The Chronographic Protocol: Validation of Textures and Colors

Adel Francis, Fabian Ardila

Abstract- Graphical modelling is considered to be a suitable approach for displaying project data because of its ability to communicate information clearly and effectively. Despite this fact, little research has been undertaken in this area with regards to the construction sector, and current methods and software do not propose standard graphical protocols. Therefore, it has been up to each planner to individually set his or her own standard. To addresses these shortcomings, the Chronographical modelling proposes a standard protocol. This paper presents the validation of the first phase of this standard protocol for construction project scheduling. This phase proposes two ranges of light and dark colors and a graphical convention for textures and shapes. The validation process was performed through a case study that evaluates the texture convention and color limits followed by the application of the proposed graphical convention to a building scheduling. These validations were performed through case studies that evaluated the visual data and assessed the necessary mental effort for finding information on the schedule. The results demonstrate clearly that the proposed convention helps to improve the visual clarity while simultaneously seeking to diminish the mental effort necessary for finding information.

Index Terms: Chronographical, Construction Project, Protocol, Schedule.

I. INTRODUCTION

Graphical modelling is considered to be a suitable approach for displaying project data because of its ability to communicate information clearly and effectively [1]. Despite this fact, little research has been undertaken in this area with regards to the construction sector. Current methods and software do not propose standard graphical protocols and it has been up to each planner to individually set his or her own standard. In contrast, too many other areas possess their own standard graphical symbols and representation. The infrastructure sector has used its own standard manual for traffic signals since 1935 [2] while urban planning, somewhat related to the construction industry, has used a standard convention of colours for the classification of land use [3] since 1965. The geotechnical sector currently uses abbreviations, textures and colours to represent soil types according to ASTM D2487-11.

A. Graphical modelling in construction project planning

Graphical modelling is not widespread within construction project planning. Tory et al. [4] present a visual comparison tool for construction schedules. Their research addresses three main components: the graphical representation of constraint types [5], [6], the interactive representation of precedence networks, and the comparison of different planning alternatives. Stott et al. [7] were inspired by a subway system, representing the project planning using lines, colors and shapes. Aigner et al. [8] propose a graphics system called Planning Lines to represent uncertainty in the time attributes of activities. This system also incorporates the concept of probability in time representing two values: the minimum and the maximum duration.

The Chronographic Modelling [9], [10] studies the graphical representation of the project in the spatial dimension. This approach analyses the visual interface, the graphic elements and the parameters associated with these elements. The goal is to establish a standard protocol for the graphical representation of construction project planning. Textures and colors are examples of graphic elements used by this protocol. Carrier-Fraser et al. [11] propose guidelines for the use of these graphics in modelling the physical entity. According to these authors, activities can be represented by textures, and colors can be linked to resources and locations. Ardila and Francis [12] validate the graphic convention of textures and shapes as a first phase of the validation of the new Chronographical standard protocol for construction project scheduling. The validation phase was performed through a case study in order to assess the suitability of the protocol and its visual clarity while simultaneously seeking to diminish the mental effort necessary for finding information.

B. Information visualization

Effective communication of information depends in large part upon the way that data is graphically represented and how we perceive and interpret this information. According to Encarnacao et al. [13], the developments of new visualization systems must take address the following three approaches:

- Technology-driven: what can be done with current technology;
- Perception-driven: what makes sense considering the constraints on the human visual system;
- Task-driven: what the user wants.

Considerable effort has been put forth towards the Technology-driven approach, where advancements in terms of information technology are remarkable. However, little attention has been given to the Perception-driven and Task-driven approaches. Tory and Moller [1] argue that it is necessary to think about how we analyze and interact with graphic variables and how it can affect the information visualization. Indeed, the brain is able to perceive multiple graphical elements simultaneously, but it cannot process them in parallel. Our vision focuses on small areas of the visual field and watches one element after another in an unintended sequence named "Attention" [14].

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Prof. Adel Francis, Construction Engineering Department, École de technologies superior, Quebec University, Montreal, Canada.

Fabian Ardila, Construction Engineering Département, École de technologie supérieure, Quebec Université, Montréal, Canada.

