An analysis of the contributions of lighting and climate to the architecture of Luis Barragán

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ABSTRACT: The present work analyses the physical determinants of natural lighting and climate control in Luis Barragan architecture as it was realized in Mexico´s west region.
Barragan carried out preliminary studies of physical conditions at his projects´ proposed sites, and there is evidence that these prior analyses addressed the subject of the regional materials employed in some of his most emblematic buildings; the finishes, colors and combinations of materials used to archieve the very particular effects and sensations his architecture evoked. They also relate to the impact of natural illumination as it passed through the windows and interior geometries he created, which are considered icons of contemporary Mexican architecture. Climate played a most important role in the disposition of interior as well as exterior spaces, because of the Mediterranean architectural influences Barragán drew upon so often in his architectural designs, adapting them correctly to the regional setting.
Environmental considerations are also analyzed for the walls, roofs, windows, porticos, patios and other architectural elements wich have given the environmental contributions found in Luis Barrgán´s work their characteristic and distinctive stamp. For all of the above, comparative study is made using available technical and physical information; current computer methods permit achievement of the principal objective, wich is to derive a series of conclusions regarding environmental contributions as they may be employed in avant-garde and sustainable building.

Keywords: natural lighting, comfort , bioclimatic approach.

1. INTRODUCTION

The current project aims to analyze Luis Baraga's architecture and its relation to site-specific environmental conditions. The lighting and climate supports which resulted from that architecture may serve as referents to be applied in the revision of current building regulations as they address climatic and lighting design. Also proposed are environmental parameters which should be considered in readapting such building standards; to promote housing and other required spaces where human activities may be undertaken more effectively, given the region's different weather conditions.

This analysis will primarily treat those conditions of thermal and lighting comfort which guided the designs. The architectural spaces were originally envisioned for carrying out physical activities which were undemanding, and thus energy consumption, job performance and ambient comfort are determined by specific habitability conditions for this climate.

2. ENVIRONMENTAL ANALYSIS.

Casa Crisco. For the environmental analysis of the building it was decided to measure temperature and relative humidity, as well as natural illumination, in the main area comprising the living room, which has a north-south orientation and is directly accessed through the entrance area. The analyzed area is 25 m^2: with its double height elevation, its volume is 155 m^3.

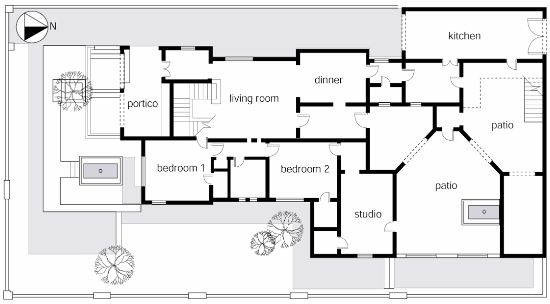


Figure 1: Architectonic plant.

Climate. 80% of the building's facades are exposed to the four basic directions. The main facade faces south, which allows it to take advantage of prevailing winds: here, as well as in the patio located in the northern part of the house, bodies of water in the form of fountains are used to permit humidification of the interior by means of evaporative cooling.

In terms of natural climate control, it was provided by architectural elements, such as double height elevation, patios, porticos, fountains and the same building materials as those employed by Barragan to achieve comfortably habitable rooms.

Lighting. Like other Barragan buildings of the early XX century, Casa Cristo is oriented along its longest section in order to take advantage of natural lighting in rooms receiving daily use. Windows were designed with this in mind, with their shape, size, orientation, geometry and colors all arranged for maximal utilization during hours with the greatest quantity, and quality, of illumination. [1]

Figure 2: Stereographic analysis.

3. ENVIRONMENTAL PARAMETERS

As a first environmental approach to Barragan's architecture, the climatic limits necessary for achieving suitable ambient comfort were processed. The study area where environmental analysis, then proposals, were done, is located at a latitude of 20° N and a longitude of 103° W, in semi-temperate climatic conditions. The main axis upon which the present work turns is the relationship existing between atmospheric phenomena with the sun's position (yearly, daily and hourly) being that which determines those environmental conditions to be considered in order to view architectural works in the context of their occupants' wellbeing.

