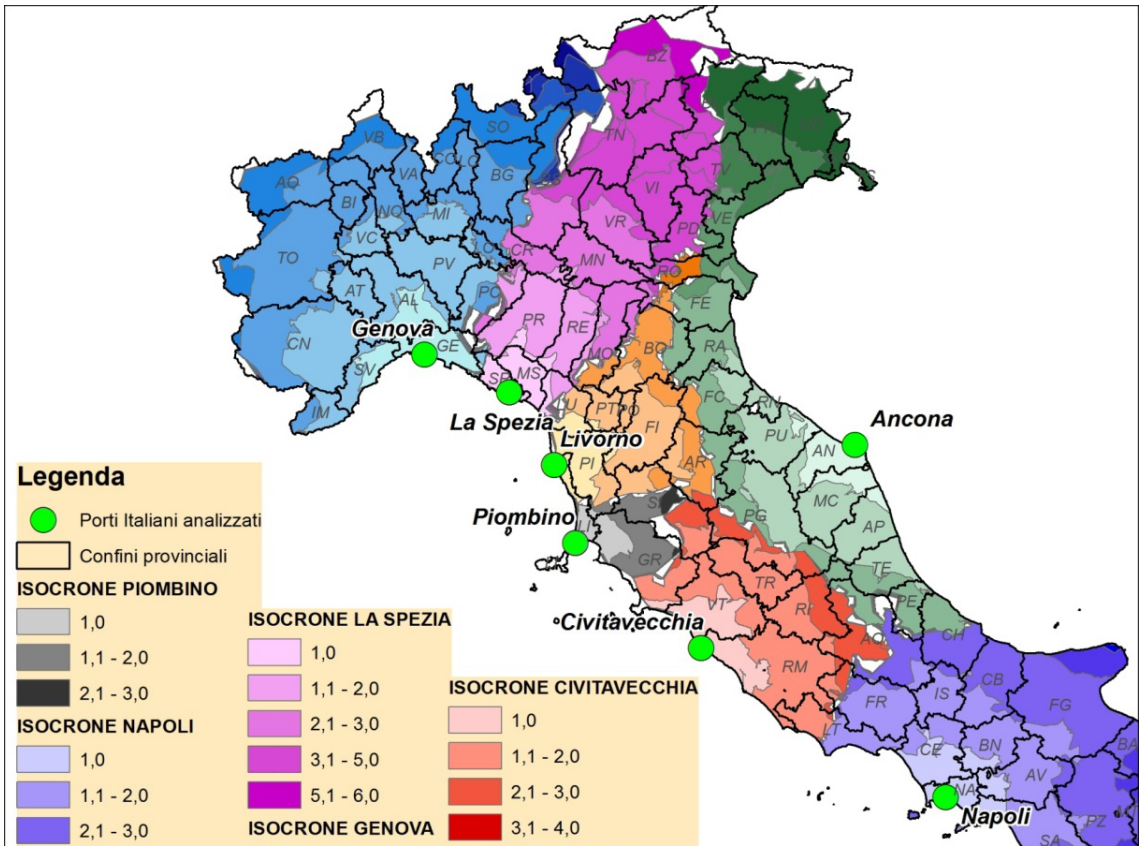

Fig. 10 Service areas of the analyzed ports.

4. Conclusions

The analysis of the political-economic dynamics shows a favorable condition to increase traffic between Europe and Algeria. In particular, Italy becomes a key partner for the trade of building materials, for the needs of agriculture modernization (new agricultural machinery, etc.) and for the industrial automation sector.

The analysis of existing routes and the results of port influence delimitation have demonstrated the feasibility of new routes, especially in the south central area of the west coast.

In fact, the port of Civitavecchia becomes a new bridge connecting north Africa for all Italian companies located in the area from Naples and Livorno, for which it would lead to a significant increase of accessibility.

Since this area is almost entirely included within the basin of the port of Civitavecchia, it results in an important solution for the recovery of the Made in Italy in Algeria.

The analysis of existing constraints highlights the need for a streamlining bureaucratic both to lighten the timing for goods input/output than port costs. This becomes a condition *sine qua non* which is difficult to think to a quantitatively significant increase in trade between Algeria and European countries, even starting from the suggested routes.

With regard to stated preference interviews [9], this work is still ongoing; we are encountering more difficulties, from the Italian companies, to provide data on their current cargo traffic while the section on scenarios of choice, constructed on the basis of a hypothetical service (to date for the route primary already highlighted Civitavecchia-Algiers), is less problematic.

Since this second part is the most important section, for the reconstruction of the users and the evaluation of potential demand, we are planning to remove the part relating to the reconstruction of existing traffic to avoid a source of friction in the compilation of the survey. Once the survey will be concluded, the model will be integrated with the data about the estimated demand for the proposed scenario and it will be elaborated a cost-benefit analysis to understand the real possibility to develop the new services. In case of positive economic results, it will be a start in the phase of involvement of the most important stakeholders.

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Journal of Civil Engineering and Architecture 11 (2017) 701-714
doi: 10.17265/1934-7359/2017.07.007

Effect of Sample Unit Size on Visually Examining Pavement Condition for Asphalt-Surfaced Roads

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Abstract: Road surface condition evaluation involves the collection of data over pavement surface for different types of distresses. The exercise consumes a lot of resources if the whole road section length is surveyed and may be prone to errors as a result of surveyors' fatigue. It is therefore important to develop a representative sample to be used when evaluating road condition manually. This study aimed at determining an adequate sample size for section level as well as a way forward for network level condition evaluation of highways in Nepal. Again the study was conducted to quantify the effects of altering the sample unit size for performing a distress survey according to the PCI (pavement condition index) and SDI (surface distress index) method separately for asphalt surfaced roads. The effect of reducing/increasing sample unit size was investigated adopting visual examination through field survey by eight teams in July, 2015, along the section of Banepa-Bardibas highway. The PCI was then calculated for each sample unit using standard deduct curves and PCI calculation methodology as per SHRP (Strategic Highway Research Program) recommendations and the computation of SDI was done as per DoR (Department of Roads) guidelines. The results show that 13% sample unit are needed for SDI and 21% for PCI computation, however, the results are out of the significant level. This is higher than DoR and SHRP guidelines. Again no strong relationship is observed between SDI and PCI values.

Key words: Pavement condition evaluation, PCI, SDI, sample size, policy implications.