Ware [15] divides the Attention process into three sub-processes:

- The Pre-Attention Process: A quick parallel process where one chooses the graphic elements to be analysed;
- Visual Perception: A slow series of processes where one analyses the graphic properties of the visual element comparing correspondence, differentiation, relationships, understanding and meaning;
- Interpretation: A process in which one interprets the analysed information and obtains results.

Rodrigues et al. [14] state that the design of visualization systems should seek to maximize the impact on the pre-attentive process. According to these authors, position, shape, colour and animation are among the graphic elements that favor the pre-attentive process.

Visualization systems using colors

Rodrigues et al. [14] note that color is also among the graphic variables that promote the pre-attentive process. According to Bertin [16], color is the second most efficient graphical variable for the encoding of nominal information. Because of its separation properties, it is possible to easily identify and differentiate information. Therefore, the use of colors would facilitate the information search process on a schedule [11].

Color consists of three components: hue (H), saturation (S) and lightness (L). Each of these components has different qualities. Hue has separation qualities while saturation and lightness have, at the same time, separation and hierarchy qualities [16]. By varying these components, we can obtain a significant number of colors. However, the number of colors to use is limited by the capacity of the human eye to differentiate them. According to a study realized by Healey [17], seven colors is the optimal number to maintain a search in parallel. In addition, they must belong to the seven color categories identified as follow: Red (R) Yellow-Red (YR), Yellow (Y), Green (G), Blue (B), Purple (P) and Red-Purple (RP).

There are many ways to encode information through color scales. Color scales can be grouped into three categories [18] according to the nature of the data to be encoded, the information to be highlighted and the tasks to be achieved:

- Hierarchical scales, which highlight the progression order of the data;
- Qualitative scales, which emphasize the separation between data, regardless of importance or progression;
- Divergent scales, which combine the concepts of separation and progression to enhance the average data and extremes.

Brewer and Harrower [19] use colors for Cartography. Their work suggests hierarchical scales of 9 colors, divergent scales of 11 colors and qualitative scales of 12 colors maximum.

Visualization systems using textures

Bertin [16] places texture in third place, after color, in terms of its effectiveness in the encoding of nominal information. Because of their separation properties, these graphic elements are extremely useful for encoding information. Carrier-Fraser, Francis and McGuffin [11] mention that textures can be very effective for encoding information in construction schedules since they favor data interpretation by association and the learning processes are more easily carried out.

The use of textures has some limitations and must follow certain guidelines in order to facilitate the pre-attentive process. Tufte [20] and Wilkins et al. [21] argue that streaked textures have very strong terminations and contrasts. This can cause visual discomfort and symptoms ranging from simple fatigue to headaches. According to Healey [17], the combined use of graphic variables such as color and texture may not favor the pre-attentive process which would cause a move from a search in parallel to a search in series. Moreover, if the background brightness resembles the texture, the texture visualization will require more time and more visual memory, and thus be more difficult to interpret. According to Carrier-Fraser, Francis and McGuffin [11], in order to stay within the pre-attentive process limits and ensure that the data search will be performed in parallel; the information represented by textures must be independent from that shown by colors. This facilitates the search for only one data type, but not both. The background brightness should also be as distinct and quite different from that used by the texture

The American National Standards Institute (ANSI) and the International Organization for Standardization (ISO) proposed standards for the use of textures. The BSI standards BS 8888 [22] and BS 308-1 [23] compile a set of guidelines for the use of hatching. Suggestions of hatching applicable to construction can be found in the standards BS 1192-3 [24], BS 5930 [25] and BS 8541-2 [26]. The National Institute of Building Science (NIBS) in collaboration with the American Institute of Architects (AIA) developed the US National CAD Standard or NCS [27]. This document compiles hatching, objects and symbols commonly used in Computer Aided Design.