Determination of preferred temperature. The first step was to determine the comfort temperature preferred by the region's inhabitants (Tn), which is known as the acceptable average temperature and, once specific regional data has been introduced, is expressed in the following manner.

Tn = 17.6 + 0.31 (19.3)

Tn = 23.5 °C

Where 17.6= is the thermic sensation factor variable and 0.31= is the correction factor

Monthly and seasonal variations. The bioclimatic analysis of temperature and relative humidity data that were measured in Casa Cristo serve as a basis for determining climate control requirements for the 24 hours of the day during different months of the year. In the first six months, temperature and relative humidity oscillations may be clearly observed. Due precisely to this oscillation, climate control requirements are based upon those first six months, which represents the coldest months requiring greater inertia, as well as the warmest months where cooling strategies must be adopted. In the second part of the year, climatic variations are not as notable as in the first. The solar circuits are similar in various months as compared with those considered in the geometric solar graphic analysis.

Isohumidity and isotherms. The isotherm and isohyet tables demonstrate said climatic variations in the analyzed building; first at sunrise, which presents the lowest temperature and highest relative humidity. Contrarily, the highest temperature and lowest relative humidity are the conditions registered midway through the solar day.

The climatic analysis method known as "isopletic" uses annual and daily dry bulb temperature variables. The same method is used in processing relative humidity data, although in both cases it is necessary to expand the hours (to 24) in order to determine the thermal delay time necessary on the respective walls. [1]

Table 1: Isotherms; temperature conditions.

Tempertature (ºC)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DIC
1:00	11.7	12.8	14.2	14.4	17	19	17.5	17.5	16	14.4	12.4	11.4
2:00	10.8	11.8	12.8	13	16	18	16.6	16.6	15	13.3	11	10
3:00	10	10.8	11.5	11.5	14.5	17	15.7	15.7	14	12	10	8.6
4:00	9	9	10	10	13	16	14.8	14.8	13	11	8.7	7.3
5:00	8	8.5	8.8	8.5	12	15	14	14	12	10	7.5	6
6:00	7.3	8	7.4	7	10.6	14	13	13	11	8.8	6.3	4.8
7:00	9.4	10.3	10.6	10.6	13.8	16.6	15	15	13.6	11.5	9	8
8:00	11.6	12.6	14	14	17	19	17.3	17.3	16	14	12	11
9:00	13.8	15	17	17.7	20.3	21.4	19.5	19.5	18.5	17	15	14.4
10:00	16	17.3	20.4	21.3	23.5	24	21.7	21.7	21	19.7	18	17.6
11:00	18	19.6	23.7	24.8	26.8	26.3	24	24	23.4	22.4	21	20.8
12:00	20	22	27	28.4	30	28.7	26	26	26	25	24	24
13:00	22.5	24.3	30	32	33.3	31	28.3	28.3	28.4	28	27	27.3
14:00	21.6	23.3	29	30.5	32	30	27.4	27.4	27	26.7	25.8	26
15:00	20.7	22.3	27.6	29	30.5	29	26.5	26.5	26	25.6	24.6	24.6
16:00	19.8	21.4	26	27.6	29	28	25.6	25.6	25	24.5	23.4	23.3
17:00	19	20.4	25	26	28	27	24.7	24.7	24	23.4	22	22
18:00	18	19.5	23.6	24.5	26.6	26	23.8	23.8	23	22	21	20.6
19:00	17	18.5	22	23	25	25	23	23	22	21	19.7	19.3
20:00	16	17.5	21	21.7	24	24	22	22	21	20	18.5	18
21:00	15.3	16.6	19.5	20	22.6	23	21	21	20	19	17.3	16.7
22:00	14.4	15.6	18	18.8	21	22	20	20	19	17.7	16	15.3
23:00	13.5	14.7	17	17.3	20	21	19.3	19.3	18	16.6	14.8	14
24:00	12.6	13.7	15.5	15.8	18.5	20	18.4	18.4	17	15.5	13.6	12.7