1. Introduction

1.1 Background

Pavement condition evaluation is one of the important components of pavement design, rehabilitation and management which include evaluation of distress, roughness, friction and structure. Most of the cost effective M&R (maintenance and rehabilitation) strategies developed using PMS (pavement management system) is due to accurate pavement evaluation [1]. Pavement condition information is used to evaluate the current condition, determine rate of deterioration, project future condition, determine M&R needs, and determine the costs to repair pavement segments. It is also used to establish M&R strategies and is often used to help prioritize M&R fund expenditures [2]. Since so many decisions supported by the PMS are based on the condition assessment, it is important to ensure that the data collected and used is accurate enough to provide the desired level of support. However, since the collection of condition data is the most expensive portion of maintaining the PMS, the cost must be matched to the resources and needs of the adopting agency [2]. Several new nondestructive technologies have been developed and applied in collecting raw condition data and processing them to produce useful condition input to infrastructure IM&R (inspection, maintenance, and rehabilitation) decision making aimed at minimizing expected total life-cycle cost [3]. Such advances initially motivated the quantification of condition measurement uncertainty and the incorporation of this uncertainty in decision making. Following this development, the spatial variation of condition has been quantified and has led to the recent extension of decision-making methods to take into account sampling uncertainty and determine the optimal sample size, along with the other IM&R activities [3].

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The evaluation of the contributions of the condition sampling-related advances to improved decision making is presented by Mishalani and Gong [4]. The results of the application of this evaluation methodology indicate that the magnitudes of the value of the condition-sampling advances of interest are found to be appreciable in both expected total life-cycle cost and IM&R agency cost.

The PCI (pavement condition index) and SDI (surface distress index) are the numerical indicator that rates the surface condition of the pavement through visual examination. These indicators provide a measure of the present condition of the pavement based on the distress observed on the surface of the pavement which also indicates the structural integrity and surface operational condition (localized roughness and safety). However, these indicators cannot measure the structural capacity; neither they provide direct measurement of skid resistance or roughness. They provide an objective and rational basis for determining maintenance and repair needs and priorities [5, 6]. Continuous monitoring of the PCI is used to establish the rate of pavement deterioration, which permits early identifying of major rehabilitation needs. The PCI provides feedback on pavement performance for validation or improvement of current pavement design and maintenance procedures [5]. Surface distress surveys of the strategic network have been undertaken annually by planning branch since fiscal year 1992-1993 [7]. The survey was interrupted for some year and it is continued form fiscal year 2012-2013.

1.2 Objectives and Scope

The main objective of this study is to assess the effect of sample unit size on pavement condition index for asphalt-surfaced roads. Specifically following objectives are set out:

- To evaluate the pavement section for SDI and PCI values;
- To recommend the suitable sample size for the evaluation of pavement;
- To develop the relationship between SDI and PCI indices;
- To compare the maintenance strategy as recommended by SDI and PCI.

2. Literature Review

For the time being, prioritizing in the selection of the roads (or resealing) will be limited to the consideration of the four parameters namely road age, visual survey ratings, traffic and strategic importance [8].

It is recommended that a section sample of 20 m long from the beginning of a 100 m section be used in evaluating the pavement surface condition of such roads. This will result in a reasonably accurate representation of the condition of the whole section with huge savings in resources [9]. Comparisons were made between PCI values calculated using standard PCI procedures (19 distress types) and PCI values calculated using modified distress identification procedures developed by the Metropolitan Transportation Commission (seven distress types) [10]

The study area in Ref. [11] consists of 10 urban road sections constituting 29.92 km of Noida city. The methodology includes identification of urban road sections, pavement distress data collection, development of individual distress index and finally developing a combined OPCI (Overall Pavement Condition Index) for the network. The four performance indices, namely, pavement condition distress index (PCI distress), pavement condition roughness index (PCI roughness), pavement condition structural capacity index (PCI structure) and pavement condition skid resistance index (PCI skid) are developed individually. Then all these indices are combined together to form an OPCI giving importance of each indicator. The proposed index is expected to be a good indicative of pavement condition and performance. The developed OPCI was used to select the maintenance strategy for the pavement section [11].

Pavement condition has been known as a key factor related to ride quality, but it is less clear how pavement

conditions are related to traffic crashes. The results in Ref. [12] suggested that poor pavement condition scores and ratings were associated with proportionally more severe crashes, but very poor pavement conditions were actually associated with less severe crashes. Very good pavement conditions might induce speeding behaviors and therefore could have caused more severe crashes, especially on non-freeway arterials and during favorable driving conditions. These results provide insights on how pavement conditions may have contributed to crashes, which may be valuable for safety improvement during pavement design and maintenance. Although the study found statistically significant effects of pavement variables on crash severity, the effects were rather minor in reality as suggested by frequency analyses [12].

Infrastructure management is the process through which IM&R decisions are made to minimize the total life-cycle cost. Measurement, forecasting, and spatial sampling are three main sources of errors introducing uncertainty into the process. The first two uncertainties are captured in the infrastructure management literature. However, the third one has not been recognized and quantified. Ref. [4] presents a methodology where the spatial sampling uncertainty in question is captured and the sample size is incorporated as a decision variable in an optimization. The results indicate that by not addressing the sampling uncertainty and decisions, the optimum IM&R decisions would not be achieved, and consequently, marked unnecessary overspending could take place [4].

The effect of sample size on PCI accuracy was investigated for asphalt roadways [10] by employing the 35-mm film automated distress data collection technique. Twenty four asphalt pavement sections were surveyed. Fig. 1 shows a plot between relative sample unit size for regular size and expected amount of error in the PCI. Fig. 2 shows a comparison between PCI calculated using 10% regular sample size and PCI calculated using a full road section. As long as the size is within 40% from the regular size, from Figs. 1 and 2 the error is limited to about 2%.

The evaluation of the contributions of the condition sampling-related advances to improved decision making is presented by Mishalani and Gong [4]. In this paper, the methodology is based on comparing decision-making frameworks that reflect the advances of interest with those that do not. The basic idea behind comparing any two frameworks is to use each to produce optimal IM&R policies that are based on the specific assumptions they reflect and then to simulate these optimal policies within the framework reflecting the truth with regard to capturing the most realistic assumptions. The results of the application of this