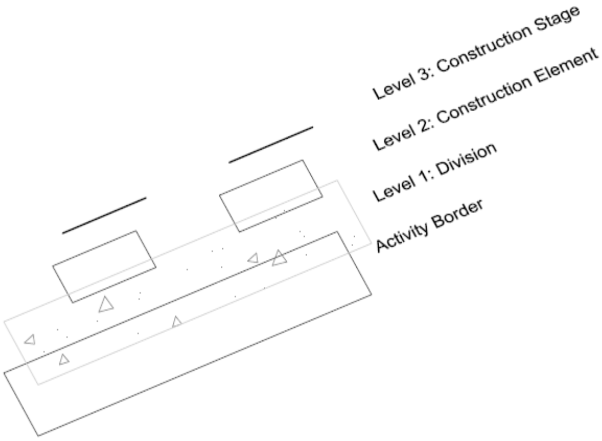
II. THE TEXTURE CONVENTION

A. Presentation of the texture convention

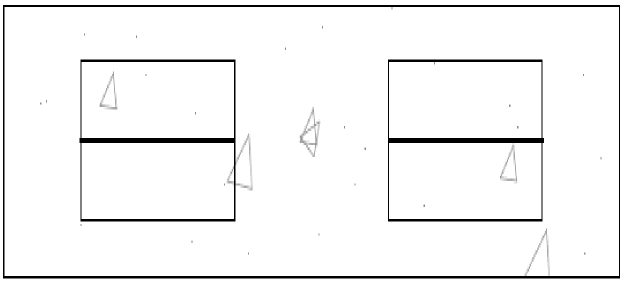
According to the Chronographical Modelling [10], activities can be represented by textures. Texture convention aims to facilitate finding, interpreting and memorizing information on a construction schedule. The Chronographical texture convention includes three levels of information, each of which is represented on a different layer. The base level represents the construction divisions according to the Master Format Classification System [28]. The graphical elements of this level include: hatching, objects, symbols, lines, and texts. The proposed texture convention is based on the standard elements listed in the US National CAD Standard [27] commonly used for the graphical representation of information in construction has been privileged.

The second and third level uses shapes and lines to represent construction elements and construction stages. Elements represent the different components such as foundations, walls, ceilings, etc., while the stages show the construction processes, such as shop drawings and the implementation phase.

Figure 1a shows a 3D view of the convention levels and the information represented, while Figure 1b is the result of the superposition of these three levels within the same work plane.



a. 3D view of the texture convention levels



b. b. Plan view of the texture convention levels

Figure 1. 3D and plan views of texture convention levels

B. Validation of the texture convention

We conduct a case study in order to validate the proposed texture convention and assess its acceptability by planners following the steps recommended by Lam et al. [29]: i) setting a goal; ii) picking suitable scenarios; iii) considering applicable approaches; iv) creating evaluation design and planned analyses. The case study was conducted in two stages by following two of the seven evaluation scenarios proposed by the same authors, namely, the VDAR: Evaluating visual data analysis and reasoning and the CTV: Evaluating communication through visualization. The first stage assessed the suitability of the texture convention and its visual clarity and the second stage evaluated the mental effort required to find the desired information on a building construction schedule.

Evaluating suitability of the texture convention

The suitability of the texture convention and its visual clarity was evaluated using a questionnaire consisting of fourteen questions. The first eight tested the intuitiveness and the simplicity of this convention while the last six questions aimed to gather the experts' opinions.