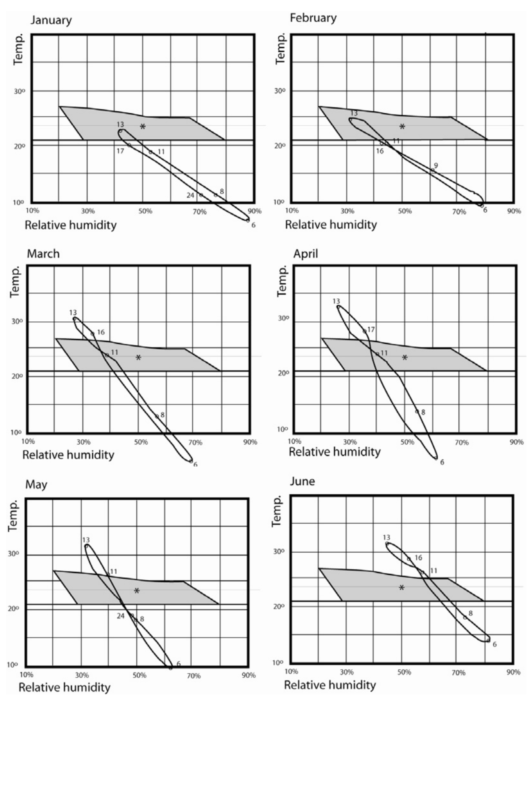
Table 2: Isohumidity; humidity conditions.

Relative humidity (%)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DIC
1:00	73.4	65.5	58.4	52.3	54	72	80.5	80	80	76.5	73.8	75
2:00	76	68.1	61	54.3	56	74	82	82	81.5	78.6	76	77.6
3:00	78.4	70.7	63.4	56.3	58	76	84	83.6	83.3	80.8	78.7	80
4:00	81	73.3	66	58.3	60	77.8	85.8	85.4	85.2	83	81	82.6
5:00	83.4	76	68.4	60.3	62	80	87.6	87.2	87	85	83.6	85
6:00	86	78.5	71	62.3	64.5	82	89.5	89	89	88	86	87.7
7:00	80	72.2	64.9	57.4	59.5	77	85	84.7	84.4	82	80	81.6
8:00	73.8	66	58.8	52.5	54	72.3	80.7	80.4	80	76.8	74	75.5
9:00	67.7	60	52.7	47.7	49	67.5	76.5	76	75.3	71.6	68	69.4
10:00	61.6	53.5	46.6	42.8	44.8	62.8	72	71.8	70.8	66.5	62	63.3
11:00	55.5	47	40.5	38	40	58	67.7	67.5	66	62.3	56.3	51.5
12:00	49.4	40.7	34.4	33	35	53.3	63.3	63	61.7	56	50.3	51
13:00	43.3	34.5	28.3	28.3	30.3	48.6	59	59	57	51	44.4	45
14:00	45.8	37	30.8	30.3	32.3	50.5	60.7	60.7	59	53	46.8	47.6
15:00	48.3	39.6	33.3	32.3	34	52.5	62.5	62.5	61	55	49.3	50
16:00	50.8	42.2	35.8	34.3	36	54.4	63.3	64	62.8	57.3	51.7	52.6
17:00	53.3	44.8	38.3	36.3	38	56.5	66	66	64.6	59.5	54	55
18:00	55.8	47.4	40.8	38	40	58	68	67.8	66.5	61.6	56.6	57.6
19:00	58.3	50	43.3	40	42	60	69.7	70	68.4	63.7	59	60
20:00	60.8	52.6	45.8	42	44	62	71.5	71.3	70	66	61.5	62.6
21:00	63.3	55.2	48.3	44	46	64	73.3	73	72	68	664	65
22:00	65.8	57.7	50.8	46	48	66	75	74.8	74	70	66.4	67.6
23:00	68.4	60.3	53.4	48	50	68	77	76/6	76	72	69	70
24:00	71	63	56	50.5	52	70	78.7	77.7	77.7	74.4	71.3	72.6

Climate control requirements. Variations in thermal oscillation represented in this table are the result of processing the data collected in Casa Cristo; here one may appreciate the different temporal periods where additional climate control is required. The proposal for also using relative humidity data is aimed toward incorporating all the results from this table into the first six month's solar graphic (the January-June solar circuit), and to geometrically obtain different exposures where it will be necessary to either maximize benefits from, or protect against, solar gains. This analysis was undertaken month by month on the bioclimatic chart, which resulted in determination of consequent thermal oscillations during the 24 hours of the day, and during the entire year.