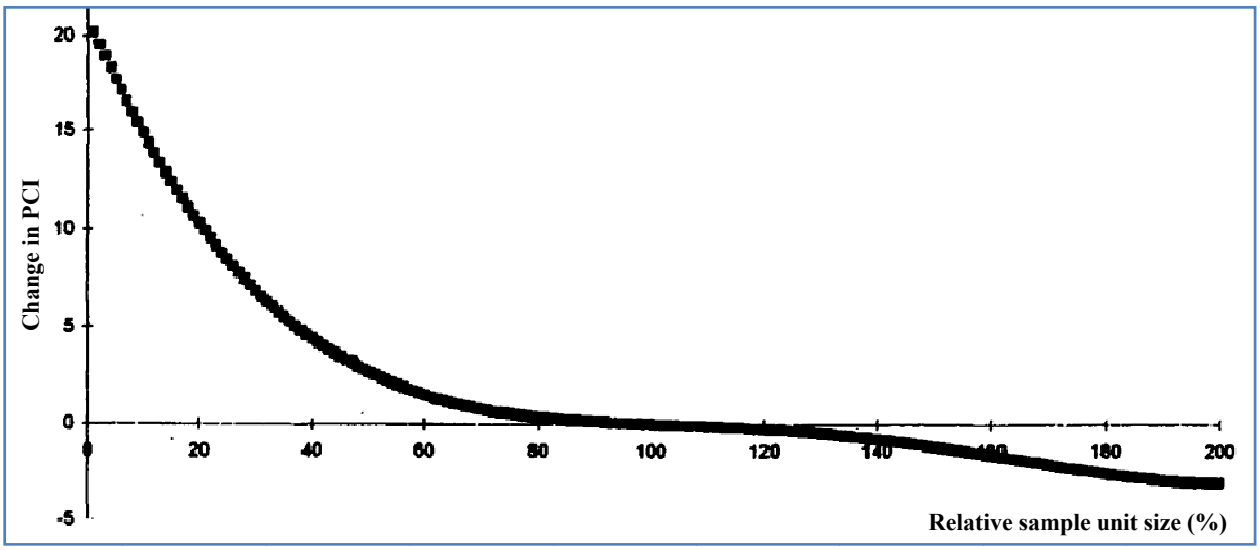

Fig. 1 Relative sample unit size and expected amount of error in PCI calculation [10].

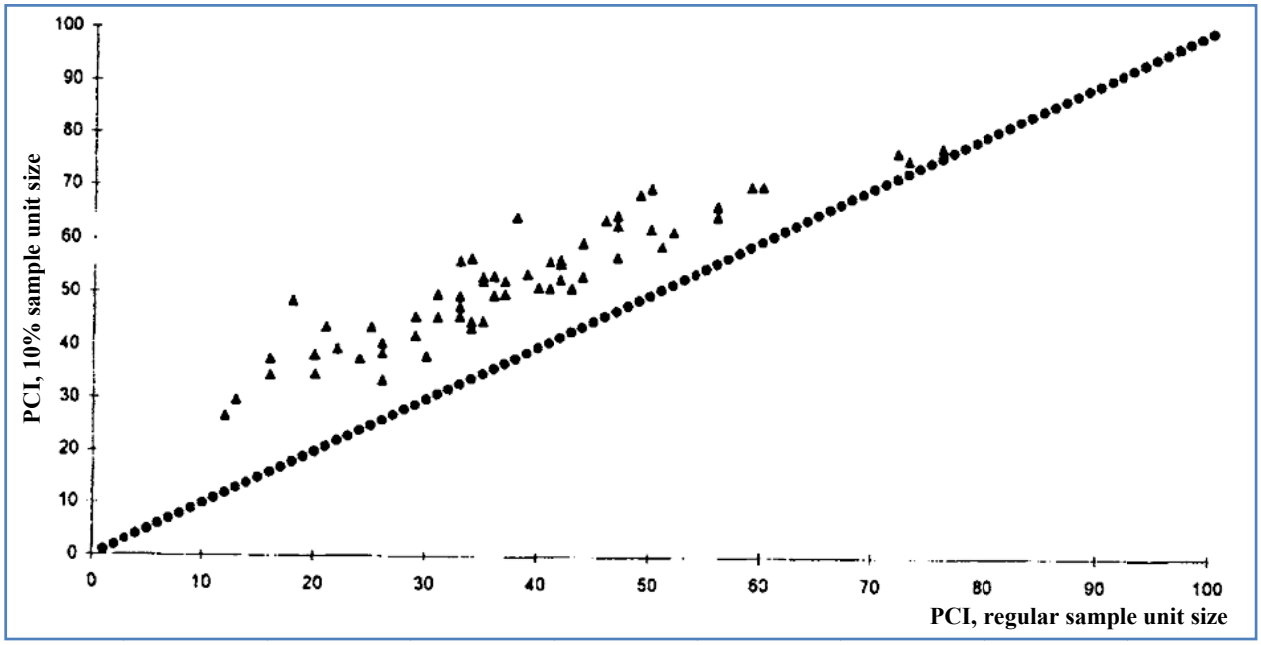

Fig. 2 Comparison of the effect of sample unit size on PCI accuracy [10].

evaluation methodology indicate that the magnitudes of the value of the condition-sampling advances of interest are found to be appreciable in both expected total life-cycle cost and IM&R agency cost [4].

3. Data Collection and Computation for SDI and PCI

3.1 Criteria for Site Selection

The project sites were chosen meeting the following criteria: "Roads with low to medium traffic volume in order to avoid accidents and conveniently collect data and the roads with as many types of distresses as possible [13]. Banepa Bardibas (BP) highway was selected for the study. The total length of the highway is about 206 km and the carriageway width is 5.5 m, with unpaved shoulders. Traffic is a hazard as inspectors may walk on the pavement to perform the condition survey. Accurate, consistent, and repeatable distress evaluation surveys can be performed by using the Distress Identification Manual for the Long-Term Pavement Performance Project [13]. Eight groups with two trained engineer in each have conducted condition surveys for the determination following categorical distresses:

- Distress type—identifying each type of distress;
- Distress severity—the level of severity of each distress present showing the degree of deterioration of the pavement;
- Distress extent—relative area affected by each combination of distress type and severity.

3.2 SDI (Surface Distress Index) Survey

There are various methods of collecting surface distress data and these increase in complexity and sophistication according to the quality of information required. The method adopted in this research is the method adopted by DoR (Department of Roads) and is a simplified procedure recommended by the World Bank which has been modified to suit the particular conditions in Nepal and the needs of DoR. The SDI is a six-level rating index from 0 to 5. The rating 0 indicates a pavement surface without any defects, whereas a rating of 5 indicates for the maximum possible deterioration. A shoulder condition survey is recommended to carry out at the same time using rating in the range 0 to 4. However, the shoulder condition is out of the scope of this research. The three most predominant types of defect present in each sample section are recorded.

3.2.1 Field Work Plan and Sampling

Pavement distresses surveys are carried out manually by the trained engineers using drive and walk survey. Surface distress comprises cracking, disintegration (potholes), deformation, textural efficiency, pavement edge defects and maintenance works (patching). These faults are visually assessed using a 10% sampling procedure and recorded using a cumulative index called an SDI. The distress elements are divided into two groups: major and minor defects. Among the different defect types, cracking, raveling and potholes are generally characterized by extent and severity, while rut depth being continuous in nature, only the severity of the deformation is noted. The defect types and therefore resulting score are different for bitumen and gravel roads, which are separately presented in Ref. [6].