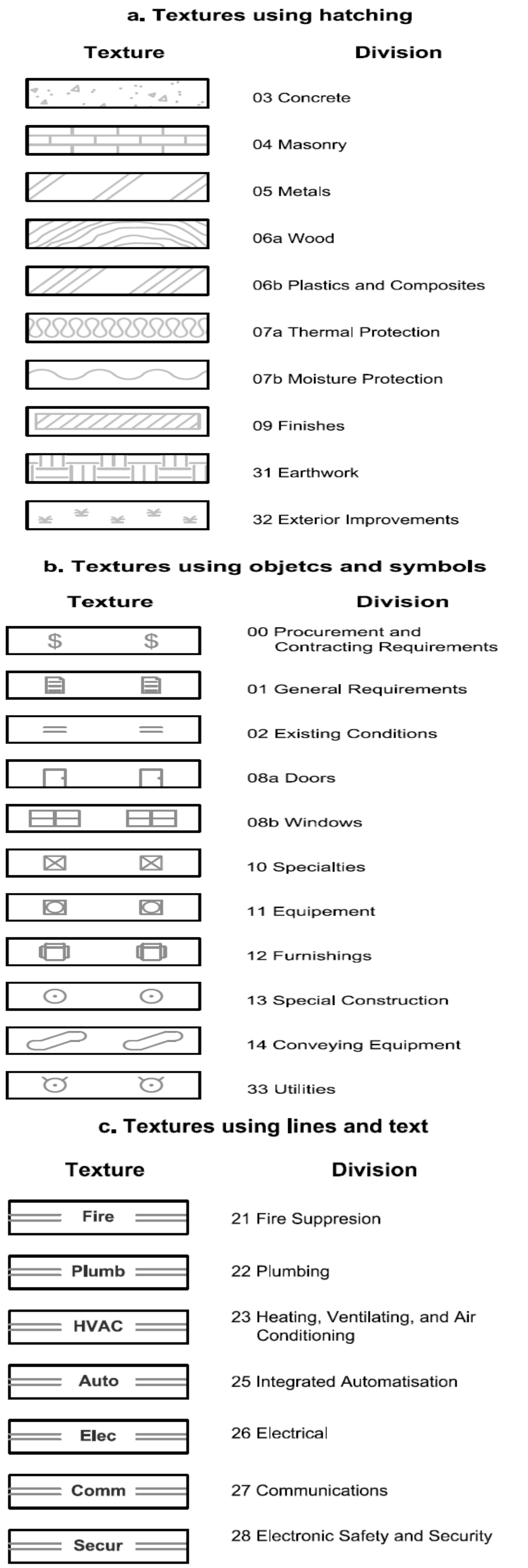


Figure 2. Textures representing construction divisions

First, participants were asked to intuitively associate each construction division with the appropriate element of the graphic texture convention. The purpose was to assess, without any prior explanation, the intuitiveness of the texture convention. Secondly, participants were asked to repeat the same exercises. This time, however, they have to attend an explanation session of the convention. The aim was to evaluate the ease of memorization of the convention. The final six questions surveyed the participants' opinions.

Figure 2 presents the validated proposal for the first level of the texture convention. This proposal has taken into account the suggestions for improvement made by participants. Figure 2A includes textures using hatching, while Figure 2B presents textures using objects and symbols. Facility services are represented by lines and text (Figure 2C).

Figure 3 shows the second level of the convention that represents the construction elements as substructure, superstructure, flooring and ceiling.

The third level, presenting the construction stage, is shown in Figure 3 and Figure 4. Figure 3 differentiates between two main stages: pre-construction and construction implementation. The dotted border lines indicate a pre-construction stage (e.g. the preparation and approval of workshop drawings) while the solid border lines indicate the construction implementation phase (e.g. equipment installation). Figure 4 details the stages of the construction implementation phase. The interior dotted lines indicate the support activities or the first task in the implementation process of a construction work (e.g. temporary work or formwork task in reinforced concrete slab implementation); the interior solid lines indicate the second or intermediate task in the implementation process (e.g. reinforcing steel bars in reinforced concrete slab implementation) while the interior bold lines indicate the last task in the implementation process (e.g. pouring concrete).

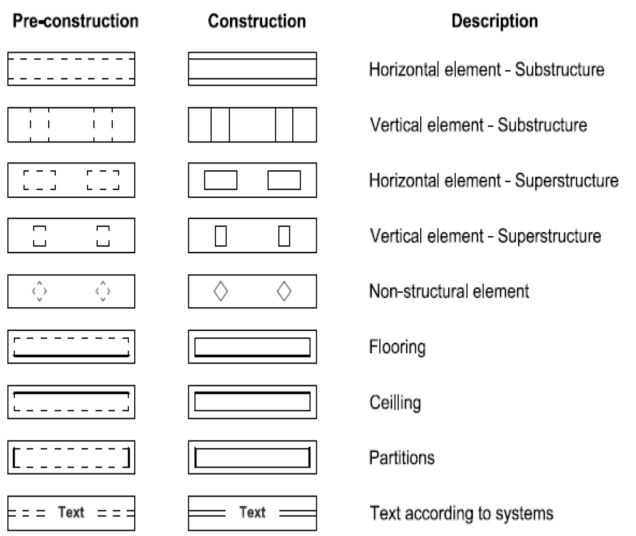


Figure 3. Convention representing construction main stages and elements and systems