Table 3: Bioclimatic behaviour.



This schema shows the weather's behavior through time, which is translated into various zones of climatic requisites – from the need for heating by natural means to ventilation and humidification which may be addressed with passive systems. [2]

Table 4: Bioclimatic requirements.

	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
1:00	350w	280w	210w	210w	140w	70w	140w	140w	140w	210w	280w	350w
2:00	350w	350w	280w	280w	210w	70w	140w	140w	210w	280w	350w	420w
3:00	420w	350w	350w	350w	210w	140w	210w	210w	210w	350w	420w	420w
4:00	420w	420w	420w	420w	280w	210w	210w	210w	280w	350w	420w	490w
5:00	490w	490w	420w	420w	350w	210w	210w	280w	350w	420w	490w	490w
6:00	490w	490w	490w	490w	350w	280w	280w	280w	350w	420w	490w	490w
7:00	420w	420w	420w	420w	280w	140w	210w	210w	280w	350w	420w	490w
8:00	350w	350w	280w	280w	140w	70W	140w	140w	210w	280w	350w	350w
9:00	210w	210w	140w	140w	Z C	Z C	70 w	70w	70w	140w	210w	280w
10:00	210w	140w	Z C	Z C	Z C	Z C	Z C	Z C	Z C	70W	140w	140w
11:00	70w	70w	Z C	Z C	V 0.3m	Z C	Z C	Z C	Z C	Z C	Z C	Z C
12:00	Z C	Z C	V 0.3m	V 0.5m	V 2m H 2.5	V 1m	V 0.3m	V 0.3m	V 0.3m	Z C	Z C	Z C
13:00	Z C	Z C	V2.0m H2.5	H 3.0	H 3.5	V 2m	V 1m	V 1m	V 1m	V 0.3m	Z C	Z C
14:00	Z C	Z C	V 1m H 2.0	V 2m H 2.5	H 3.5	V 2m	V 0.5m	V 0.5m	V 0.5m	V 0.3m	Z C	Z C
15:00	Z C	Z C	V 0.3m	V 1m H 2.0	V 2m H 2.5	V 2m	V 0.3m	V 0.5m	V 0.3m	V 0.3m	Z C	Z C
16:00	Z C	Z C	Z C	V 0.3m	V 1m H 2.0	V 1m	V 0.3m	V 0.3m	Z C	Z C	Z C	Z C
17:00	70w	Z C	Z C	Z C	V 0.3m	V 0.5m	V 0.25	Z C	Z C	Z C	Z C	Z C
18:00	140w	70w	Z C	Z C	Z C	V 0.3m	Z C	Z C	Z C	Z C	Z C	Z C
19:00	140w	140w	Z C	Z C	Z C	Z C	Z C	Z C	Z C	Z C	70W	70W
20:00	210w	140w	Z C	Z C	Z C	Z C	Z C	Z C	Z C	Z C	70w	140w
21:00	210w	210w	70w	Z C	Z C	Z C	Z C	Z C	Z C	70w	140w	210w
22:00	210w	210w	140w	70w	Z C	Z C	Z C	Z C	70w	140w	210w	210w
23:00	280w	210w	140w	140w	70w	Z C	70w	70w	70w	140w	210w	280w
24:00	350w	280w	210w	210w	70w	Z C	70W	70W	140w	210w	280w	350w

If this data is employed graphically, the bioclimatic situation for the site in question is obtained; utilizing the results season by season, it is possible to create design strategies that will counteract possible sensory discomfort. In other words, by identifying adverse environmental conditions and determining comfort factors as well as various design alternatives, specific design of bioclimatic control strategies as they are needed then becomes viable.

The design of Casa Cristo obeys these climatic factors to a considerable degree: Mediterranean architecture is similar to that of these latitudes. The area where measurements were taken has double height elevation and an entrance porch which reduce the solar radiation that might contribute to a sensation of discomfort.