The 10% sampling procedure comprises a walk-over survey generally covering the last 100 meter section in each kilometer of the road on which the SDI is to be determined [6, 7]. The full width of pavement is to be evaluated for each sample of length 100 m.

3.2.2 SDI Data Use

The SDI is averaged over each road link or section under consideration. The results can be used to provide the objective assessment of the pavement condition and to indicate the need for periodic maintenance, rehabilitation or reconstruction. For assessing pavement condition, the terms "Good", "Fair" and "Poor" are used based on averaged values of SDI as presented in Table 1.

These values are based on conditions in Nepal. Planned maintenance can be carried out on roads in good/fair condition and rehabilitation or reconstruction is generally needed for roads in poor condition to bring them to a maintainable state. Similarly, an indicator for different types of pavement remedial action is given by the percentage of the number of sample section with the given SDI values of a particular link as shown in Table 2.

3.3 PCI (Pavement Condition Index) Survey

The information was processed to obtain PCI values for each road section sample and for whole section. The pavement is divided into branches that are divided into sections. Each section is divided into sample units. The type and severity of pavement distress is assessed by visual inspection of the pavement sample units [5]. Information about date, location, branch, section, sample unit size, slab number and size, distress types, severity levels, quantities, and names of surveyors, were recorded on data sheets [14]. Again the instruments used are measuring tape (30.0 m and 3.0 m length with 2 mm and 1 mm least count) straightedge, scale (300 mm).

3.3.1 Field Work Plan and Sampling

First, divide the pavement sections into sample units. Individual sample units to be inspected should be marked or identified in a manner to allow inspectors and quality control personnel to easily locate them on

Table 1 SDI chart for pavement condition in Nepal [6].

SDI values	Condition
0~1.7	Good
1.8~3.0	Fair
3.1~5.0	Poor

Table 2 Pavement remedial action based on SDI values in Nepal [6].

Percentage SDI values	Action
20%, $SDI = 5$	Reconstruction
10%~30%, $SDI = 4$	Rehabilitation
20%~30%, $SDI = 3$	Resealing with local patching
20%~30%, $SDI = 2$	Resealing only

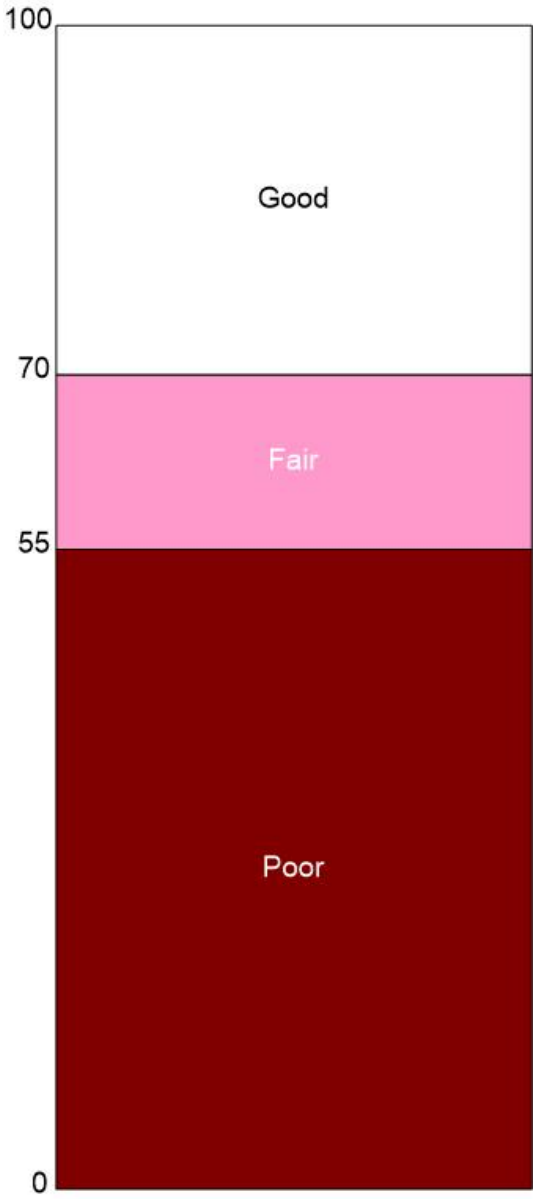

Fig. 3 PCI rating system [15].

the pavement surface. The minimum number of sample units (n) that must be surveyed within a given section to obtain a statistically adequate estimate (95% confidence) of the PCI of the section is calculated using Eq. (1), the following formula and rounding n to the next highest whole number [5]:

$$n = Ns^2/[(e^2/4)(N-1) + s^2] \quad (1)$$

where:

e = acceptable error in estimating the section PCI; commonly, e = 65 PCI points;

s = standard deviation of the PCI from one sample unit to another within the section;

N = total number of sample units in the section.

If obtaining the 95 % confidence level is critical, the adequacy of the number of sample units surveyed must be confirmed. The number of sample units was estimated based on an assumed standard deviation. The actual standard deviation (s) can be calculated as follows (Eq. (2)):

$$S = \sum_{i=1}^{n} (PCI_i - PCI_s)^2 / (n-1)^{1/2} \quad (2)$$

where:

PCI_i = PCI of surveyed sample units i;

PCI_s = PCI of section (mean PCI of surveyed sample units);

n = total number of sample units surveyed.

The revised minimum number of sample units should be calculated (Eq. (1)) which is to be surveyed using the calculated standard deviation (Eq. (2)). If the revised number of sample units to be surveyed is greater than the number of sample units already surveyed, select and survey additional random sample units. These sample units should be spaced evenly across the section. Repeat the process of checking the revised number of sample units and surveying additional random sample units until the total number of sample units surveyed equals or exceeds the minimum required sample units (n) in Eq. (1), using the actual total sample standard deviation. Once the number of sample units to be inspected has been determined, compute the spacing interval of the units using systematic random sampling. Samples are spaced equally throughout the section with the first sample selected at random. The spacing interval (i) of the units to be sampled is calculated by the following formula (Eq. (3)) rounded to the next lowest whole number:

$$i = N/n \tag{3}$$

where:

N = total number of sample units in the section; and

n = number of sample units to be inspected.

The first sample unit to be inspected is selected from sample units 1. The sample units within a section that are successive increments of the interval i after the first selected unit also are inspected.

Additional sample units only are to be inspected when non-representative distresses are observed. These sample units are selected by the user.