With three levels of information, the texture system is a logical knowledge system. This system simplifies and facilitates the memorization of information by decreasing the number of elements to memorize; it consists of 33 items in the first level of construction divisions, eight (8) items for the second level of the construction elements and four (4) items for the third level of construction phases. Using these three levels of information, the texture convention is extended to 1056 representation items.

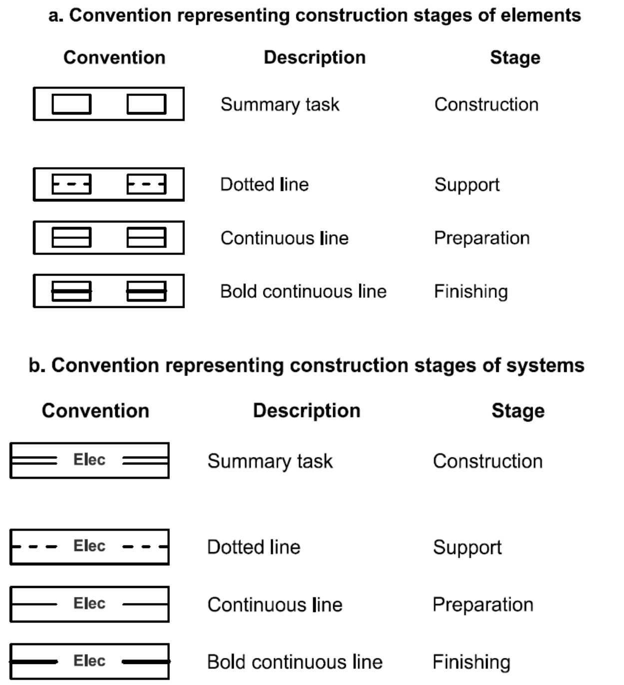


Figure 4. Convention representing construction stage of elements and systems

Table 1 shows the percentage of correct answers for questions one to eight. According to this table, more than half of the participants were able to intuitively identify the meaning of textures using hatching. Nearly 90% of the participants succeeded in memorizing the meaning of these textures after attending the explanation session. In the case of textures using objects and symbols, the results were lower. However, despite these lower results almost 67% of the participants were able to remember the meaning of textures after the explanation session. Concerning the second and third level of the convention, representing the construction elements and stages, the results was very encouraging with a success rate of 100% when evaluating the ease of memorization

Table 1. Success rate of questions 1 through 8 regarding the texture convention

Questions	Evaluated topic	Figure	Intuition	Knowing the answer
1 and 3	Textures using hatching	2a	56%	89%
2 and 4	Textures using objects and symbols	2b	27%	67%
5 and 7	Convention representing construction stages of elements	4a	85%	100%
6 and 8	Convention representing construction stages of systems	4b	68%	100%
	Average		**59%**	**89%**

Questions 9 through 14 aim to gather expert opinions about the meaning and graphical quality of the textures and graphics used. Participants had the opportunity to express their opinions and make suggestions for improvement. Table 2 shows the acceptance rate for the textures assessed in these questions. According to this table, the acceptance percentage is greater than 70% in most cases.

Table 2. Acceptance rate of questions 9 through 14 regarding the texture convention

Question	Evaluated topic	Figure	Accepted	Non accepted	N.A.
9	Textures using hatching	2a	72%	23%	5%
10	Textures using objects and symbols	2b	62%	28%	10%
11	Textures using lines and text	2c	71%	22%	7%
12	Convention representing construction elements	3	76%	21%	3%
13	Convention representing construction stages of elements	4a	100%	0%	0%
14	Convention representing construction stages of systems	4b	93%	7%	0%
	Average		**79%**	**17%**	**4%**

Evaluating the mental effort required to find the desired information

This stage tested the ability to search for information, on a building construction schedule, based only on the texture convention. The schedule does not include any other indications, markings or texts. The timeline presented the design, the procurement and the construction stages of the foundations, structures, finishes and systems for a building project. Participants were asked to answer 16 open questions regarding searching for information and demonstrating the comprehension of the Convention.