4. ARCHITECTURAL ELEMENTS AND MATERIALS UTILIZED

4.1 Architectural elements and building materials.

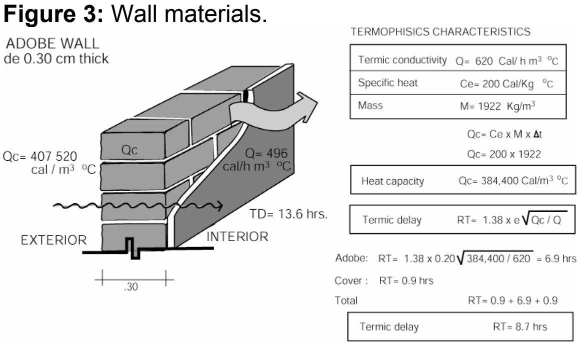
The flooring materials used are glazed clay tiles, which have traditionally been installed to obtain a feeling of coolness. The walls are composed mainly of adobe bricks, 30 to 40cm thick, and varying in floor-to-ceiling height from 240 to 600 cm. The building system includes horizontal structural elements of wood; in the foundation, stone footings are used for reinforcement.

In the case of windows and glazing materials, various geometries were used which correspond with the creation of atmospheres and sensations according their destined use in realizing activities in the interior spaces. Utilizing different materials for glazing is also seen as creating atmospheres with color: some of these materials were especially manufactured for this purpose by glassblowers who worked more often at selling glass kitchenware.

4.2 Thermophysical properties of floor and wall materials employed.

As was mentioned earlier, adobe brick is the material most used in the walls, although wood and whitewashed stone should also be considered. For the floors, only glazed clay tiles were used in the interiors, with exteriors of whitewashed stone. Thermal behavior of these materials is described in accordance with their thermophysical properties, and compared with today's most frequently used materials. Thermal conductivity, specific heat and thermal delay were calculated to establish bioclimatic conditions for Casa Cristo. As may be seen, adobe has less thermal conductivity, an intermediate specific heat and greater heating capacity; which allows it to experience a greater thermic delay during which the heat obtained from exposure of the material to solar radiation may be captured, stored and disseminated in the interior during more temperate hours. [2]

Figure 3: Wall materials.

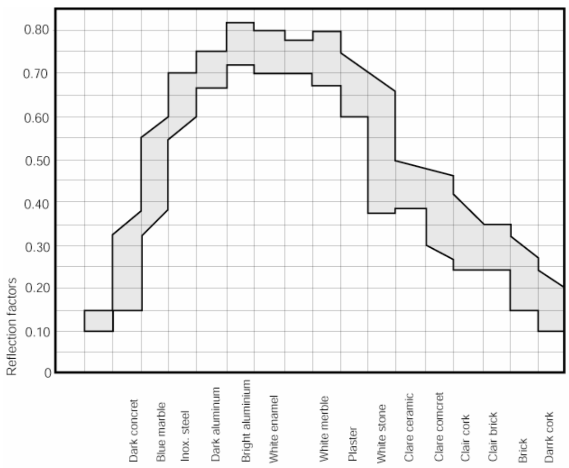


4.3 Physical transmission properties of glazing materials and reflection of colors on interior walls.

Also indicated earlier were the physical conditioning factors of glazing materials, which offer various alternatives for providing the flow of light and heat, and facilitate views of the outside. As regards control of solar gains, windows are used as barriers to convection, as they have high conductivity and do not directly contribute to reducing conduction losses. In the case of Casa Cristo, the various colors and materials utilized vary in their capacities to transmit, reflect and absorb radiation according to the length of the lightwave.

The quantity and quality of lighting available in the interior of an architectural space is directly related to the factor of glass transmission. The following numbers (Table 5) shows the results obtained from an analysis of materials employed in the building being researched, and indicate reduction of the sunlight factor within the space.