3.3.2 Computation of PCI

The total quantities of each distress type are added for at each severity level, and recorded in the "Total Severities". The units for the quantities may be either in square feet (square meters), linear feet (meters), or number of occurrences, depending on the distress type. Divide the total quantity of each distress type at each severity level by the total area of the sample unit and multiply by 100 to obtain the percent density of each distress type and severity. Determine the DV (deduct value) for each distress type and severity level combination from the distress deduct value curves. Determine the maximum *CDV* (corrected deduct value). The following procedure must be used to determine the maximum *CDV* [5]:

• If none or only one individual deduct value is greater than two, the total value is used in place of the maximum *CDV* in determining the PCI; otherwise, maximum *CDV* must be determined;

• List the individual deduct values in descending order. Determine the allowable number of deducts, m, using the formula (Eq. (4)):

$$m = 1 + (9/98)(100 - HDV) \leq 10 \tag{4}$$

where:

m = allowable number of deducts including fractions (≤ 10); and

HDV = highest individual deduct value;

• The number of individual deduct values is reduced to the m largest deduct values, including the fractional part. For:

(1) Determine maximum *CDV* iteratively;

(2) Determine total deduct value by summing individual deduct values. The total deduct value is obtained by adding the individual deduct values;

(3) Determine q as the number of deducts with a value greater than 2.0;

(4) Determine the *CDV* from total deduct value and q by looking up the appropriate correction curve for AC pavements;

(5) Reduce the smallest individual deduct value greater than 2.0 and repeat above steps until $q = 1$;

(6) Maximum *CDV* is the largest of the *CDV*s.

• PCI calculation by subtracting the maximum *CDV* from 100 (Eq. (5)):

$$PCI = 100 - \max CDV \tag{5}$$

$$PCI_S = \overline{PCI}_r = \frac{\sum_{i=1}^{n}(PCI_{ri} * A_{ri})}{\sum_{i=1}^{n} A_{ri}} \quad (6)$$

where:

$\overline{PCI}_r$ = area weighted PCI of randomly surveyed sample units;

PCI_{ri} = PCI of random sample unit i;

A_{ri} = area of random sample unit i;

n = number of random sample units surveyed.

If there is no additional sample, then PCI of the section is given by Eq 6 but if additional sample units are surveyed, the area weighted PCI of the surveyed additional units (PCI_a) is calculated using Eq. (7). The PCI of the pavement section is calculated using Eq. (8).

$$\overline{PCI}_a = \frac{\sum_{i=1}^{n}(PCI_{ai} * A_{ai})}{\sum_{i=1}^{n} A_{ai}} \quad (7)$$

where:

PCI_a = area weighted PCI of additional sample units;

PCI_{ai} = PCI of additional sample unit i;

A_{ai} = area of additional sample unit i.

$$PCI_s = \frac{\overline{PCI}_r (A - \sum_{i=1}^{m} A_{ri}) + \overline{PCI}_a (\sum_{i=1}^{n} (* A_{ai})}{A} \quad (8)$$

where;

A = area of section;

m = number of additional sample units surveyed; and

PCI_s = area weighted PCI of the pavement section.

The overall condition rating of the section should be determined by using the section PCI and the condition rating [5].

4. Results and Discussions

Following are the summary of the data that are collected from the field.

Table 3 shows for SDI values whether Table 4 shows for PCI values. As per DoR guidelines, the SDI value of the section based on Table 3 is 2.3. Similarly, the PCI value from Table 4 based on SHRP (Strategic Highway Research Program) guideline is computed as 63.4. Based on Table 1, and the SDI value 2.3, the pavement condition is "Fair". Again based on PCI value of 63.4 and from Fig. 3, the pavement condition is "Fair". Hence, it is concluded that the findings of both the system (SDI and PCI) are same, i.e., pavement is in "Fair Condition".

Table 3 SDI of each of the sample.

Sample No.	Chainage (m)		Chainage (km)									SDI for sample unit
	from	To	9+	10+	11+	12+	13+	14+	15+	16+	17+	
	Area ==>		550	550	550	550	550	550	550	550	550	
1	0	100	2	3	3	2	2	3	3	2	2	2.444
2	100	200	3	2	2	2	2	2	2	2	2	2.111
3	200	300	3	2	2	3	3	3	3	2	2	2.556
4	300	400	2	3	3	2	2	3	3	1	1	2.222
5	400	500	3	3	2	2	3	2	3	2	1	2.333
6	500	600	2	2	2	2	2	2	2	2	2	2.000
7	600	700	3	2	3	2	3	3	2	2	2	2.444
8	700	800	1	3	3	2	3	3	2	2	3	2.444
9	800	900	3	3	2	2	2	2	2	2	2	2.222
10	900	1,000	5	2	1	2	2	2	2	2	2	2.222
Average SDI of the section												2.300

Table 4 PCI of each sample unit.

Sample No.	Chainage (m)		Chainage (km)									PCI for sample unit
	from	To	9+	10+	11+	12+	13+	14+	15+	16+	17+	
	Area ==>		550	550	550	550	550	550	550	550	550	
1	0	100	76	50	81	58	87	37	2	58	65	57.111
2	100	200	64	60	56	39	70	78	69	33	42	56.778
3	200	300	71	71	86	74	86	35	53	56	58	65.556
4	300	400	78	56.1	78	92	92	45.9	57.5	45.9	69.5	68.322
5	400	500	60	60	44	40	91	65	16	74	100	61.111
6	500	600	27	88	89	26	94	30	25	62	32	52.556
7	600	700	56	79	59	70	88	35	78	92	69	69.556
8	700	800	85	62	79	67	71	60	51	85	63	69.222
9	800	900	60	60	91	68	96	58	80	74	45	70.222
10	900	1,000	22	62	90	77	73	84	59	60	62	65.444
Average PCI of the section												63.381