The schedule was presented as a Gantt chart in PDF format in order to avoid influencing performance by using an unfamiliar presentation method or planning software. Participants could graphically interact with the schedule by performing simple actions, such as zooming, and moving throughout the schedule. To answer questionnaires, participants had no prior training and had to use the knowledge gained in the previous phase outlined above.

Figure 5 shows a part of the schedule. Bar annotations and activity labels were added for the comprehension purpose of this paper. Annotations on activities A to D indicate the different levels of information according to the texture convention (Figures 2 to 4). Annotations on bars representing activities E to H indicate the activity names based on the texture convention interpretation.

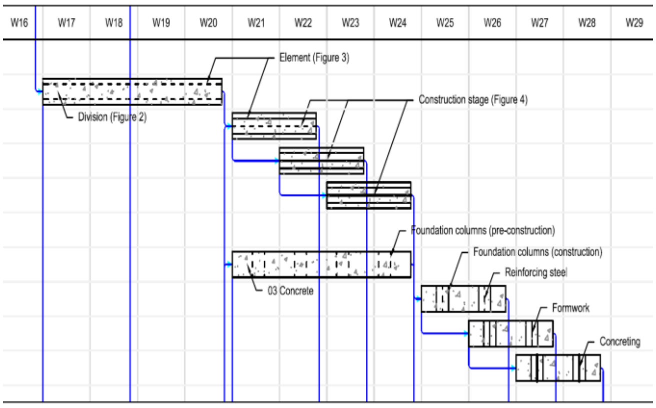


Figure 5. Fragment of the schedule used during the case study

Table 3 summarizes the obtained results. Three people worked individually and twelve people worked in teams: i) two teams of three; and ii) three teams of two. Despite the fact that participants used only the knowledge acquired during the first part of the case study, almost 70% of the questions were answered correctly a rate which jumps to 84% when considering partially-correct answers. People working in teams were able to establish group discussions which positively influenced the accuracy of their responses compared with those who wrote the test individually. However, the number of people per team does not appear to have had a significant impact on the performance of the group.

III. THE COLORS CONVENTION

The Chronographical model defines the Physical Entities (PE) that represents all work, resources and locations (work placement) required to perform the construction operations.

The graphical Protocol representing the work is mainly shown using the texture convention as demonstrated in the previous section. Resources and locations use colors as the main graphical means. While resources use a range of dark-colored fills, location is shown through a range of light-colored fills. The objective of this section is to define the two different ranges of colors, a dark range and a light range of fill colors.

A significant number of colors can be obtained through the variation of their components: hue (H), saturation (S) and lightness (L). However, the capacity of the human eye to differentiate colors limits the number of colors to use in order to favor the pre-attentive process.

To address this constraint, [11] propose working with light and dark color scales independently with regard to maximizing the number of colors available while simultaneously minimizing the impact on user performance. In addition, light color scales also allow simultaneous use of other graphical elements such as texture and text [10].

In order to obtain a light and a dark range of colors, it is necessary to evaluate the following:

- The variations in colour components;
- The limits between light and dark colours;
- The limits between the colour categories;
- The maximum number of colours per category.

Table 3. Success rate by question regarding a construction schedule using the texture convention