Table 5: Reflection factors of different materials

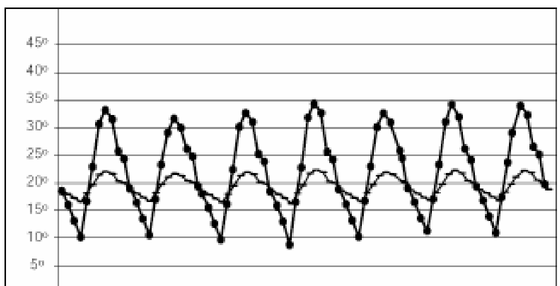


[3]

5. TEMPERATURE MEASUREMENTS

Measurements were developed using dataloggers, during the warmest months of the year: March, April and May. Data shown in the next table refer to measurements obtained in the building's interior, and in its connection with the exterior. The main room where these measurements were taken is the living room, which has a western exposure; with an exterior obstruction from the neighboring building which does not significantly impact the interior's thermic behavior. Also, this room is spatially related to the entrance porch, and at its upper level has a series of windows with both southern and northern orientations. Air temperature was taken every ten (10) minutes. (Table 6)

Table 6: Interior thermic variations



As may be observed in the aforementioned table, thermal oscillations occurring in the city of Guadalajara during the hot months are significant; the variation may reach as high as 25º. However, in the house's interior, variations do not exceed 7º C. This is mainly attributed to the building material (adobe, in this case), permitting necessary thermal delays which avoid the fluctuations obtained in the exterior. The lesser variation is also due to the walls' thickness: it is not known whether this is a matter of adherence to the building standards of the time, or whether it may be explained by some other factor outside the scope of the present work. It should be mentioned that the use of adobe has nearly disappeared from today's construction of modern edifices: the erroneous idea has arisen that, because the city is located in a seismic risk zone, adobe is not a structurally suitable material.

6. MEASUREMENTS OF NATURAL LIGHTING

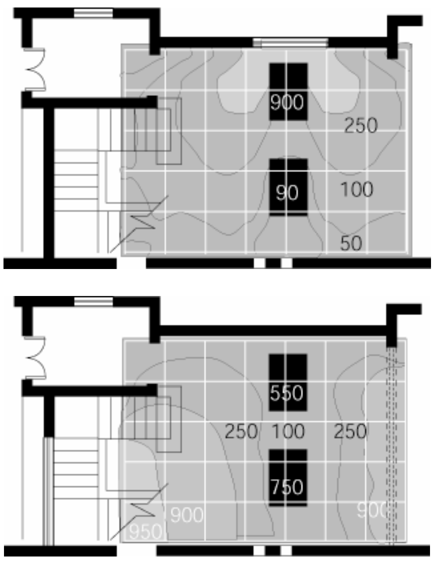
Measurements were taken with a Gossen Mavolux 5032C digital luxmeter during the same climatic season (March, April and May) as the climatic analysis. The hours at which measurements were taken, values for the sky's luminance and cloud cover factors are represented in the following table.

Given the above-defined spatial conditions, light measurements were taken in Casa Cristo's living room area. The minimum number of measurement points was defined by calculating room index.
Room Index = length of the space X width of the space / [(Room height – work surface) X (length of the space X width of the space)]. Work surface is assumed to be at a distance of 100 cm (39 in.) The analyzed space is 5.00 x 5.50 meters with 24 fixed measurement points. Measurement values are shown with isolux drawn lines (contour lines), in ranges from 0 to 1000 lux at 50-lux intervals. [4]

5.1 Results of natural lighting measurements.

The results show that lighting conditions are more than adequate. The minimum value obtained in the analyzed space is 50 lux and the maximum is 900 lux, which gives an average of 405 lux (Df=4.94%), where it is possible to conduct such activities as relaxation, reading and administrative work such as those currently undertaken there by the Union of Arquitects of the state of Jalisco.

Figure 4: Lighting conditions.



7. CONCLUSIONS

This work studies thermal comfort conditions in Luis Barragan's architecture, using in situ measurements of air-temperature and bioclimatic processes to develop architectural design proposals. The data shows high temperatures that may adversely affect comfort in the dry-hot season of March, April and May, but it was also found that ambient comfort may be achieved by using the design strategies Barragan employed in his architecture: double elevations in those spaces receiving daily use, and the employment of porticos, patios, water treatments and materials which have traditionally been used to achieve interior coolness.

Also studied are Casa Cristo's interior lighting conditions. With data gathered from luxmeters and systematically processed, it was confirmed that using Barragan's various window options will yield those ambient and sensory conditions characteristic of his works. It is likewise necessary to emphasize the fact that using his characteristic materials and colors contributes to creating environments which distinguish contemporary Mexican architecture. The analysis of materials makes particular reference to those utilized in wallcoverings and finishes, and to types of window glass.

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