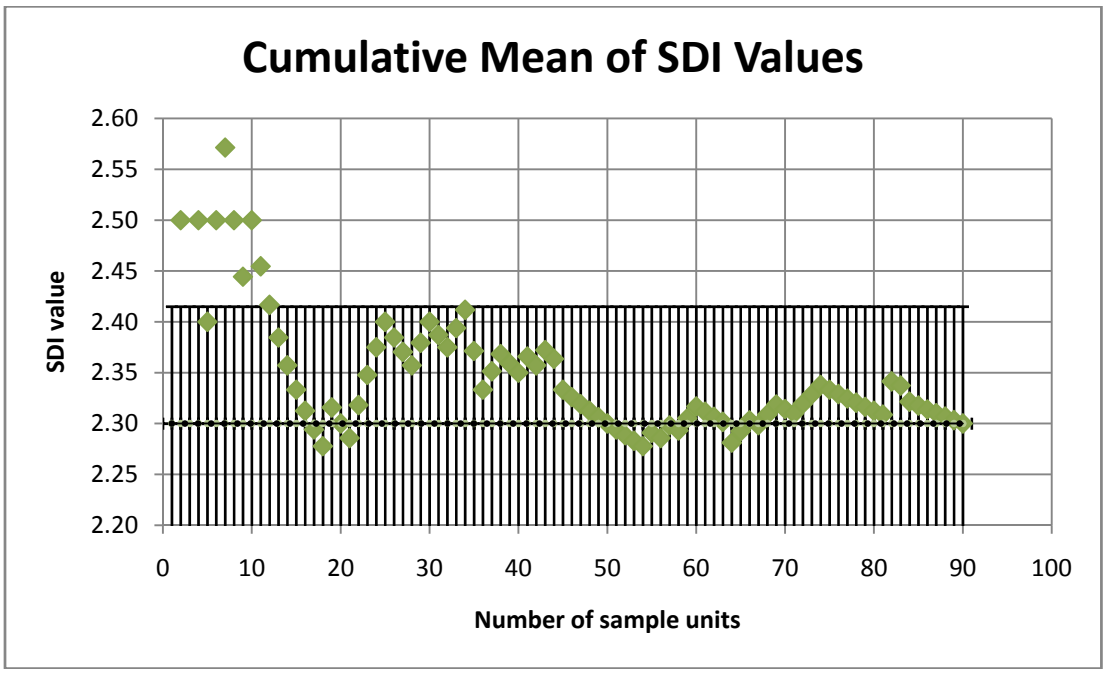

Fig. 4 Cumulative mean value of SDI over number of sample units.

4.1 Effect of Sample Size on Error and Precision

According to SHRP recommendations, the PCI values should lie within ±5%, however, based on DoR recommendations, there is no criteria for the validation of the data observed from field for SDI based on DoR recommendations. So based on ±5% permissible error and from Figs. 4 and 5, the recommended sample size for SDI is 13% and that for PCI is 21%.

The effect of sample size over the accuracy on the pavement condition data was found best fit on logarithmic equation R^2 value = 72% (Fig. 6 and 7). For linear equation R^2 value = 55%, for polynomial R^2 value = 67%, power and exponential are not feasible for these trendline. In other words, the error decreases exponentially at lower sample size and the rate of error reduction will decline for higher sample size. So, it can be said that the taking 100% sample for the pavement condition evaluation is the loss of time and money. So selection of accurate sample size is very much important

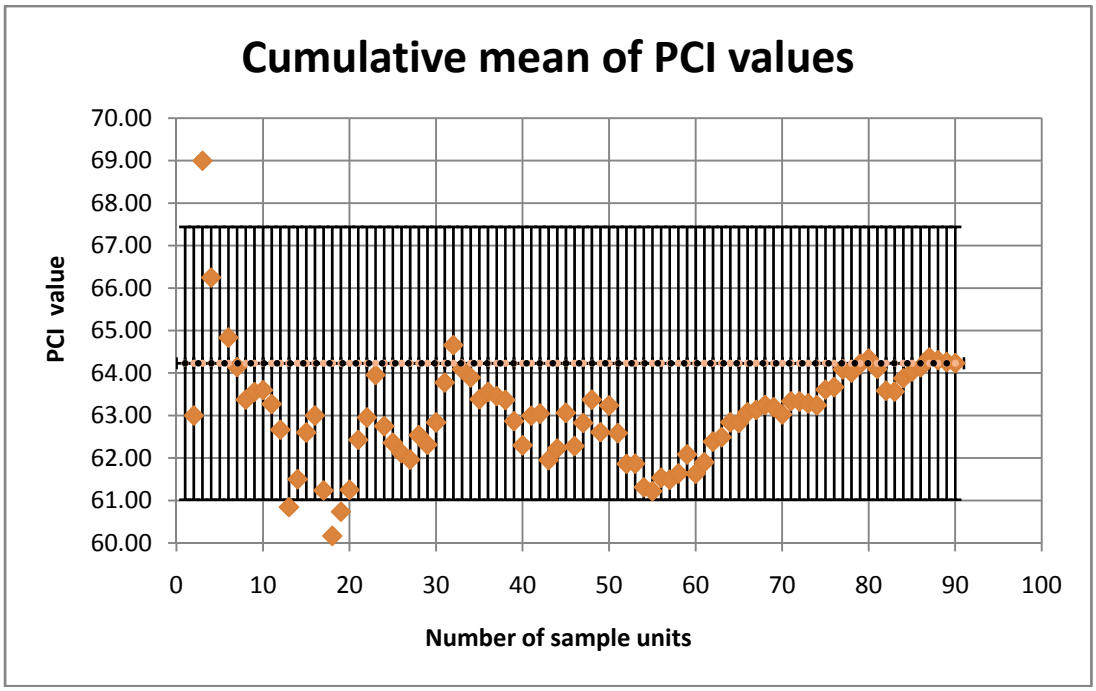

Fig. 5 Cumulative mean value of SDI over number of sample units.

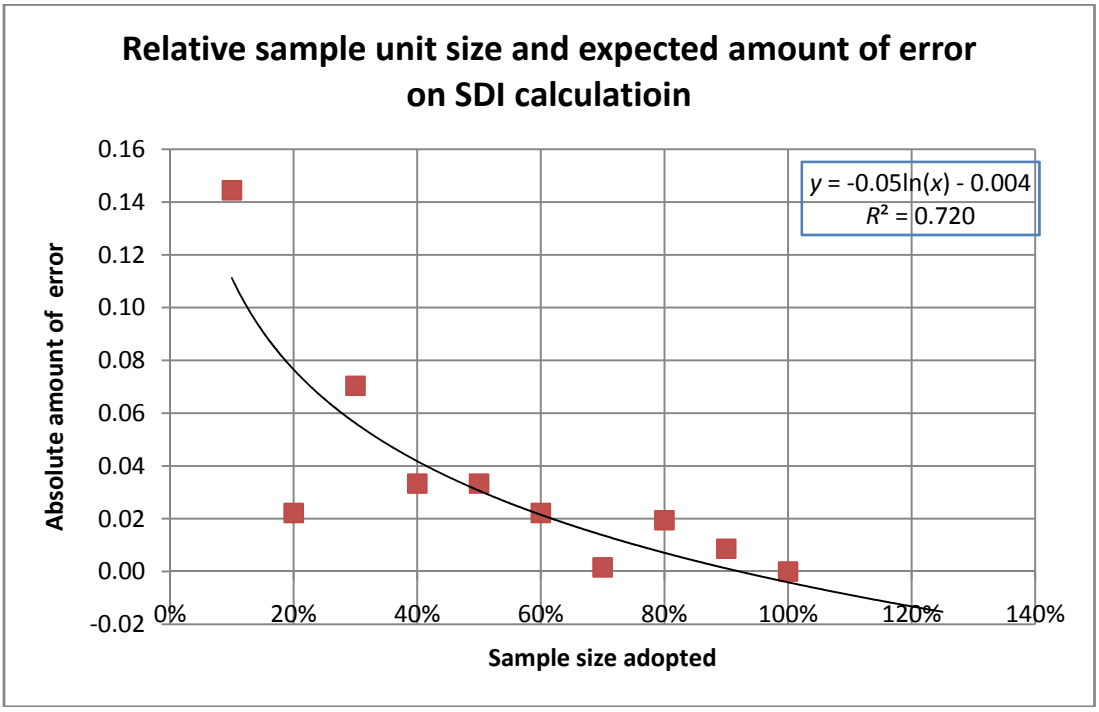

Fig. 6 Relative sample unit size and expected amount of error in SDI calculation.