No.	Question	Correct	Approx.	Wrong	N. A.
1	How long does it take the procurement process? Note: the bidding is made after completion of the design phase	88%	13%	0%	0%
2	The preliminary studies (soil study) are included in the schedule?	63%	25%	0%	13%
3	Indicate the start and end date of the foundation construction Note: do not take into consideration the workshop drawings	50%	13%	38%	0%
4	Could you indicate if plumbing works are required before the construction of the slab-on-grade?	63%	38%	0%	0%
5	The foundation construction requires the installation of wood piles?	100%	0%	0%	0%
6	The building structure is mostly made of concrete or steel?	75%	25%	0%	0%
7	How many floors is the building?	50%	25%	25%	0%
8	Indicate the start and end date of the structure construction? Note: the structure starts with the ground floor beams and ends with the construction of metal stairs (non-structural metallic element), do not take into consideration the workshop drawings.	13%	38%	50%	0%
9	When does the interior finishing begin?	25%	13%	63%	0%
10	How long does it take the installation of exterior doors and windows?	100%	0%	0%	0%
11	How long does it take to finish the interior walls?	38%	13%	38%	13%
12	The building will have an elevator?	100%	0%	0%	0%
13	Is it possible to delay the workshop drawings activities of HVAC without affecting the successors?	100%	0%	0%	0%
14	Is it possible to delay the workshop drawings activities of Fire Suppression without affecting the successors?	75%	25%	0%	0%
15	The plumbing fixtures requires the preliminary installation of furniture such as cabinets and countertops?	63%	38%	0%	0%
16	When it is scheduled to begin the earthworks and exterior improvements?	88%	0%	13%	0%
	Average	**68%**	**16%**	**14%**	**2%**

According to Bertin [16], hue has separation qualities while saturation and lightness have, at the same time, separation and hierarchy qualities. Figure 6 presents the primary colors for the additive color system (RGB) and subtractive color system (CMYK). Each primary color has a different value of hue, yet they have the same value of lightness (50%) and saturation (100%).

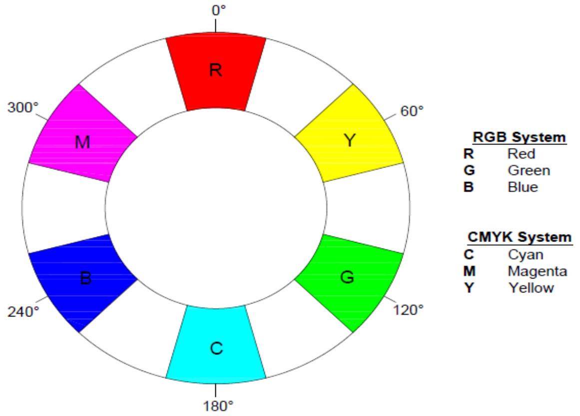


Figure 6. Hue values of primary colors

Regarding the color categories, Healey [17] argues that seven colors is the optimal number to maintain a search in parallel. However, it could be possible to increase the number of colors by using variation patterns of color components. These variation patterns follow Bertin's theory [16]. Hue is used as the primary variable to ensure differentiation between colors because of its separation qualities. Lightness and saturation are used as auxiliary variables to improve differentiation between colors. Table 4 presents hue, saturation and lightness limits for each color category and the number of colors recommended by category. Notice that the limit values of color components are different for light and dark colors.

Table 4. Hue, saturation and lightness limits for each color category

a. Light colours

Colour category	Hue		Number of colours
	From	To	
Red-Purple (RP) [1,2]	300°	330°	2
Yellow-Red (YR) [1,2]	0°	35°	2
Yellow (Y) [1,2]	55°	65°	2
Green (G) [1,2]	85°	165°	2
Blue (B) [1,2]	195°	210°	1
Purple (P) [1,2]	240°	270°	1
		Total	**10**

1 Saturation between 80% and 100%
2 Lightness between 85% and 90%

b. Dark colours

Colour category	Hue From	Hue To	Number of colours
Red-Purple (RP) [3, 4]	310°	335°	1
Red (R) [3, 4]	355°	5°	1
Yellow-Red (YR) [3, 4]	25°	35°	2
Yellow (Y) [3,4]	55°	65°	1
Green (G) [3, 4]	85°	150°	3
Blue (B) [3, 4]	180°	240°	4
Purple (P) [3, 4]	270°	290°	2
		Total	**14**

3 Saturation between 80% and 100%
4 Lightness between 35% and 55%

Figure 7 shows the saturation and lightness variation from primary colors. When the saturation value is reduced, all colors obtained seem to be dark colors (Figure 7a). In contrast, the lightness variation allows obtaining both light and dark colors (Figure 7b).

a. Saturation variation from primary colours

		Saturation variation																		
Hue	Lightness	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10
0	0.50																			
60	0.50																			
120	0.50																			
180	0.50																			
240	0.50																			
300	0.50																			

b. Lightness variations from primary colours

		Lightness variation																		
Hue	Saturation	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
0	1.00																			
60	1.00																			
120	1.00																			
180	1.00																			
240	1.00																			
300	1.00																			

Primary colours (RGB and CMYK systems)

Figure 7. Lightness and saturation variation from primary colors

Following several months of trials and testing, the conclusion was to set the hue at a range between 0 and 360° as the principal separation intervals. For dark colors, the lightness range varied between 35% and 55% and the saturation between 80% and 100%. For light colors the lightness range was varied between 85% and 90% and the saturation between 80% and 100%.

Figures 8 and 9 illustrate an example of how a color scale was composed using a specific variation pattern of color components. Notice that, the variation of lightness and saturation improves the differentiation between colors.

		Base scale			Scale obtained			
Categ.	H	S	L	Colour	VP	S	L	Colour
RP	300	1.00	0.90		X	0.80	0.85	
	330	1.00	0.90					
YR	0	1.00	0.90		X	0.80	0.85	
	35	1.00	0.90		X	0.80	0.85	
Y	55	1.00	0.90					
	65	1.00	0.90		X	0.80	0.85	
G	85	1.00	0.90		X	0.80	0.85	
	165	1.00	0.90					
B	205	1.00	0.90		X	0.80	0.85	
P	255	1.00	0.90					

VP Variation pattern: colours with a subtle variation of lightness and saturation

Figure 8. Light color scale obtained by using a specific variation pattern of color components

		Base scale			Scale obtained			
Categ.	H	S	L	Colour	VP	S	L	Colour
PR	320	1.00	0.55		X	0.85	0.40	
R	0	1.00	0.55					
YR	25	1.00	0.55		X	0.85	0.40	
	35	1.00	0.55					
Y	60	1.00	0.55					
G	85	1.00	0.55					
	120	1.00	0.55		X	0.85	0.40	
	150	1.00	0.55					
B	180	1.00	0.55					
	200	1.00	0.55					
	220	1.00	0.55		X	0.90	0.50	
	240	1.00	0.55		X	0.80	0.45	
P	270	1.00	0.55		X	0.90	0.50	
	290	1.00	0.55					

VP Variation pattern: colours with a subtle variation of lightness and saturation

Figure 9. Dark color scale obtained by using a specific variation pattern of color components

The validation process was conducted through a case study in order to assess the suitability and the visual clarity of the dark and light range of colors, the limits between light and dark colors, the limits between colors categories and the maximum number of colors per category. The results of the color case study allowed for the validation and adjustments of the results. This will allow users to build their own scales based on the proposed parameters.

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AUTHORS PROFILE

Prof. Adel Francis ing. PhD is an associate Professor, in the Construction Engineering Department, École de technologie supérieure, ETS, Quebec University. He is a titular of a BS degree in civil engineering, a Master degree in Project management and a PhD degree in Project Planning and computer management. In this area, he developed numerous applications, published many papers, and act as presenter in several conferences. My research interests are focused on visualization, optimization and graphical modeling of project planning. The last decade has been primarily dedicated to the study, analysis, development and implementation of a Chronographic modeling approach for construction operation planning.He has also more than 25 years of relevant industrial relevant experience in the field of construction engineering. Within these years, he worked for public services, consulting engineering groups and general contractor corporations. His experiences consisted of a varying duties and responsibilities as establishing strategies, planning and managing construction projects, monitoring construction work schedules, conducting cost control, risk analyses and value engineering, preparing contract documents, reviewing and evaluating tenders, intending estimations, and performing feasibility studies as well as financial and economic analyses.

Fabian Ardila ing. jr, M.Eng. Fabian Ardila holds a bachelor's degree in Civil Engineering and a master's degree in Construction Project Management. His research interests are focused on the application of information technologies in visualization and graphical modeling of project planning and monitoring. He has more than 10 years of experience in the construction industry. Through his career, always related to project management, he has participated in the realization of several building and urban infrastructure projects.