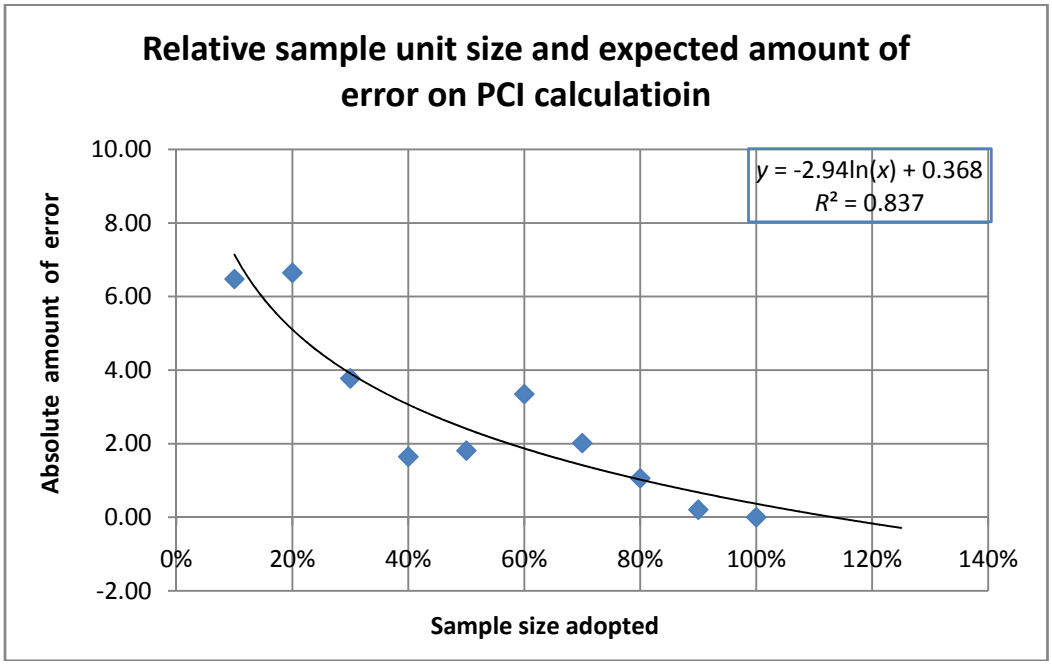

Fig. 7 Relative sample unit size and expected amount of error in PCI calculation.

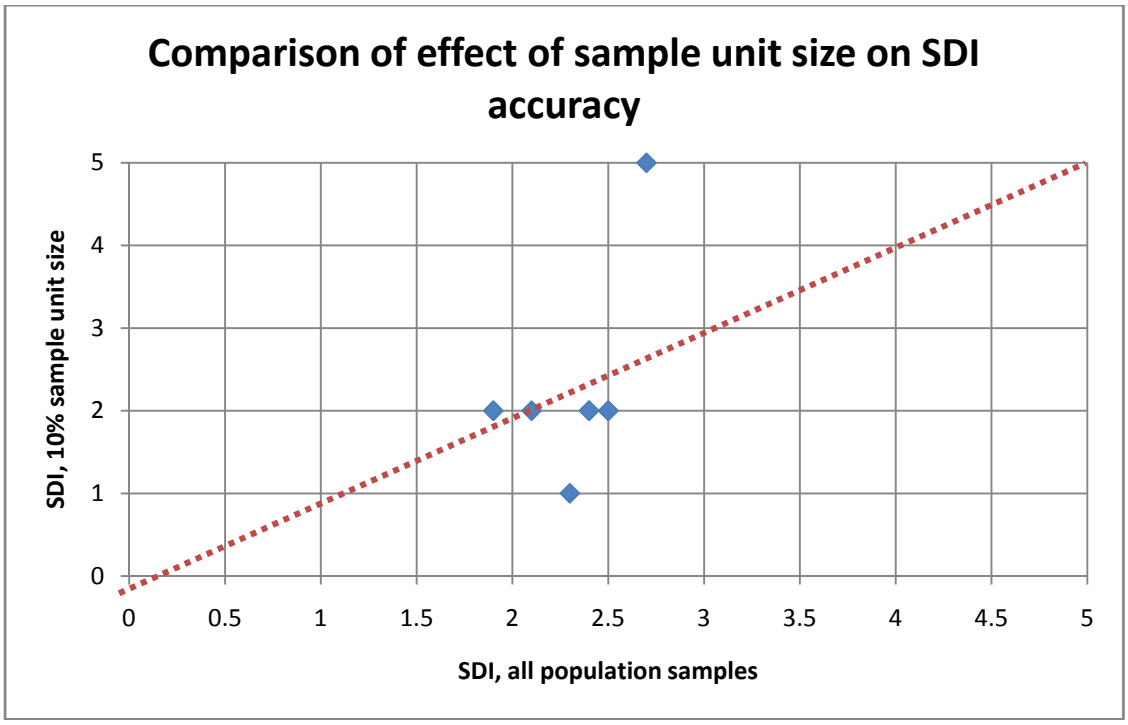

Fig. 8 Comparison of effect of sample unit size on SDI accuracy.

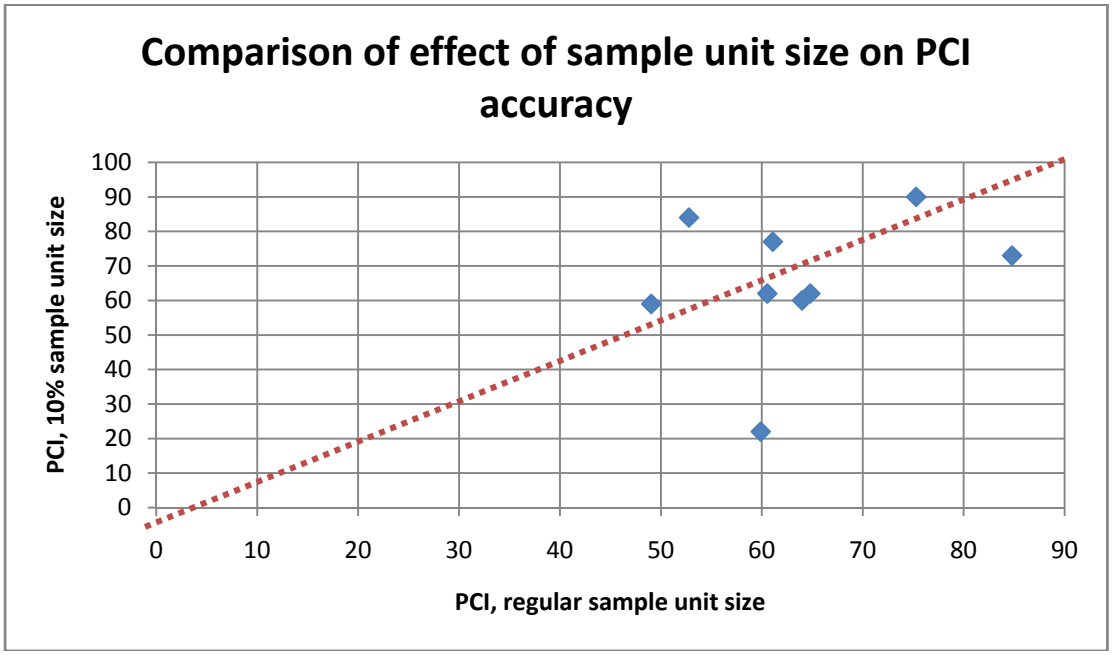

Fig. 9 Comparison of effect of sample unit size on PCI accuracy.

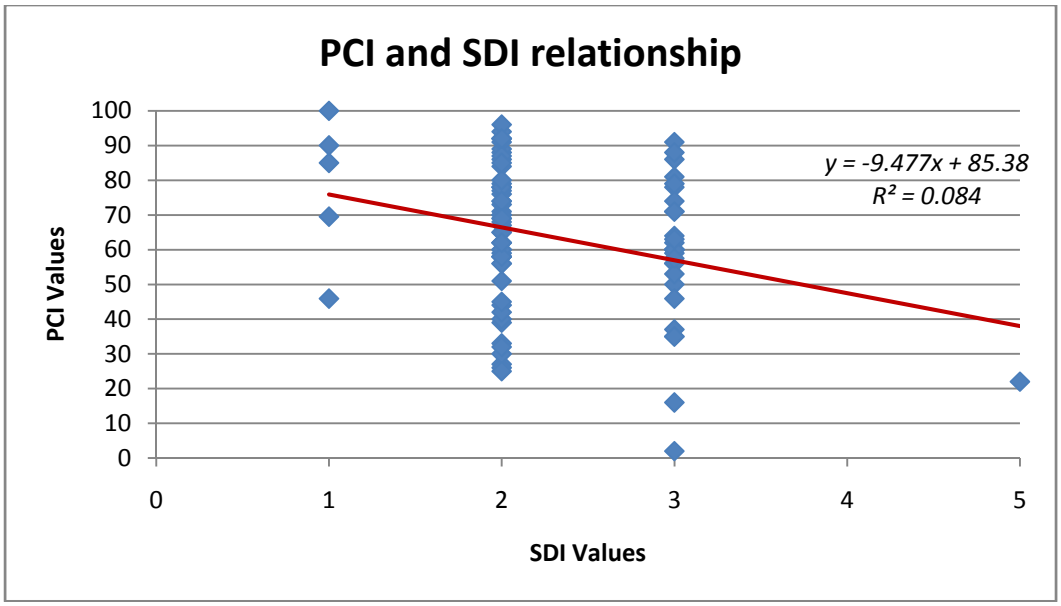

Fig. 10 SDI & PCI relationship in linear pattern.

that it should be representative of the road section. These results are also supported by Fig. 1 [10].

Figs. 8 and 9 show the comparison between 10% sample data and the whole population. The results show that the 10% sample will not be the representative of the population. Similar results are also supported by Fig. 2 [10].

4.2 Relationship between SDI and PCI

It is tried to develop the relationship between SDI and PCI based on the same data. The single and multiple regressions is analyzed for the development of best fit model. The power, exponential and logarithmic models are also being tested along with linear and curvilinear pattern of the database system. Fig. 10

shows the linear relation between SDI and PCI value with R^2 value of 8%, which means that the model is only 8% reliable. The polynomial equation of second degree is found same level of goodness. So it is concluded that the not strong relationship is found between SDI and PCI.

5. Conclusion and Recommendations

The value of SDI and PCI is computed for the section of Banepa-Bardibas highway and the SDI value as per DoR guidelines is computed as 2.3 and that for PCI based on SHRP guideline is computed as 63.4. Based on both SDI and PCI, the recommended condition of the pavement condition is the same which is in "Fair Condition". For *SDI* = 2.3, resealing with local patching is recommended as the M&R technique, however, as per PCI, the recommended techniques are based on distress types and the probable causes of distresses. The comparison between sample data and the population data shows that the 10% sample will not be the representative of the population. Again, the effect of sample size over the accuracy on the pavement condition data was found best fit on logarithmic equation with R^2 value = 72% for SDI and that for PCI is 84%. Hence, it is concluded that the pavement condition evaluation survey for the whole population is the loss of time, labour and money, and selection of accurate sample size is very much important such that the sample will be the representative of the population within the permissible precision. Based on ±5% permissible error, the recommended sample size for SDI is 13% and that for PCI is 21%. It is concluded that the 10% sample size as recommended by Ref. [6] seems insufficient, so a rigorous analysis with higher sample size is recommended in order to revise the national guidelines for the pavement condition evaluation for SDI survey. Finally, the no strong relation is found between SDI and PCI. As the samples are limited with similar type of failures, a rigorous analysis with higher sample size is recommended for further studies.

Acknowledgments

The author would like to express sincere thanks to Assoc. Prof. Dr. Thusitha Chandani Shahi for continuous motivation and guidance during preparation of this paper. The author also would like to thank the following research groups for collecting data from various samples of the highway section: Aashish Kandel, Ajay Kumar Gupta, Anga Lal Rokaya, Bhaskar Chataut, Bhim Bahadur Maharjan, Bidur Chaulagain, Bijaya Rana, Gopal Gautam, Indra Tamang, Madhav Prasad Adhikari, Pradeep Prasad Bhatt, Pushkar Poudel, Rabi Pokhrel, Shailendra Malla, Subash Pyakurel, Suddhumna Hamal, Sunil Kumar Tilak, and Ujwal Shrestha.

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Journal of Civil Engineering and Architecture
Volume 11, Number 7, July 2017
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